Crafting Experience

Designing Digital Musical Instruments for Long-Term Use in Artistic Practice

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Abstract

This thesis collects a series of publications that all present work where digital musical instruments (DMIs) played a central role. While the papers focus on the individual projects where the DMIs were created, the first part of this thesis describes patterns and insights arrived at by comparing the projects and the DMIs, as well as discuss them in the context of other contemporary research.

The projects described in the included papers all are quite different, but the role I performed in them was consistent in many ways. I position myself as a crafts-person, and trace the practice of crafting digital musical instruments through the projects. As a working metaphor, I present the idea of the DMI-craftsperson as a translator between different domains. This requires a broader outlook than the mechanics of the instruments themselves, including some working understanding of the domains that the DMI interacts with.

The relationship between DMIs and contemporary musical practice is a thread that runs through the work. I criticise the practice of exclusively performing laboratory based evaluations, and the concept of rigid and requirements based evaluations of artistic artefacts. Instead, I argue, relying on Sonic Interaction Design and embodied aesthetics, that the complexities and nuances of performance can only be fully explored by engaging in long-term artistic practice.
Sammanfattning

I denna avhandling presenterar jag en samling artiklar som beskriver olika projekt där utveckling av nya digitala musikinstrument har spelat en viktig roll. Artikelarna beskriver enskilda projekt och den inledande kappen kompletterar dessa ingående beskrivningar med ett större grepp där projekten läses i grupp för att ta fram mönster och insikter som träder fram först på den abstraktionsnivån. Även om projekten i sig varit av olika karaktär har min roll i dem varit konsekvent och jag använder därför mina egna bidrag till projekten samt mina egna erfarenheter som konstnär och instrumentbyggare för att belysa de praktiker som finns i spel i dessa och liknande projekt. En metafor för det arbete jag beskriver är hur instrumentmakare kan fungera som en översättare mellan olika domäner, såsom det kroppsliga och det klingande.

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Contents

Aknowledgments .................................................. ix

Contents ......................................................... x

1 Introduction ................................................. 1
  1.1 Thesis Outline .......................................... 3
  1.2 Included Papers ......................................... 4

2 Practice, Crafts and Materials ......................... 11
  2.1 Artistic Practice ......................................... 12
  2.2 Research practice ....................................... 14
  2.3 Digital Materials ........................................ 15

3 Background ................................................. 17
  3.1 Aesthetics of Interaction ............................... 17
  3.2 The Crafting of Digital Musical Instruments .......... 23
  3.3 Aesthetics and Knowledge Production ................. 32

4 Digital Musical Instruments ............................. 35
  4.1 Augmented Circus Apparatus .......................... 36
  4.2 Nebula ..................................................... 39
  4.3 Sound Forest .............................................. 42
  4.4 Optical tracking systems ............................... 45
  4.5 The Throat ............................................... 48

5 Discussion .................................................. 53
  5.1 Crafting .................................................... 53
  5.2 Instruments in Long-Term Use ......................... 57
5.3 Probing Artistic Knowledge ........................................ 62
5.4 Summary .......................................................... 65

6 Conclusions .......................................................... 67
  6.1 Future Work ..................................................... 68
  6.2 Crafting Experience ............................................ 69

Bibliography .......................................................... 71
Chapter 1

Introduction

Digital musical instruments (DMIs) are fascinating. They can be engaging, impossible, incredible, spark discussions, challenge or empower existing artistic ideas, or be the origin of completely new possibilities. Therefore, not only the instruments themselves are worthy of study, but also their conceptualisation, their construction, their use, their influence, and how they are shaped by, and shape, different artistic practices. In this thesis, I would like to read a selection of my published work in an aesthetically conscious mode of interaction design, and more particularly contextualise it within the field of Sonic Interaction Design, focussing on crafting aspects of digital musical instruments. The projects all are different, but the role I performed in them was quite similar and I analyse my own work through the lens of crafting to look at the practice of crafting digital musical instruments and the role of the DMI craftsperson in projects where DMIs are developed.

My aim is for the topics discussed to be useful for researchers and practitioners that are involved in the crafting of DMIs, and hopefully also to some degree readers with a broader interest in human computer interaction (HCI).

The outset of my PhD work, while drawing on the experiences from several of the projects I had done previously as a freelancing craftsperson of musical instruments, was primarily a continuation of the topic of my master thesis (Elblaus, 2012) and first papers dealing with artistically directed prototyping (Elblaus et al., 2011, 2012; Unander-Scharin et al., 2013). In condensed form,
the main questions at the time could be summarised as: “Can artefacts of artistic importance be designed from within HCI?” and “How can artistic practice be integrated into, as well as guide, a participatory design process?”.

While the ambition was to contribute to the general field of HCI, the particularity of the projects were acknowledged insomuch that the validity of the findings were, at least initially, confined to the specific case of digital musical instruments. The context of that crafting process was to vary in the studies I was involved in during my PhD work, from opera, dance, chamber music, contemporary circus, and everyday interactions. While my task in these contexts was similar, it is important to state that the reaction and adaptation to the specific material qualities of the different situations were essential to my understanding of DMI design, leading to the reframing of my work as a crafting practice. Since the particular materialities and the site specific manipulations required were so evocative to me, and the concept of crafting so powerful, I asked: “Are specific accounts of practical design work, sharing both methodology and results, a valuable knowledge contribution?” and “How can we understand DMI design as a material conscious crafting practice, and what happens if we do?”.

Finally, as the crafting aspects of DMI design solidified, combined with the initial questions on integration of artistic practice into the design process, the question of adoption and long-term use of the DMIs became more pressing. Moving from materiality from a craftsperson’s perspective to the sociomateriality of the community and practices of contemporary music and its instruments, I asked: “How do we limit the scope of our investigations if our instruments remain in the laboratory where they were made?”, “What sociomaterial qualities or other factors influence the adoption of a DMI into contemporary musical practice?”, and “How can DMIs function as a tool for investigating musical practice?”.

So, taken as a whole, the general direction of the work presented in this thesis has been to explore the possible research benefits of integrating DMI crafting, contemporary musical practice, and Sonic Interaction Design research. In this thesis, I will compare the projects in the included papers and read them both with all the topics above in mind, but also with a particular focus on my personal contributions to the work, and what role I have played in the projects, as all of the work has been collaborative. In this reading my primary question will therefore be:
What characterises the role of the DMI-craftsperson in multidisciplinary artistic projects where DMIs are developed?

1.1 Thesis Outline

This is a compilation of theses. As such, it has two distinct kinds of content. The main contributions are the included papers found in the second part, at the very end of this book. In this, the introductory first part, I will introduce the work, contextualise it, and present my collected thoughts on the topics presented in an attempt to discern patterns and surface connections that can only be observed when the work is viewed as a whole. In the next section, the included papers are presented, each with a very brief summary of its content and a statement about my contributions.

Chapter 2 explains my personal background and approach to the project work that is presented in the included papers. In Chapter 3, a background of related work that I will use to further contextualise my papers is presented. Chapter 4 contains a presentation of a selection of the digital musical instruments that I have created, together with colleagues, that I will use as examples in the discussion. While most are more thoroughly described in one or more papers, the unified descriptions in Chapter 3 serve as an introduction that will give the reader enough to continue to the discussion without first reading the papers.

The discussion in Chapter 5 offers a complementary view to the papers themselves, building from the work presented in Chapter 3, using the instruments presented in Chapter 4 as examples, presenting my personal view of the emergent themes of the included papers, drawing also on how the projects described in the papers have evolved after publication.

In Chapter 6, I sum up the discussion and trace possible future directions in which I would like to continue to explore the themes of this thesis.
1.2 Included Papers

The following papers are included in this thesis. They share a focus on the creation and use of digital musical instruments, and all of the DMIs in Chapter 4 originate from the work described in these included papers.

**Paper A: Artistically Directed Prototyping in Development and in Practice**

Ludvig Elblaus, Kjetil Falkenberg Hansen and Carl Unander-Scharin

This paper is an extended version of a previous conference paper presented at the Sound and Music Computing Conference 2011, that in turn was based on my master’s thesis (Elblaus, 2012), also published in 2012. The instrument presented in this paper is *The Throat*, and the paper outlines the early prototyping and co-creation process. The paper highlights the participatory design work and the extraction of tacit knowledge from participants in the process. The extracted knowledge was situated artistic knowledge and aesthetic judgement, which was essential in the development of the prototype. The system is still in use, albeit in an further developed version, at the time of this writing.

My contributions was the technical work on constructing the hardware as well as programming all software for control and signal processing. All authors shared the work of writing the paper, and were involved in the design process, with Unander-Scharin’s principal artistic direction. The HCI framing using wicked problems, participatory design, tacit knowledge, and the concept of examining artistic knowledge guiding technical prototyping was present already in the master thesis, and further developed together with my co-authors.

**Paper B: Singing Interaction: Embodied Instruments for Musical Expression in Opera**

Ludvig Elblaus, Carl Unander-Scharin and Åsa Unander-Scharin
This paper describes the work with the opera *Sing The Body Electric! - a Corporatorio* that was conceived and performed in 2012–2013, using several adopted or re-developed digital musical instruments. The project required the repurposing of existing technical components to new artistic contexts, from composing, through rehearsals, and performance as well as touring. The article discusses what new scenic subjects that may emerge from all of these activities and how the use of digital musical instruments in some cases might blur distinctions between, for instance, performer, instrument, and piece.

The conceptual and practical work of designing the instruments was shared between the authors, as was the writing of the paper. I constructed the underlying digital materials, programming interaction and signal processing.

**Paper C: Modes of Sonic Interaction in Circus: Three Proofs of Concept**

Ludvig Elblaus, Maurizio Goina, Marie-Andrée Robitaille, and Roberto Bresin
*Sound and Music Computing Conference, 2014 (pp. 1699-1706)*

In this paper, a collaborative design project for the development of new ways of integrating sonic interaction in circus is presented. Several different new systems were developed, grouped together in three different case studies, called *explorations*, denoting different conceptual approaches to the inclusion of interactive audio into the performances. All of the systems were developed in tight collaboration with particular circus performers, tailored to their act, as well as with a circus director that curated the larger experience of the combined acts into a cohesive performance. All instruments were constructed in a studio setting, used in rehearsals, and ultimately used in public performances.

My contributions were the first and second exploration in the paper, developing the instruments for contortion, hoop, aerial hoop, Cyr wheel, and vertical rope. Similarly to paper A, the circus performers’ craft guided the development, and the constructed artefacts informed their performances in return. The writing of the paper was shared between the authors, but the sections on the first and second exploration are authored mainly by me.
Paper D: Uncanny Materialities: Digital Strategies for Staging Supernatural Themes Drawn from Medieval Ballads

Ludvig Elblaus, Carl Unander-Scharin and Åsa Unander-Scharin

This paper documents the use of digital musical instruments in the piece Varelser och Ballader (Beings and Ballads), performed by the authors together with another singer and dancer, as well as the chamber music ensemble Musica Vitae in Växjö, Sweden, 2016. The main topic is the use of the uncanny qualities of the digital to bring themes of transformation, fluid identity, and monstrous beings to the stage. By exploiting the possible disjunctions between the bodies and actions of the performers on stage, and the auditive result, and playing with the audience expectations, the themes of the original ballads used as inspiration for the piece were brought to life in a felt and present way.

All authors contributed equally in the writing of the paper. In the text, my main focus was the development of the theme of the uncanny and the reinterpretation of the challenges of the digital on stage, the education of the audience, and how and if to explain the models of action and consequence before or during the performance. I also developed and programmed all the digital musical instruments used in the performance, but their role in the piece and their final design was a collaborative effort by all authors.

Paper E: Sound Forest/Ljudskogen: A Large-Scale String-Based Interactive Musical Instrument

Roberto Bresin, Ludvig Elblaus, Emma Frid, Federico Favero, Lars Annersten, David Berner, and Fabio Morreale
Sound and Music Computing Conference, 2016 (pp. 79-84)

In this paper, a design concept for a interactive museum installation is laid out. The installation is an multimodal experience that blends light, haptic vibrations, and audio. In a partly mirror-clad room, five glowing strings are suspended from floor to ceiling. By manipulating the strings, visitors to the museum can explore different pieces, either commissioned and created by external composers,
or etudes and demonstrations created by pedagogues and students of schools affiliated with the museum.

The work in the project and the writing of the paper was largely carried out in a joint workgroup including all authors. My contributions were to the conceptual development, and I handled the software side of the technical infrastructure, as well as sensors and analysis of sensor data.

**Paper F: Nebula: An Interactive Garment Designed for Functional Aesthetics**

Ludvig Elblaus, Vasiliki Tsaknaki, Vincent Lewandowski, and Roberto Bresin

*CHI Extended Abstracts on Human Factors in Computing Systems, 2015 (pp. 275-278)*

In this paper we describe the first iteration of the Nebula garment. A black cloak covered with metallic studs that can detect some characteristics of the movement of the wearer. In the version of the garment described in the paper, the generated control data was sent to sound producing software that produced a real-time auditive response to the actions of the wearer. In the group of authors, we all had different crafting practices that needed to coexist in the project, and the main point of the paper is how those practices could be combined, leading to the concept of functional aesthetics as a guiding principle for this kind of work.

My contributions, apart from the shared work in the project and in writing the paper, was to create all software for the project as well as do the sound design and visualisations of the data.

**Other publications**

In addition to the papers that are included in this thesis, I have published research on other related topics, like the public installation Musikcyklarna (The Music Bikes). I have also worked with basic research into perceptual qualities of body movement sonification, such as the studies on fluidity and auditive influence on spontaneous movement in children. Other papers include work with sonification of wheelchair movement for training and rehabilitation as well as
more theoretical texts bordering on artistic research. While not explicitly included in the thesis, this work has also contributed to the work and discussion presented in this thesis.


Ludvig Elblaus, Carl Unander-Scharin, and Åsa Unander-Scharin. 2016b. Which scenic subjects may emerge when interacting with machines through vocal and bodily virtuosity? In *CARPA4-Colloquium on Artistic Research in Performing Arts*. Theatre Academy Helsinki


In this thesis, a recurring theme will be that of practice. I will refer to *my practice* and will mean something particular when I do. In an effort to make this clear, this chapter will deal with the fundamental demarcations of my role and my practice in the different projects that form the foundation for this thesis. To do that, I will give a brief description of what I consider my background and my work in general to be, and then show how that wider practice differs from the particular mode of work I performed that became the basis for this thesis.

I have been involved in artistic practice for much longer than I have been doing research. Furthermore, much of my research, and in particular the selected work that is included in this thesis, has been closely connected to artistic work and artistic contexts. I also argue that my own craft skills have been integral to my ability to embed myself deep enough into the projects from which my research findings are drawn, so a brief outline of my background is needed to situate my artistic development and to show how I have positioned myself aesthetically in my own work. As a craftsperson, my tools and materials of choice are very important to me, so I will also give some examples of the more practical aspects of my work.
2.1 Artistic Practice

I started with traditional music training, with the trumpet as my main instrument, moving from classical playing to contemporary music and different improvisational traditions with some years playing in the mid century jazz tradition before moving on to free form improvisation and conceptual and instruction based pieces. Parallel to this, I have been composing and performing electronic music, starting in the mid 90s with software samplers with built in sequencers called trackers, mainly Fast Tracker II, and some years later moving into the DAW-based production flows that are prevalent today. Around the turn of the century, I became more interested in more open and non-linear environments and I started to work with Jeskola Buzz, Csound\(^1\), Native Instruments Reaktor\(^2\), before settling on Max/MSP\(^3\) that became my first real experience with crafting completely new digital musical instruments. The Nord Modular platforms, both G1\(^4\) and G2\(^5\), from Clavia were also important for me at that time and I still return to them, both for their characteristic sound and the ease of use which makes them ideal examples of contemporary instrument design. Finally, I moved on to SuperCollider\(^6\), and that has to this day been my environment of choice for composition in general and high performance real-time audio in particular. Since around 2010, I have also become increasingly interested in hardware modular synthesizers, especially analogue ones, to the point where I have assembled a system of my own that has been used as a live instrument (in a slightly reduced configuration) in ensemble playing on tours, as well as being a central component in sound design and composition in my studio work. The ephemeral nature of the complex analog signal chains made possible in analog modular synthesis offer a refreshing complement to the digital world of infinite undo, and the resource management necessary when working with hardware can also activate new artistic impulses that might lay dormant when faced with the infinite resources and blank page that the computer offer when used as a

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3. https://cycling74.com/
musical instrument.

In addition to composing and performing my own work. I have also written music for other performers, exploring new modes of collaborative compositional strategies that has led to pieces for french horn, guitar and ensembles. I have also worked on public installations and performances that combine theatre, dance, acoustic and electro acoustic music paired with digital scenography, as well as children’s theatre.

Although music has always been my main mode of expression, I have also worked with digital graphics for some time, starting with ray tracing rendering software in the 90s to produce still images, but moving gradually to more real-time computer graphics using various platforms, e.g. Processing\(^7\), before moving to OpenFrameworks\(^8\), that I consider to be my preferred way of creating real-time interactive graphics today. While initially separate from my musical practice, the two have fused lately and I have started to produced audio visual works as well as a few audio reactive video installations.

In all of this work, I have tended to gravitate towards some concepts again and again. Below, I have grouped artistic concepts that have interested me for a very long time into three themes.

**Systems** Algorithmic and generative structures, complex systems, emergence, endless variation, evolutionary and mutation-based systems, aleatoric composition, and chance music.

**Materials** Embracing imperfections and exploiting material qualities of tools and storage mediums, the characteristics of analog tape, tape echoes, spring reverb, the particular dynamic compression and sound of VHS, analog synths, vinyl records, early digital reverberation systems, bucket brigade delays and short wave radio.

**Listening** Drone music, deep listening, very slow and drawn out musical structures, alternate tuning systems, music as architecture, loudness, and the physicality of bass.

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\(^7\)https://processing.org/
\(^8\)https://openframworks.cc/
Conversely there have been topics that I have touched on but never really explored, such as text based composition, spatialisation, functional harmonic complexity, maximalism, virtuosity, and I have also moved away from free improvisation in favour of fully composed music or structured improvisation hybrids like instruction pieces.

2.2 Research practice

In the work presented in this thesis, I have engaged in specific mode of working that, while clearly stemming from my own artistic practice, is still distinct from it in its motivation, its mechanics, and its goals. While my own artistic understanding and crafting skills have been essential to the projects I have been a part of, it has been crucial that they have all been driven by aesthetic direction from others than myself. Instead of me exploring my own artistic practice, in the same process that I have been working for many years before I started my research and have continued in parallel to the research, I have engaged in a variety of artistic practices unknown to me, and tried to support the aesthetic goals of others. Indeed, in the cases of circus and opera, I had literally no experience before I started my research projects in those fields.

By working in this manner, I have hoped to make visible some traits of how artistic practice can function in the development of new interactive materials and artefacts, specifically musical instruments. There are two ways in which I claim this has been made easier as a result of this organisation of the projects. First, by having the final aesthetic judgement external from the process of crafting the artefacts themselves, a level of abstracted communication is added to the process. The material cannot simply guide the hand, which forces the tacit and unspoken to be formulated in order for it to be transferrable. This act of making explicit has taken the form of a streaming series of brief impulses, often verbal but also given in other ways, e.g. demonstrations or gestures, woven into all the participatory work, studio sessions, workshops, rehearsals, that have been the backbone of all the development work described in the papers. To be clear, it is not a matter of making a philosophical or musicological review of the aesthetic qualities in the final instruments (if indeed such finality can ever be reached). The second important characteristic of the method employed has
been the challenging of the habitual patterns of my crafting practice. Moving into unfamiliar fields has made my own practice visible again, as I have had to become conscious of what parts of my craft that are appropriate to bring into the for me unfamiliar contexts and what I have had to learn and create from scratch.

2.3 Digital Materials

I have chosen to use the term digital musical instrument throughout this text. The term is widely used, and I prefer it to NIMEs (New Instruments/Interfaces for Musical Expression), a term that is possibly used as often in research publications. This decision might be interpreted to mean that I consider the fact that the instruments had digital components to be the most interesting thing about them. This is not the case. In fact, it is possible that my observations of my work with DMIs would be applicable to other forms of instrument building, such as acoustical instruments, electro-acoustic instruments, or analog instruments. However, since my own material of choice is the digital, I limit my claims to DMIs, without ruling out any other possible application.

As contemporary discourse tries to narrow in on the particular qualities of the digital, there has surfaced a need to address all that is not digital. Sometimes, the word analogue is used in this way, as in “not digital” and sometimes also “not virtual”, i.e. tangible. My position is that a digital piano and an acoustic piano are similar in the same way that a digital computer and an analog computer. Furthermore, the acoustic piano and the analog computer are not very much alike, even though the widest use of the term analogue could suggest that they are. Whether something is digital or not is, in my view, not always the most important defining characteristic. However, all of the instruments presented in this thesis has undeniably digital components, e.g. micro controllers, general purpose computers, source code, digital signal processing. Furthermore, the digital was the primary domain of my contributions, and I alone created the digital parts of the instruments presented in this thesis, in contrast to other parts that were collaborative efforts or ready-made components.

So, in summary, DMI is a suitable label to refer to the quite heterogenous collection of artefacts presented. The "Digital" is also of special significance, not
simply because I ascribe a particular value to the digital over other materials, but because it was a method of contribution to the projects exclusive to me.
Chapter 3

Background

The work that is presented in this thesis is related to artistic contexts and practices. My framing of this work, as described in Chapter 2, is based both on a personal artistic perspective as well as placed in an academic tradition. As this is a thesis in Sound and Music Computing and not the fine arts, to contextualise the work, I will in this chapter present examples of related theory in interaction design, especially work where the concept of aesthetics is explicitly used. Furthermore, I will look at the particular sub field of Sonic Interaction Design, a useful framing of the work in the included papers, and conclude with a presentation of related work that specifically pertain to the crafting of digital musical instruments. All of the DMIs in the included papers use the human body as a source of control for the performer, so I will also discuss some literature that deals with the body as a way of understanding the world through embodied experience.

3.1 Aesthetics of Interaction

Musical instruments are, if not artworks in themselves, at the very least, aesthetically charged objects with impact on artistic practice. Digital musical instruments fall within the domain of Human Computer Interaction (HCI), but they are not an object of study without complications. In this section, I will highlight some work that points to the issues involved in looking at DMIs in
a HCI context, and why, as Tanaka (2006, p. 278) puts it, “The richness and complexity of music [...] make it a challenging application area for HCI.”

HCI has a commercial and product oriented tradition, stemming from enterprise software engineering, using rigid requirements and an engineering approach to problem solving. Contemporary interaction design has come a long way from those rigid beginnings, but it cannot be applied in artistic contexts without creating a tension between the commercial and product oriented tradition and values of HCI and artistic goals. Many of these goals that are often undisputed in interaction design are turned upside down when working in an artistic context that might promote ambiguity, discomfort, or interpretation rather than clarity, information, or function (Benford et al., 2012). Nevertheless, the HCI community has acknowledged the potential in examining design practice and interactivity from the perspective of digital arts practice (Taylor et al., 2013).

But it is not only when examining the arts that interaction design is in need of fresh outsets. The fact that the domain of interaction design has expanded from professional products, and tools used in some workplaces, to increasingly envelope all aspects of life, can be one motivating factor to why other guiding concepts might be needed (Petersen et al., 2004). This is in line with the future scenarios sketched out by the proponents of the Internet of Things, where our devices, furniture, architecture, both through explicit interaction as well as implicitly, using biometrics and ambient sensing, would leave no aspect of human life disconnected from a web of intertwined interaction, a network of networks, an Internet of Everything (Botta et al., 2016).

Bardzell identifies a transition from goals of “performance, utility, and satisfaction” to an interaction design steeped in culture that must be read aesthetically to be properly understood, but warns of the common pitfall of cherry picking when borrowing tools and theory from aesthetics and critique (Bardzell, 2009). Furthermore a critical aesthetic perspective can help untangle the social real-world implications of interaction design as it moves from tools in the workplace, “Interaction design is design for social structures and performative practices” (Bardzell et al., 2010).

One should note that it is not only through aesthetics that interactive artefacts have been designed with other goals and values than technical require-
ments. See for instance the critical design of Dunne and Raby (Dunne, 2008), or Norman’s cognitive approach that elevates intuitive ease of use as a primary goal from which all else must follow (Norman, 2013). However, there is still a change as to the explicit critique of the existing design goals and an equally explicit use of the term aesthetics to not only understand existing work, but to be a generative tool in the design of new artefacts.

The use of the term aesthetics is not unambiguous however, and it should not be treated as such. Petersen et al. warn against the superficial use of aesthetics to mean the “immediate visual impression of products”, and puts forward a pragmatist aesthetics of interaction that encompasses all that emerges in interaction as a result of the interplay between users’ socio-historical lived experience and the object in use, the interaction itself being the origin of the aesthetics of an object (Petersen et al., 2004).

Pragmatism, and contemporary readings of Dewey in particular, has been a popular framework for the development of these ideas in interaction design. Broadly, most of them share the goal of identifying what else, instead of or in addition to, we need beyond the seemingly straightforward traditional goals of efficiency and effectiveness to understand contemporary interaction situations. Dewey’s *Art as Experience* has proven useful in that it addresses experiential qualities in interaction that are grounded in everyday life, as experienced through our bodies. Dewey (2005, p. 12) writes:

[...] life goes on in an environment; not merely in it but because of it, through interaction with it. No creature lives merely under its skin; its subcutaneous organs are means of connection with what lies beyond its bodily frame, and to which, in order to live, it must adjust itself, by accommodation and defense but also by conquest.

With this outlook, separating interaction and experience, or even interaction and life, becomes meaningless. Living is interacting with our surroundings with our embodied selves. When the whole body is considered, in all its multitude of possible shapes, activities, and subtleties, a holistic approach that promotes body awareness and design strategies that acknowledge the primacy of the body seems not only reasonable, but necessary (Höök et al., 2016; Schiphorst, 2011).
If a contemporary understanding of the aesthetics of interaction design rejects strict dualist models, or at the very least acknowledges the importance of the embodied experience, and sometimes goes all the way to propose the primacy of the body, how then can we understand the body as such and the moving body in particular? Loke et al. (2007) outline the use of embodiment and the phenomenology of Merleau-Ponty in interaction design, and go on to analyse several design frameworks with regards to their relationship to the body, concluding that several parallel frameworks can be beneficial as they offer different insights. In Phenomenology of Perception, Merleau-Ponty (2012) expands the understanding of the body, beyond the material, mechanical, collection of stuff into a thing, like any other thing. Instead, he shows the complex, but at the same time intuitive, phenomenal body, an embodied mind.

Within neuroscience, there seems to be growing support for an embodied understanding of experience, based on observed activation of the parts of the brain connected with movements when observing others performing, e.g. playing a musical instrument (Bangert and Altenmüller, 2003; Watson, 2006), lending further credibility to the notion of the experiential body as present not only in performing but also in experiencing a performance. Learning a new instrument seems to quite quickly, through the plasticity of the brain, create audio-motor connections that provide the foundation for understanding and learning, rather than being the crown achievement arrived at after years of practice (Proverbio et al., 2014).

So, in summary, many researchers in the field of interaction design have come to the realisation that as the domain of interactive artefacts move out of the original, more constrained, specialist and workplace situations into the everyday life of many people, the mechanisms and dynamics of their existence and use change. From the requirements-driven, functional and measurable, to a social, embodied, emotional context. This, in turn, allows for other specialised professional practices that benefit from this newfound perspective to be more easily studied, such as the design and use of musical instruments.

**Sonic Interaction Design**

Sonic Interaction Design (SID), a subfield of interaction design, concerns itself with the particularities of the auditive modality. SID was first formalised in the
eponymous project led by Davide Rochesso (Rocchesso et al., 2008). While the framing and stance of SID is particular, many of the underlying techniques are developed and well researched tools in other fields, e.g. sonification (Hermann et al., 2008). The recently increased use of aesthetics in interaction design, outlined in the previous section, is foundational for SID. Franinović and Salter (2013) offer a generative definition of SID as being:

1. A spatiotemporal-material process - The distinct acoustic and temporal materiality of audition makes it an unique modality with particular perceptual processes, distinct from e.g. vision or haptics.

2. An act of poiesis or making that is an active process or formation - Experiencing sound is a multifaceted process of movement, listening, that in different degrees actively produces the experience.

3. Situated, concrete, and embodied - The poetic action above is inextricably connected to the acoustic reality of the particular context of listening, as well as the body of the listener.

4. Performative and emergent - Sonic interaction constitutes itself in time through different agencies operating in tandem with each other, who these agents are and how they interact matter for the experience.

5. Nonrepresentational - As sound is not independent of context or perceiver, it is not a set of unambiguous objective symbols. Audition in general, and music in particular, are not neutral channels of information.

The model described in the list above distances itself from a few commonly proposed characteristics of sound and music and this stance is worth clarifying. SID, as stated above, is performative, situated, embodied and particular, and emerges through interaction in a way that is personal to the agents involved.

There are some fundamental traits, so commonly shared in humans that it is reasonable to assume their presence in most situations involving human listeners. Acoustics and biology restrict what frequencies and sound pressures that are audible. There are many useful studies exploring the limits of auditive perception, where perceptual evaluations are performed to arrive at statistical measurements of the powers of distinction of human hearing, such as the
just noticeable difference of various psychoacoustic phenomenas, such as loudness or pitch (Tervaniemi et al., 2005). Digging deeper there are other more subtle psychoacoustic and multimodal illusions and effects, like temporal integration (Garner, 1947), the McGurk effect (McGurk and MacDonald, 1976), the Haas effect (Haas, 1972), and many others. However, while certainly very useful, knowledge of the underlying mechanics of audition and psychoacoustics does not give us a full answer to all questions of human auditive experience. For that, we need a wider generative framework that builds from the truths discovered in the basic research, without replacing or discarding them. Much in the same way that the fact that a philosopher can answer other questions about the human condition than a surgeon does not invalidate the surgeon’s knowledge, in fact, anatomical knowledge could be useful also for the philosopher. In Lehman’s prolific Embodied Music Cognition and Mediation Technology, he writes on the progress in the field and his motivation for the inclusion of the body and embodied cognition that (Leman, 2008, p. 49):

[... ] scientific methodology has been expanding from purely physical issues (music as sound) to more subjective issues (music as experience). The connection between the two draws on fundamental relationships between mind, body, and matter.

The concept of embodied music cognition (EMC) is a framework for understanding experiential and meaningful qualities of audition, considering the body to be the mediator between an intellect and an external musical reality of matter and energy. However, the body is not a passive conduit but functions as an active explorer, making knowledge production possible, as Lehman writes on the case for an embodied action component for the cognitive tradition: “knowledge does not emerge from passive perception, but from the need to act in an environment” (Leman, 2008, p. 43).

EMC and SID contain similar ideas but are in the end quite different. EMC stems from a musicological and cognitive tradition, concerned with the transference of meaning between matter and mind, and furthermore, through mimesis, between minds, e.g. performer and audience or composer and audience. SID on the other hand is a communal effort to build on existing knowledge from interaction design, the arts, musical practice, that place a high value on the ir-
reducible aesthetic experiential qualities of all sounds. SID, therefore, is easier
to connect to the research tradition of aesthetically conscious interaction design,
and can even be said to have emerged out of such a movement.

Contemporary advances in machine learning have allowed embodied en-
gagement to take on new forms in participatory design activities supporting the
crafting of DMIs. Although inclusivity and the extraction of tacit knowledge al-
ways has been central to participatory design activities, it is an interesting shift
to have the participating stakeholders teach the software by allowing partici-
pants to show what they want through action, in a sense bypassing, or perhaps
complementing, the observations, interpretation and implementation of the de-
signer (Fiebrink, 2017). Another similar example is the work of Baldan et al.
(2016) where new tools for sound design that are controlled by voice sketching
are developed, allowing users to sing or mimic the auditive characteristics of
a desired sound as instructions for a digital systems that responds with a suit-
able sound model for further manipulation. The same research project has also
uncovered very interesting albeit preliminary results demonstrating the deep
connection between gestures and vocal sketching, demonstrating the power of
embodiment in auditive experience (Lemaitre et al., 2017).

3.2 The Crafting of Digital Musical Instruments

*Digital lutherie* was a term introduced by Jordà (2004) in attempt to pin down
the elusive set of knowledge that is needed to create new digital musical in-
struments. Not only a combination of skills, e.g computer science and musical
knowledge, but rather an emergent skill in its own right, that can and needs to
be observed and explored, particular not only in its scope but also in its charac-
ter. Jordà (2005, p. 8) writes:

Digital lutherie is in many respects very similar to music creation. It
involves a great deal of different know-how and many technical
and technological issues. At the same time, like in music, there are
no inviolable laws. That is to say that digital lutherie should not be
considered as a science nor an engineering technology, but as a sort
of craftsmanship that sometimes may produce a work of art, no less than music.

Others have also suggested a crafts approach to the production of interactive materials and I have myself used the crafting aspects of digital musical instruments as the topic of my licentiate thesis (Elblaus, 2015a). Computer source code itself, a fundamental component of most things digital, can be argued to be a design material with craft-like practices surrounding it (Lindell, 2014; Bergström and Blackwell, 2016). Sennet includes both Linux programmers as well as more traditional manual practices, e.g. weaving or carpentry, in his definition of crafts, writing that crafting is not simply a skill set but an attitude towards practice, calling it quality-driven work emphasising the “craftman’s desire to do good work” (Sennett, 2008, p. 241). Schön’s concept of the reflective practitioner is also widely cited, denoting the way that crafting as an activity relies on tacit knowledge produced and exploited in doing (Schön and DeSanctis, 1986). Dewey, again, writes beautifully on the integration of perceiving and acting (Dewey, 2005, p. 51):

As we manipulate, we touch and feel, as we look, we see; as we listen, we hear. The hand moves with etching needle or with brush. The eye attends and reports the consequence of what is done. Because of this intimate connection, subsequent doing is cumulative and not a matter of caprice nor yet of routine. In an empathic artistic-esthetic experience, the relation is so close that it controls simultaneously both the doing and the perception.

Many descriptions of crafting build on this fusion of activities that are otherwise often separate. Thus, crafting can be summarised as a largely non-verbalised set of skills and practices where decision making and learning cannot be separated from doing. It is driven by desire and even passion, but not overpowered by these emotions as “when we are overwhelmed by passion, as in extreme rage, fear, jealousy, the experience is definitely non-esthetic” (Dewey, 2005, p. 51), that is to say that it is not mindless and recklessly impulsive, but rather a carefully honed reflective practice that challenges the division between the intellectual and the practical. This makes it a suitable framework
from which to explore the aesthetics of interaction. Especially from my perspective as a producer of interactive materials in the form of digital musical instruments, crafting is by far the most suitable metaphor for my experience of and understanding of my work.

Since the formation of the CHI workshop turned conference on *New Interfaces for Musical Expression* (Poupyrev *et al.*, 2001), it has functioned as a center for interface builders that wanted to control digital musical processes through other means than those traditionally offered by the computer. The conference has always featured both theoretical and practical content, as Tanaka (2010) puts it, “Two of the predominant themes were the definition of an electronic musical instrument, and approaches to mapping gesture to sound.”. A goal, shared by many in the community, has been to reach expressivity, a term that is taken to mean a fidelity in the control that allows a performer to express, whatever it is she wants to express, to the fullest extent, like the possibilities afforded by many traditional acoustic instruments.

This content agnostic idea of expression isn’t without critics, and it can be unpacked to show a common underlying model of text and act that presupposes a duality of a written score and an expressive rendering, something that might not always be the case, especially in contemporary music (Gurevich and Treviño, 2007). The I in NIME has been considered too reductive by some, as the notion of the interface only represents a part of the puzzle (Jorda, 2005), leading to the idea that perhaps what is needed is rather new instruments, rather than interfaces, for musical expression. Others argue that it is the performers that bring the expressions into the equation, thus a search for expression is pointless without a more human centered approach, a connection with virtuosi players, and the larger contemporary music culture (Dobrian and Koppelman, 2006).

Furthermore, from an engineering point of view, expressiveness is hard to define and even harder to measure, even though several frameworks for evaluation exist (Poepel, 2005; Kiefer *et al.*, 2008; O’Modhrain, 2011; Jordà and Mealla, 2014). Already at the first NIME conference, researchers argued that HCI methods should be used to evaluate DMIs, using musical tasks that would be performed to evaluate the level of expression afforded by the instrument (Orio *et al.*, 2001), an approach that can be criticised for not paying attention to the experience of playing the instrument (Johnston, 2011). In per-
haps the most comprehensive framework for evaluation to date, put forward by Giordano et al. (2013), a thorough set of methods for evaluating any sound producing object in a laboratory setting by verifiable perceptual measurements is presented. Arguably, this set of best practices are rarely implemented, and many studies are content with small scale informal evaluations where fellow musicians and or researchers explore DMIs, often in the context in which they are built (Barbosa et al., 2015).

This drive towards unifying models of evaluation can be criticised in a similar way to how aesthetics in some cases has challenged formal evaluation in interaction design. Perhaps, to be able to fully explore the complex embodied socio-material musical practice of instrument use, simplification isn't possible. As Gurevic and Treviño write in the author commentary to their paper Expression and its Discontents: “No matter how much we might want evaluation to become straightforward, we argue, it shouldn’t be, and something is wrong if it is.”(Refsum Jensenius and Lyons, 2017, p. 311). Connecting back to the beginning of this chapter and the tension between formalised and product centred design and artefacts of artistic value, pointing out that it isn’t even a given that musical interaction should be easy, McDermott et al. (2013) write:

The fields of HCI and interaction design are not wrong in their assumptions and findings that users sometimes find interfaces frustrating, and that productivity can be improved through good design. However the very vocabulary being used here “users, frustration, and productivity” seem ill-suited to describe music interaction. Users are musicians. Productivity can’t be measured. Frustration is part of a musician's growth.

At the core of this tension lies the question of how a musical instrument is instrumental in a different way than a tool, and how we accept and even expect to be challenged by our material in artistic practice, whereas we do not in other situations that are not striving towards artistic goals. (Tanaka, 2006, p. 269) writes:

In this regard, it is not so necessary for an instrument to be perfect as much as it is important for it to display distinguishing characteristics, or “personality”. What might be considered imperfections or
limitations from the perspective of tool design often contribute to a “voice” of a musical instrument.

Looking forward, as more and more DMIs are produced, straying further from the traditional acoustic instruments from which so many commonly used metaphors are drawn, even the idea of a fixed instrument, separate from a performance or a piece, can be challenged. Baalman (2017) writes:

As performers manipulate their instruments at the core of their functionality, they take away the notion of an instrument having a predefined behaviour. With code that can be changed and compiled on the fly, the design of an instrument, or the making of a composition, becomes a fluid process and a performance in itself.

The quote applies to some current experimental musical practices, especially the live coding scene (Collins et al., 2003), and it is not unreasonable to learn from these examples and deconstruct, or even in some cases dismiss, the rigid notions of composer, piece, instrument, performer, and audience.

The audience’s experience is rarely perfectly acoustmatic, i.e. a pure auditory experience of the performance, but rather the result of complex interplay between many different components, e.g. performers’ gestures that don’t mechanically contribute to the music as such might still be very influential in how the performance is perceived, especially in regards to expressive or emotional qualities (Davidson, 1993; Tsay, 2013). These ancillary gestures have also been shown to be consistent for musicians between performances of the same piece, demonstrating that they are not only important for the audience but a significant part of a performers expression, and central for how musical structure is communicated (Wanderley et al., 2005). Therefore, when introducing a DMI or similar system in a performance setting, careful consideration must go into the design of the spectator experience, i.e. the view of the interaction from the point of a spectator as opposed to (in the simplified model) the performer (Reeves et al., 2005), with researchers devising strategies to evaluate DMIs from the audience perspective (Barbosa et al., 2012). For some, the fundamental question is whether the audience understands the mechanics and rules of the interaction (Schloss, 2003), if there is “a clear gesture-sound causality” (Emerson and
Egermann, 2017), while other studies suggest that the question is if they appreciate it (Bin et al., 2016). Interesting studies have been done on the ability of audience members to judge the qualities of performances or even detect errors or mistakes (Fyans et al., 2009, 2010), with results suggesting that the issue is complex and that the audience use non-musical cues, such as body language or facial expressions, in judging the qualities of the performance, reacting empathically to the perceived intentions of the performers rather than auditive characteristics (Dahl and Friberg, 2007). The question of the audience’s understanding of the performers achievements is not just relevant for DMI crafters, it is important to remember that there are pieces or even genres that rely on the audience’s ability to understand the difficulties in the attempted musical content and appreciate the virtuosity of the performance (Hamilton, 2007, p. 105). This further confirms the embodied complexity of the live performance situation.

With DMIs used to perform in new ways on stage, the audience might also trouble the performance in new ways, such as hacking the digital innards of wireless controllers (Hindle, 2016), prompting the question whether that would be an act of aggression, art, or perhaps both. More peaceful, or at least a priori agreed upon ways of allowing the audience to interact with staged performances have been a popular topic of research. Some use notation or visual scores as an intermediary to open a controlled way for audience members to affect the performance (Hayes et al., 2016). Other have more elaborate forms of interaction, like the massive interactive scenography and robots of Tod Machover’s Death and The Powers (Torpey and Bloomberg, 2014).

For a DMI to even get in contact with an audience, it has to be adopted to some degree into contemporary music practice. Adoption is to be understood as whether it ends up in prolonged use, with music written for it, players practicing and performing with it, and so forth. Like traditional instruments, DMIs must be crafted to adress and exploit the performance ecosystem of performer, instrument, and environment, something many successful DMIs have done to remain relevant and attractive to performers (Waters, 2007). It might seem counter-intuitive to discuss how to design for and achieve long-term engagement for DMIs, as musical instruments in general are so often used for long periods of time, by amateur musicians, without the need of external motivation. Using the intrinsic motives of mastery, autonomy, and purpose, Wallis et al. (2013) offer
seven “abstract qualities” that they suggest should inform DMI crafting to foster long-term engagement by making DMIs, among other things, easier to learn, demonstrate to others, offer a challenging complexity and provide sufficient rewards for the effort put in. The effect on an instrument’s long-term adoption of its ability to be demonstrated and taught is interesting as it points towards the sociomaterial aspects of DMIs and that there are other social activities surrounding instruments that matter other than performing with them.

While there is often a big hurdle for contemporary composers to reach a second performance of their pieces, McPherson and Kim (2012) identify another similar obstacle for DMIs: the second performer, arguing that since most of the new DMIs are built to perform a certain task in a particular piece, they might be considered to be to limited musically, and for wider adoption there would need to be a balance between over-determination of use through the encoded musical ideas in the design and the possibilities offered by the design. To some degree, this view presupposes the role of the DMI to be a solo or soloist instrument, as there are several examples of supporting instruments that indeed are widely adopted, yet offer a very limited range musical output and thus could be considered over determined. Orchestral percussion like the triangle or the timpani are good examples of this. Later in the same article, McPherson et al. go on to offer “suggestions to instrument designers seeking to establish their instrument in a broader community”, among others encouraging the use of familiar models of music making, the need to provide access to the instruments to composers and musicians, and the (at least gradual) separation of piece and instrument.

Some researchers encourage the fusion of composition and instrument (Cook, 2009), as it can serve as a design strategy to ensure that musical intent and need is put into the design of instrument itself. However, this also invites the issues of the second performer. Magnusson writes that DMIs “are adapted to personal artistic expression, thus obfuscating the distinction between the instrument and the composition. This fact illustrates how unlikely it is that many of the digital musical systems developed today will establish themselves in the manner of our beloved acoustic instruments.” (Magnusson, 2010).

This kind of adoption, as used in the examples above, is to be put into use in a musical context that is, at least to some degree, external to the
nity of craftspersons who concern themselves with digital musical instruments. This community is sometimes, a bit inaccurately, called the NIME community. The NIME community is an assemblage of many overlapping sub-communities, largely scholarly, with formalised knowledge transfer, but there are many examples of sub-communities with less formal knowledge sharing (Marquez-Borbon and Stapleton, 2015). However, the NIME community does not contain every researcher and craftsperson that is interested in DMIs. Thus, there are even more sub-communities to consider. The DMI community is arguably similar to, or even overlapping with, the maker community. Makers can be characterised as curiously tinkering, modifying, hacking and repairing all manner of electronics, sometimes with clear goals in mind and sometimes as a playful or exploratory activity. Maker culture is now an established topic for the HCI community (Ames et al., 2014; Rosner et al., 2014), offering potential new insights into DIY practice, critical and political making, and new potentials for HCI research collaboration (Lindtner et al., 2014). There are also large communities where new software instruments are created surrounding popular frameworks and programming languages, such as ChucK, SuperCollider, and Max/MSP. While diverse, these crafting communities still share an interest in exploring the materiality and possibilities of new technology, at least in part, for its own sake. The adoption that is sought, is not primarily from these communities, but rather from the composers, the performers, and the audience of contemporary musical culture, even if many inhabit more than one group. One approach to move in that direction is for researchers and craftspersons to act as a bridge between these communities and including members of non-making traditions in the design processes.

In participatory design, the concept of infrastructuring has gained traction, because, as Björgvinsson et al. write, “[…] innovation today, to a large degree, demands extensive collaboration over time and among many stakeholders.” (Björgvinsson et al., 2010). Infrastructuring is understood as an ongoing activity that serves as a platform for the renegotiation of various agencies of human and non-human actors, allowing for new ideas to emerge. Instead of the controlled studies of early participatory design, infrastructuring activities change the role of the designer to be a provider and manager of dynamic situations that entangle participants and things. The work of Green (2014), while
not explicitly calling on the tradition of participatory design or the concept of infrastructuring, points in a similar direction through musical practice-led research where ensemble playing functions as a platform for the generation of knowledge about DMIs. For a DMI to be able to be introduced in these wider interconnected contexts, there are also technical considerations, not the least of which is the actual technical capability to connect with other technologies. Lindell (2016) calls this design consideration the “ecology of other artefacts” and writes that “a design has to fit an ecosystem to be accepted by the artistic community”.

Also in musicology and organology (the classification and study of musical instruments), some researchers have shifted from viewing instruments as passive objects defined by their sound producing characteristics, a mode of thought more than a hundred years old originating in a text by Von Hornbostel and Sachs (1961), towards a view of instruments that draws on the socio-material life of things themselves. Including such perspectives in the research on crafting DMIs does not mean that fundamental questions to the field of NIME need be abandoned, in fact, many of the foundational NIME research questions are shared with contemporary organology, e.g.”[…] why certain sentiments are easier to express with a given instrument” (Sonevytsky, 2008, p. 113).

In a move similar to how Feyerabend (2010) demonstrates the practice-based performative aspects of the scientific research, Tresch and Dolan (2013) draw parallels between instruments of music and instruments of science, exploring how the idea of instrumentality as in the extensions of human capabilities allows us to look at musical instruments as tools that allow us to explore and answer questions. These developments in organology have not gone unnoticed by the NIME community, for a thorough review of contemporary organology from a NIME perspective see Magnusson (2017).

Bennett (2009) writes on the agency of objects and vibrant matter, showing how aliveness has been formulated in a variety of ways by many thinkers, and how it can help us understand the complexity of contemporary life, especially artefacts incorporating interactive materials. Bennet’s work builds on the ideas of actor network theory, where Latour (1996) famously awards agency to dynamic relational networks of actants, i.e. possibly non-human actors, meaning that the source of an action is to be taken as an actor, regardless of the char-
acteristics of that source, dispersing with the idea of agency as a exclusively human gift. Assuming this view of a complex interplay of actors rather than human subjects and their tools allow us to see that disrupting a temporary stability by introducing new or modified actants, forcing a renegotiation of many or possibly all relationships in the network could produce new knowledge, not only about the new or modified actant, but of all participants in the network.

3.3 Aesthetics and Knowledge Production

The embodied experience that so much of the work presented in this chapter puts a high value on can be seen as an alternative to the dualistic ideas of mind and matter, where mind, through language is often given the monopoly on the production of knowledge. Knowledge is articulated, an idea must be formulated, and so through metaphor, language itself is enforcing the power of language. Yet, Dewey tells us that the way that we experience the world is the very basis of our understanding of it. Mark Johnson writes of the limiting implication of such a dualist view (Johnson, 2008, p. 207):

[...] the idea that only words can have meanings ignores vast stretches on the landscape of human meaning-making. It leaves out anything that cannot be linguistically encoded, and it denies the status of meaning to most of the meaning-making that occurs beneath our conscious awareness and beneath representational structures. On this view, the last place one would look for meaning is in the arts.

Yet, the pervasive model of scientific knowledge sharing is based on the written word. Acknowledging that so much interesting knowledge exists in practical, physical, embodied practices and experiences, research into these knowledges faces a challenge of communication and dissemination. One framework for bridging practical exploration and language-based abstractions suitable for communication is research through design (RtD). RtD is a model that allows designers, behavioural scientists, and engineers to tackle wicked HCI projects, extracting relevant knowledge for all disciplines involved, with a focus on exploiting the full skill sets of the designers involved (Zimmerman et al., 2007).
But RtD is not a standardised practice, and there is a case to be made against convergence, for plurality, as design inherently relates to previous work differently than the rigour of repeated experiments in the natural sciences (Gaver, 2012). *Annotated portfolios* have been one way of communicating results from design related inquiries, e.g. in RtD, allowing researchers to find a sort of middle ground between the results being the artefact(s) or extracting everything into a written report. The annotations are one of many ways to bring together the material of the portfolio, and many superficially different formats could be considered as an annotated portfolio, but the aim is to be descriptive of the past and generative of future possibilities (Bowers, 2012). Finding and developing representations like the annotated portfolios is important, since for most researchers, the resulting artefacts of RtD-like research are rarely experienced in their physical materiality, instead, the written documentation, often research papers, are the representation that is most widely accessible (Pierce, 2014).

If we accept the researchers’ ability to extract useful knowledge from practical work, lived experience, and embodied observation, we must then ask the question: what is the nature of that which is extracted? Some of this knowledge can be *intermediary-level knowledge*, that is, it exists in a layer of abstraction between the purely theoretical and the particular and practical. Höök *et al.* have developed a framework for understanding useful and generative collections of this intermediary knowledge dubbed *strong concepts*. Strong concepts reside between theory and instance, do not claim universality, but instead specific applicability, “partial ideas, that is elements of potential design solutions, that can be appropriated by designers and researchers and used in the creation of new instances” (Höök and Löwgren, 2012). Strong concepts are not the only formalisation of intermediary-level knowledge. *Patterns*, as made popular by Alexander *et al.* (1977), are another way of structuring knowledge by grouping it into archetypes or generic solutions. Another one is the idea of *bridging concepts*, that differ from strong concepts in that they “can simultaneously be developed from theory, rather than being predominantly abstracted from design practice.” (Dalsgaard and Dindler, 2014).

While there are definitive challenges involved in approaching interaction from an embodied aesthetic perspective, it is by no means impossible and the wide selection of work in this chapter should offer insight in the variety of ways
in which it can be done. Furthermore, it should be noted that the goal of putting together these particular thinkers and works is not to produce aesthetic knowledge about the arts, but to show how an embodied aesthetic understanding of experience can function as a tool to extract knowledge from situated artistic practice and bring it into the realm of Sonic Interaction Design. There are many contemporary theories of aesthetics and knowledge production in the arts that focus on different things than the embodied experience. The work of Pasztory shares the critique of language and text as the privileged modality of art but moves away from the body in favour of the things themselves, framing “art” as a fluid category (among others, e.g. “craft” or “curiosities”) that shifts to include and exclude objects over time: “It is not possible to separate art from non-art; there are only things of various sorts, functions, forms, and meanings. […] Objects heretofore not considered works of art are in no way different—they can all be appreciated and classified by aesthetic criteria. Aesthetic criteria determine dress, the arrangements of homes, cities, highways, transport, and spacecraft.” (Pasztory, 2005, p. 10). Mersch proposes an epistemology of aesthetics that is defined in part by the very fact of its particular mode of operation (Mersch, 2015, p. 168): “[…] when we talk about an epistemology of aesthetics, and in particular of the arts, we are always talking about art’s unique manner of generating knowledge, and thus actually about an aesthetics of production.”, meaning that there are internal mechanisms of knowledge production in the arts that are not the topic of this thesis, as well as other aesthetic understandings of art that could push research in other directions. Instead, cohabiting the spaces of artistic practice, or even experiencing one’s own performance, equipped with the collected understanding of embodied cognition, is a generative process of use to HCI. So, the collected work in this chapter is not to be taken as an exhaustive overview of all aesthetic modes of production, or a claim on all artistic knowledge for HCI, but rather to construct a particular methodological model that shows how knowledge can be produced and disseminated, in general and in the activities described in the included papers, through embodied aesthetics as a form of knowledge production.
Chapter 4

Digital Musical Instruments

In this chapter, I will present the different digital musical instruments, or series of DMIs, that I will use as examples later in this thesis. All of the DMIs in this chapter are also described in the included papers, some at length and other more briefly. Here, each DMI is described in terms of concept and practical manifestation. The aim of having a more unified presentation is to make it easier to compare and contrast them, as well as clarify their use in the upcoming discussion.

As the scholarly accounts of the instruments rarely allow for a full technical description, links to the complete source code for the custom softwares developed is provided for anyone to examine further, hopefully learn from, and put to use. However, all recorded samples, piece-specific information like pitch data, and all other saved settings are removed, as I do not consider them mine to give away.

Furthermore, the kinds of activities that the DMI has been involved are described and the hours it has been in use is estimated. This is a rough estimate that covers the time any version of the DMI has been tested in development, rehearsed with, demonstrated or deployed in an exhibition context, and performed with on stage.
4.1 Augmented Circus Apparatus

**Main concept**
A reframing of circus apparatus manipulation by amplifying the usually unheard faint sounds produced as a side-effect, to increase intimacy and degree of materiality in the performance.

**Used by**
Professional circus performers.

**Mode of interaction**
The same intricate routines usually performed with the apparatus, with the addition of some particular moves to induce certain wanted sounds.

**Synthesis methods**
Amplification and digital signal processing of high gain wireless microphones.

**Technical Components**
Wireless microphone systems, SuperCollider, Ableton Live.

**Estimated time in use**
>250 hours

**Selected performances**
Gynoïdes Project, Bêta Test IV, DOCH School of Dance and Circus, Stockholm, Sweden, 2013.


Gynoïdes Project, Bêta Test V, Festival Pisteur D’Étoile, Obernai, France, 2013.
The School of Dance and Circus in Stockholm and KTH Royal Institute of Technology have had several long standing collaborative projects, one of which I participated in. During that project I was involved in the creation of several new digital musical instruments. The three presented in this section, while distinctly different, were all based on the same basic fundamental concept: amplification and digital signal processing of acoustic sounds of the physical manipulation of circus apparatus.

The three augmented circus apparatus were an aerial hoop, a metal ring suspended in the air, a rope, and a Cyr Wheel, a metal wheel, used on the ground, large enough for a performer to stand or even suspend herself inside it, see Figure 4.1.

Because of the wide difference in acoustic qualities between the three apparatus, they each had a distinct sound even before the digital augmentation. The rumbling of the Cyr Wheel carried information on its weight and power that contrasted the ease with which the performer moved it around. Hearing the crackling strain of the rope made the tensions and weight shifting visceral, and in a similar way the rapid patterns of shifting hands on the aerial hoop added a layer of intensity to the experience. However, the sounds were faint and rarely travelled to the audience. So, rather than trying to invent a sound model that would convey as much or as interesting nuances as the acoustic sounds already present in the performance situation, amplification with wireless microphones was the chosen technique. The sound could then be digitally altered before being played back into the performance space. Different strategies were used but they could be sorted into three categories, 1) amplification...
with enhancements that exaggerated qualities in the acoustic signal, 2) distortion, where pitch shifting and other techniques twisted the sound into becoming a contrasting counterpart, and 3) temporal sustain, where delays and resonant reverberation effects were used to allow the performer to build up soundscapes that lingered through the performance.

The DMIs were developed iteratively through studio work with the participating circus performers and director. While there were explicit discussions, especially initially regarding the practicalities of setting everything up, much of the communication was done through demonstration and collaborative experimentation, leading the creation of a shared understanding of the individual goals of the performers as well as the directors overarching idea for the show. This activity gradually turned into rehearsals as the DMIs and the pieces solidified.
## 4.2 Nebula

**Main concept**  
A wearable piece of technology that would, through the concept of functional aesthetic, have as integrated parts as possible.

**Used by**  
Exhibition visitors and a professional flautist.

**Mode of interaction**  
As the wearer moves, both explicit and implicit interaction with the studs on the garment are registered and translated into musical output.

**Synthesis methods**  
Sample based granular synthesis, subtractive synthesis, and frequency modulation synthesis.

**Technical Components**  
Conductive studs and thread, X-OSC, SuperCollider.

**Source code**  
https://github.com/elblaus/nebula

**Estimated time in use**  
>100 hours

**Selected performances**  
The Genoa Science Festival, Genoa, Italy, 2015.


Ischia Musica, Ischia, Italy, 2018.
The Nebula garment is a thick studded cape that explores implicit and explicit physical control over digital sound creation. The garment itself is made from a thick black fabric with a silky liner. The outer layer is penetrated by clusters of metal studs. Between the two layers a network of conductive thread connects the studs into clusters and connects the clusters to a micro controller that transmits electrical current out into some of the clusters and is able to detect if any of the active clusters come into contact with the passive clusters by measuring any incoming voltage.

The resulting bursts of activation are transmitted to a computer that integrates the data streams into activity measurements and computed a centroid of the activity, i.e. a weighted centre on the vertical axis of the garment where the activity is taking place. The behaviour of the integration can be tuned in the software allowing for different behaviours, from quick bursts of transients to slow build-ups and long decays.

To relate to the fluttering streams of activation that the garment produces
when two clusters are running through each other, sample based granular synthesis was chosen as the method to produce the resulting sound. This allowed for cascades of micro events that on a macro scale corresponded to the movements in the garment, and strengthened the stochastic nature of the interaction.

The DMI was created in a collaborative crafting process where the tensions between the different materials and disciplines were surfaced and explored. This lead to the functional aesthetics concept that informed the framing of the several exhibition demonstrations where more than a couple of hundred of visitors have tried the garment in a variety of contexts, often sparking discussions and speculations on possible future use cases.
## 4.3 Sound Forest

**Main concept**  
A room scale platform for musical interaction connecting sound, haptics, and light.

**Used by**  
Museum visitors.

**Mode of interaction**  
Plucking and pulling fiber optic strings that run from floor to ceiling.

**Synthesis methods**  
Phase modulated tones in just intonation intervals and a system of layered pre-produced samples.

**Technical Components**  
Contact microphones, SuperCollider, Python, Node.js, JavaScript, DMX-controlled LED-drivers and fiber optic cables.

**Source code**  
https://github.com/elblaus/sound-forest

**Estimated time in use**  
>2500 hours.

**Selected performances**  
The Sound Forest installation was a commissioned work for the Swedish Museum of Performing Arts. It inhabits a partially mirror-clad room and consists of an ensemble of five practically identical strings. The strings, made out of fiberoptic rope with a core of highly durable wire, run from floor to ceiling. In the ceiling there is a loudspeaker, an LED-based RGB driver for the optical fiber, an ultra sonic range finder, and a contact microphone that is attached to the wire. In the floor, each string runs through a platform that has bass shaker speaker elements attached to it. This construction allows the strings to glow in individually DMX-controlled RGB colours. Interaction with the string can be detected by the range finder and the microphone. Each string can also play back audio through the loudspeaker in the ceiling as well as vibrate the section of the floor that surrounds the string.

Sound Forest is a technical infrastructure, including in addition to the hardware mentioned above, a set of softwares, that take care of the communication with the LED driver and the range finders, offering a unified interface to control the installation. The actual content and behaviour of the installation is fluid, and the goal is for the museum to continuously commission works for the installation, use it in the pedagogical activities that are a regular part of the mu-
seum’s programme, as well as for it to be a platform for further collaboration between KTH Royal Institute of Technology and the museum, e.g. designing a new version of the installation already being a recurring student task in courses at KTH.
## 4.4 Optical tracking systems

<table>
<thead>
<tr>
<th><strong>Main concept</strong></th>
<th>A robust and autocalibrating real-time translation of optically registered movement to music.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Used by</strong></td>
<td>A professional dancer as well as exhibition visitors.</td>
</tr>
<tr>
<td><strong>Mode of interaction</strong></td>
<td>Performing different movement characteristics in pre-defined sections of the performance space to activate corresponding audio feedback.</td>
</tr>
<tr>
<td><strong>Synthesis methods</strong></td>
<td>Sample based granular synthesis, phase vocoder based pitch invariant time stretched sample playback, frequency modulation and subtractive synthesis.</td>
</tr>
<tr>
<td><strong>Source code</strong></td>
<td><a href="http://www.github.io/elblaus/tracking-tools">http://www.github.io/elblaus/tracking-tools</a></td>
</tr>
<tr>
<td><strong>Estimated time in use</strong></td>
<td>&gt;1000 hours.</td>
</tr>
<tr>
<td><strong>Selected performances</strong></td>
<td>CARPA, University of the Arts, Helsinki, Finland, 2016.</td>
</tr>
</tbody>
</table>
I have for several years experimented with developing several different versions and iterations of optical tracking systems for live performance and installations. The two most used series of DMIs were called *The Charged Room* and *The Observers*.

The Charged Room has become an umbrella term for a set of pieces that have been realised with an evolving but still coherent set of tools for real-time analysis of human movement for the purpose of gestural control over digital sound synthesis. Leveraging the advances in open source computer vision frameworks, like *OpenCV*\(^1\), the system has consistently been based on ceiling-mounted digital cameras feeding a computer running a combination of software for computer vision and signal processing.

The main difference between the pieces that have been realised with this set of softwares have been the performer, the staging, and the musical content. Three notable pieces were *Oh My Body* where an operatic soprano sang while producing electronically altered versions of the same aria she was singing,

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\(^1\)https://opencv.org/
Morgondagar, where a dancer performed using processed violin recordings, and Luftouvertyr, where a chamber orchestra, seated in a concert setting, performed recordings of their own playing, using musical gestures without producing any acoustical sounds.

The Observers are in part built on similar technical systems as the Charged Room. The big difference is that The Observers have an actual physical presence on stage. Instead of a single eye with a god-like view of the stage, The Observers (as seen in Figure 4.4) have a situated and directed gaze. This means that they are subject to the same physical properties of the stage as any human actors they might share the stage with, inviting a completely different kind of play. For instance, a performer can hide from an Observer, a view can be blocked by a piece of the set, and different parts of the stage become visible to different Observers.

Similarly to development of the various versions of The Throat (see Section 4.5), the development processes for the different tracking system based DMIs were tiered collaborations where the core team stayed consistent and all had a big influence on the direction. In addition to this, the various versions that were developed were all used in exhibitions and performances where both visitors and professional performers used them and those experiences were also used to feed the development of the DMIs, both through observing behaviour but also in spontaneous discussions and by directly asking for the explicit experience and opinions of the performers. More than 10 professional performers and many more exhibition visitors have used some version of these DMIs.
4.5 The Throat

Main concept
A performance based gestural manipulation of real time voice processing and accompaniment.

Used by
Virtuoso opera singers.

Mode of interaction
Execution of predetermined gestured detected by sensors attached to hand and arm.

Synthesis methods
A wide range of digital signal processing such as spectral manipulation using phase vocoding, delay based phase modulation, and polyphonic diatonic pitch shifting.

Technical Components
Wireless microphone systems, SuperCollider, Python, Arduino, Zigbee, X-OSC, varistors like bend sensors and pressure sensors.

Source code
http://www.github.io/elblaus/the-throat

Estimated time in use
>1000 hours.

Selected performances

2:30, Cape Town Opera, South Africa, 2013.

Extended Opera, Liszt Academy, Budapest, Hungary, 2014.
The Throat is a gesturally controlled wearable system for real-time manipulation of the operatic voice. It has been a label affixed to a long series of incrementally different instruments that have explored the power relationship between singer and accompaniment by allowing the performer to create tonal backgrounds and abstract soundscapes to perform on top of. The first version that I participated in developing was specifically geared towards an operatic lead part in a piece based on Joseph Merrick, also known as The Elephant Man.

While the initial use as a palette of vocal deformities informed the range of processing available, the modular platform created for the sound processing back end of the instrument was easily extendable, leading to The Throat being used in many other performances.

In all the iterations of the instrument, it has always consisted of a wireless microphone system, sensors attached to the arm and hand using some sort of glove, sometimes with a separate sleeve, a box worn on the body with electronics and a power supply, and a separate set of software running on a computer.
that performs the signal processing.

The many versions of The Throat have meant several years of effective development time, in addition to the time spent rehearsing and performing, spread out over the period from 2011 until the time of this writing. This work was closely tied to the process of generating a repertoire of pieces for The Throat through open ended exploration and material generation, by adopting existing compositions as well as writing new compositions specifically for The Throat. Like the optical tracking systems, the people involved in the projects were in two distinct groups, a core team that was heavily involved in the development through iterative studio work and a much larger group of performers that by participating in one or more productions got to learn and perform with a version of the DMI. Not all productions were traditionally commissioned works, for instance, it was used in course work at the University College of Opera in Stockholm.
Figure 4.6: An early prototype test with singer Håkan Starkenberg.
In this chapter, I will discuss the work presented in the included papers of this thesis, informed by the background presented in Chapter 3, using the digital musical instruments presented in the previous chapter as examples. This chapter is divided into three sections. Each section tackles a theme, or scope, that I consider to run through all or almost all of the work. As such, the themes are all interconnected, but they can be thought of as three steps of increasingly widening perspectives. Moving from the perspective of a craftsperson interacting with material, to the DMI as one of many actants in a complex weave, to how DMIs can help us probe and explore the behaviours of the network itself and ask questions about artistic practice.

5.1 Crafting

In Chapter 3, we saw examples of theory from interaction design in general, Sonic Interaction Design, and research on the creation of digital musical instruments in particular, that considered the experiential body, aesthetics, and crafting to be important. The examples had different perspectives, using different literature, different exemplars, yet, I argue that taken together, they point in a direction that is also suggested in my work. In this section I will try to discuss this direction: How we can use a body conscious crafting approach to engage with artefacts of artistic importance from a Sonic Interaction Design
Starting from the craftsperson is very natural for me as it has indeed been my role in the projects in the included papers. This practical work experience led to my framing of it as crafting, and that framing in turn, has informed my analysis of the origin and life of digital musical instruments. In my view, the craftsperson, in action, performs a fusion of many different practices, often considered to be separate. We have seen many examples of how the essence of crafting is put forward as a bridging of dichotomies, e.g. learning and doing, reflecting and acting. The use of the term perform is important here, for it is in the very act of crafting that these knowledges fuse. Crafting is not a fusion of other skills that are prepared in advance and then brought into the crafting situation, it is in the very moment that crafting is performed that the fusion happens. The reason for this is materiality. The fact that crafting is a close conversation with the material that is being manipulated makes it performative, it makes it live.

The conversation between craftsperson and material is, as the word manipulation suggests, often physical, as in that the craftsperson is manually in contact with physical objects. It is easy to accept that tacit embodied knowledge could be active in such a situation, that subtle changes in the material could inform the craftsperson’s actions, even though that influence could be hard to put into words or state explicitly. Many kinds of components involved in digital musical instruments can easily be classified into this model of activity, e.g. creating hardware components, augmenting physical instruments, hacking existing objects. However, I would argue that there are two prevalent materials that, while perhaps superficially of different classes, are also subject to the same mode of craft: source code and the human body.

The digital parts of digital musical instruments will to some degree include programming. Whether it is done using a visual programming environment or writing code, at some point, the behaviour of the interactive material will be specified by manipulating logical symbols of some abstraction. Putting aside the fact that this manipulation is inherently physical in that it uses physical input methods, such as keyboards and mouse pointers, I argue that there is no inherent difference in the relationship between craftsperson and material in this case compared to the case of the manipulation of a physical material. The notion that code is a design material is not new, and, as we saw in Chapter 3, shared
by other researchers. However, this has some important consequences when considering the particular case of crafting DMIs. Especially so, taken together with the idea that the human body, is another prime design material for DMI crafting.

Let us consider what it means, in this context for something to be a design material, from the perspective of the craftsperson. Primarily there is a need to have intimate knowledge about the material’s possibilities, how it behaves, and how its behaviour changes as a result of circumstances, external impulses, fatigue or other factors. Furthermore, the craftsperson needs to both be able to assess the current status of the material, and to manipulate it. But when considering what I stated above regarding the fusion of different domain knowledges performed by the craftsperson, because of the hybrid nature of DMIs, there is also the need to accurately translate behaviours between the different material domains. Therefore, I would argue, that the notion of crafting in the context of DMIs is not only useful because it describes the exploratory melding of activities that usually are temporally distinct, e.g. learning and doing, but furthermore that it is useful because it describes the domain fusion that is needed to bring about valuable musical interaction.

This means that when designing for the body or bodily expression, even virtual materials must be approached with a bodily understanding. One must have a real embodied experiential understanding of how a change between a linear and an exponential mapping feels, or how different interpolations of sensor data might affect the movements of the person that the sensors are tracking.

This translation of bodily understanding to material properties and back again is not only fundamental to crafting as a solitary activity, it is a crucial skill for crafting digital musical instruments with others. In formally participatory design work or, at least inclusive studio sessions where performers, directors, or other contributors of artistic direction are to give feedback or work iteratively during crafting, the manipulation of concepts can be done in different domains, using different vocabularies. e.g. the compositional possibilities of an instrument might be discussed in a different set of terms than how the physical constraints of the instrument alter the performers presence on stage. For concepts to move from one domain to another there is a need for a translator, someone who can understand a nuance or a quality of an event in one domain
and relate it to behaviour in another.

These translations between domains are a powerful metaphor for what digital musical instruments are, or what roles they have been put into in the projects I have worked in. Behavioural connections between material domains like music, drama, composition, performance, interactive materials, as well as practical aspects of the realities of contemporary musical practice, e.g. rehearsals and touring.

In this view, the DMIs become a sort of nexus through which many intentions and impulses flow and become translated as per the logic of the instrument. Yet, I would not argue that all of the domain knowledge and the crafting performed in the creation of the DMI is therefore built into the instrument. It might be evident in the larger process from which the DMI has emerged, and to some degree discernible from the pieces that have been performed with the DMI, at least to other craftspersons, what the subtleties of the translations and the behavioural linking between material properties in different domains might be. Therefore, I argue that thorough descriptions of DMI crafting are useful and worthy of study. Furthermore, the study of others’ crafting processes and the extraction of hidden or tacit aspects of DMI crafting from one’s own work is what allows DMI crafting to make valuable knowledge contributions to Sonic Interaction Design.

If DMI crafting is understood as a mode of translation, we can compare the resulting instruments to algorithms for machine translation of language. As Hofstadter (2018) points out, one troubling possibility in such systems is that the result is indeed made up of the symbols of the target domain but does not necessarily contain the same meaning. This kind of poor machine translation is using a set of events in one domain to trigger events in another domain without in any way guaranteeing that the intended meaning is maintained. So to avoid this, we need to understand both the source and destination language. Simply following a sparse set of rules for turning some symbols in one to some other symbols in the other will not get us very far. This situation is further complicated by the fact that we might have artistic intentions that require intentional mis-translations from the literal, meaning that it is perfectly viable to alter or even reverse the literal characteristics of input and output, e.g. the smallest gesture producing the most forceful sound. Therefore, this is not to be taken
to mean that there is some optimal or natural connection between a gesture in an interface and an auditive result. Rather, it even further increases the need for proficiency in both target and source domains, and the ability to translate or transmute between them so artfully that they fuse into one coherent idea in the DMI. By not just connecting symbols but connecting meaningful experiential qualities, inputs and outputs will not simply be linked and proportional, but express something greater. This does away with the notion of an interface being useful independent of a sound source, only when matched can they be understood and critiqued.

Materiality plays two important roles here. First, rightly, the interface is thought to be worthy of special attention because of its physicality, it becomes a thing of material concern, subject to laws and knowledge from lutherie and other crafts. Secondly, a more problematic definition by negation, everything else becomes virtual and in the purview of computer science and signal processing, governed essentially by math, the art of the abstract.

A critique of this duality can be formulated by the presence of the performers’ experiences. To them, the duality of the physical and the virtual is not useful, they must engage with the resulting whole.

5.2 Instruments in Long-Term Use

Expanding our horizon beyond the origins of digital musical instruments, and considering what, if anything, is to become of them once they exist in the world, we need to consider messy multitude of possibilities that lie beyond the initial crafting context. One aspect that I find particularly interesting is whether the DMI will end up in use, and furthermore, what actions or qualities of actions contribute to the adoption of digital musical instruments into contemporary musical practice and culture. These considerations must resonate in ideation, crafting, the participation in the design process, the project management and infrastructuring of the situations into which the DMI is placed.

Why this is important depends on the goals of the stakeholders involved in the process in the first place, but if we consider the academic aspects of DMI crafting, it is important because the scope of resulting claims must match the scope of research. In other words, to answer questions about musical instru-
ments, the DMIs must be considered as such, performed and rehearsed with as such. I have come to move away from the traditional HCI optimisation approach, where expressivity is an objectively quantifiable characteristic of an instrument in itself, and the performance of etudes suffice as investigations into musical goals. In contrast, I consider musical instruments to be sociomaterial constructs, in the same way that I consider music and musical practice to be social and cultural domains.

I will use examples from my work to illustrate what I consider to be the defining factors in the ongoing agency of the DMI, with the benefit of knowing more about their long-term use than I did at the time of writing the included papers. The examples are, The Throat, the three performance systems developed with circus artists, the Nebula garment, and the Sound Forest installation.

The Throat (see Section 4.5) had a very good probability of longevity. As I entered the project, earlier versions had already been in use for some time, there were pieces composed and performed with the instrument and most importantly, it had a dedicated performer that was willing to invest time and resources to further the artistic project that the instrument was necessary for. The defining characteristic of The Throat, over the years that has been in use, is how has operated as a consistent conceptual construct, pursuing the same artistic and technical qualities, e.g. empowering the performer, autonomy, self-accompaniment, while the actual technical implementation has shifted over the years. If we stay with the framing of DMIs as translations between behaviours and characteristics of different material domains, then one could envision a conceptual DMI that without being tied to a particular implementation still encapsulates enough to create an reasonably clear identity.

I think that this is an interesting organological development, that could well be formalised to give us a language to help categorise DMIs. With the singular exemplar on one end of the spectrum - situated, unique, particular - and a conceptual design programme on the other - exploratory, following a trajectory, moving. In the case of The Throat, there was also another infrastructure that greatly helped both keep the programme alive and provide new participants, namely a series of courses in which students in each iteration studied and performed with The Throat. So, in summary, The Throat was and still is a DMI that continuously produces new knowledge by remaining in use, finding new
shapes, new contexts, and new performers. This is due to a combination of beneficiary informal as well as formal supporting structures, as well as a result of a fluidity of form that has allowed the idea of the instrument to survive any particular technical implementation.

The digital musical instruments that were developed in collaboration with circus artists (see Section 4.1) inhabited a context very different from The Throat. The project and the DMIs were set up to be transient in almost all possible ways. The group of performers were a temporary construct for that very project and was disbanded directly after. The technical infrastructure, while procured for the project, was considered reusable, but the DMIs themselves were from the beginning prototypes created for a series of experimental performances (called beta tests in the project). The projects were structured in different ways because they had differing goals, one a long-term investigation of a particular mode of performance, the other a series of explorations of different possible additions to a performance praxis. But they also reflected the differences in the practices of the art forms of contemporary opera and circus. One priding itself on tradition and monolithic structures and the other on a nomadic relationship to piece, performance, and troupe. Here, the traditions and labour structures of the art form itself made some things easy and some hard. Factors that are completely out of the picture when looking at DMIs as an engineering problem ended up being key to determining what were good design decisions in this case.

The Nebula garment (see Section 4.2) was a design provocation that turned out to be a very interesting prompt for speculation and imagination for many who tried it or saw it used. While it hasn’t been used as extensively as the other DMIs, it has still been used in a few stage performances and has had a piece composed for it. But the main contributions have come from its wide use at demo sessions, workshops, conferences, science fairs, and other public outreach contexts. It offers us in interesting complication regarding the idea of use, or what it means to end up in use.

The accessible nature of Nebula, a garment that easily goes above your other clothes, requiring no special skill and requiring nothing more that for the wearer to move, makes the barrier of entry low. Indeed, it was made to function that very way, allowing us to ask very different questions than we could with The Throat or the augmented circus apparatus that required much more commit-
ment to be explored. The Throat functioned more like a traditional virtuoso instrument, and while it inspired artistic direction, more often features were put in to realise particular artistic goals, i.e. the artistic direction led the technical development. The augmented circus apparatus were an exploration of extending existing expertise. Nebula was seemingly just a shroud. But people took it seriously and found it to be evocative - because of material properties. While the visual aesthetics was striking and certainly drew an interest, I would argue that it was the physical characteristics, the felt experience of the weight and the richness of the materials that gave the garment both actual and metaphorical heft. The interaction with the garment became intimate, and many immediately had the impulse that they needed for other people to try it so that they could share the experience, while very few tried to explain how it felt to wear it. This, I would argue, is the strength of the Nebula garment, it offers a low cost of entry, and it provides the wearer with an intimate and rich experience that is evocative of possible scenarios of use and new versions of the design.

If we compare this arguably meaningful public use of Nebula with The Observers (see Section 4.4), we notice some very interesting similarities and differences. Superficially the barrier of entry for a novice user, like an attendee at a demo, is even lower for The Observers than it is for Nebula. No garment is required, and as the interaction is camera based, everything else is removed, leaving only the movement performed. However, this difference, this move from felt materiality to virtuality fundamentally changes the interaction for the participants. Where Nebula was evocative and always at some point turned into a discussion of the garment, its weight, how it was made, the experience for a novice interacting with The Observers was often guarded and tense. Instead of the focus being on a thing that was worn, the focus was on the body itself. The garment interacted physically with the wearer, informing movement, restricting, and thus became something to struggle against. The camera offers no such guidance. While The Observers were very successful instruments for on stage performance, the lack of materiality became an obstacle for novice interaction. As the public demo, with instructors, participants, audience, is a social setting, it is easy to read this setting as a set of power relations and even a politics of who gets to do what. This political dimension can also be folded back into the crafting of DMIs, as we will see with the Sound Forest installation.
Two interesting counter-examples that illustrate how the notion of materiality can be regained, even in a camera based virtual interaction are the pieces Morgondagar and Luftovertyr, from Beings and Ballads, described in Paper D. In the former, a skilled dancer performed a microscopic dissection of a handful of pre-recorded violin notes, moving through the sounds with extreme precision as she moved across the stage. In the latter, a string orchestra performed a garbled and chaotic collage of recordings of their own playing, following a score and performing corresponding musical gestures, without allowing their bows to touch the strings of their instruments. I would argue that in both cases the interaction was meaningful because materiality was reintroduced. The dancer is in constant dialogue with her body, it is naturally a constant physical presence. The same can be said for the orchestra, with the added materiality of the instruments, that function as an extension of the body for players with that level of expertise. Therefore, it is not as simple as camera-based interaction being virtual and without body. The full situation must be considered, and we never escape our own bodies and the bodies of the performers we experience. Reintroducing the body as a materiality where it has been abstracted away can be a matter of redirecting attention to what is already there.

Sound Forest is different from the other DMIs in this thesis in that it is designed to function more as an ensemble or an orchestra rather than an instrument. Not just in the sense that it is more than one instrument that can perform more than one piece, but more importantly in the way that an orchestra is an institution, that offer learning opportunities as well as formal commissions of work. Essentially, it is infrastructure to allow others to explore real time musical interaction on a room scale in a public setting, either for learning or in a professional capacity. Instead of providing the project owner, the museum, with a monolithic, finished piece, a machine that commissions new pieces was installed. This way, ample opportunities were created for future collaboration on the integration of new pieces, pedagogical demonstrations, integration into courses on university level, ensuring that new knowledge will continually be uncovered. This is a distinct strategy for increasing the chances of both longevity and meaningful activity, but it highlights how political and sociomaterial aspects of DMIs determine their possibilities.

All digital musical instruments must not, and should not, be investigations
into the same domains or ask the same questions. However, since the con-
texts in which the instruments are put and the material qualities of the artefacts
themselves dictate what is possible to explore, homogeneity in one leads to ho-
mogeneity in the other. In this section, we have seen how DMIs can function
as infrastructure as well as tools for virtuoso performers, how they can offer
meaningful evocative interaction for novice users. Central to understanding
why these different outcomes came about, is to connect the materialities of the
crafted instruments with the sociomaterial reality in which they exist.

5.3 Probing Artistic Knowledge

We have seen that there is a complex interplay between material and craftsperson
in the making of digital musical instruments, and that sociomaterial aspects
also decide the faith of the DMI in the context of contemporary musical prac-
tice. In Chapter 3, I gave examples of the notion that DMIs could function as an
active investigatory probe, not only an object to be accepted or dismissed by a
community. This means that by studying the DMI we study its context, since so
much of the actual characteristics of the DMI in use are arrived at in interplay
with other people and things. The most interesting things about how a DMI
functions is not immanent to the DMI but emergent. Jorda (2005) writes:

Music instruments are not only in charge of transmitting human ex-
pressiveness like passive channels. They are, with their feedback,
responsible for provoking and instigating the performer through
their own interfaces.

In this section, I will try to add to the information in the papers, regarding
how the DMIs influenced the artistic practice that they came in contact with.

The Throat was very interesting in how it shone a light on performance
practices of opera, especially when it moved from its first performer and on to
the many others who would practice and perform with it during the courses in
which it was used. Arguably, the mechanics and signal processing was highly
tailored to its first performer, leading to an overfitting problem when given to
other performers. However, because of shift in the power relationship as the
DMI became part of a curriculum, where a mismatch between performer ability
or preference and behaviour of the DMI earlier was seen as a problem with the DMI, the same kind of conflicts were now reframed as a fault of the performer. This was not true for every cause for friction, e.g. obvious failure in the digital material, but the shift was nevertheless observed. Naturally, it is difficult to reduce several years work to one observation or one mode of influence, as it was active in so many different contexts together with so many different performers and other artistic artefacts. Yet, the solidification of the DMI in the didactic use was interesting and foundational for how it was allowed to influence performer practice to such a degree that it did. My co-author Unander-Scharin (2015) has written about the actual influence on the vocal practices of the participating singers, but I want to stress here that the fact that the instrument was imbued with a rigidity, a finality, was a key factor in enabling that influence, it was de facto given power.

It should be noted that it was not the abstract conceptual clash of operatic practice and contemporary electronic music that provided the friction from which these observations could arise. It was the inherent material sensibilities of the DMI that made certain aspects of staged vocal performance matter in ways it usually didn’t for the participating singers. A good example of this was the choir function that highlighted the singers’ vibrato and gave new meaning to how the singer pitched, and charged the signers amplitude consistency with consequences that the singer had not had to consider before. Another example was how the gestural interface disrupted the physical stage presence of the singer, charging some, previously abstract gestures with logical meaning.

The augmented circus apparatus also gradually changed the relationship between performer and instrument. It was explicitly reported by the participants that they not only changed their act when using the DMI, but that the act of searching for appropriate DMI-compatible additions to their performance allowed them to find new material with other kinds of characteristics than they would have found without the DMIs. While the DMIs were developed iteratively together with the performers in this case, the transient nature of the project simply didn’t allow for large changes in the underlying technical implementation of the DMIs, leading to a joint search for the biggest impact that was manageable within the time constraints of the project. This introduced, if not a finality, at least a rigidity to the DMIs in that they could be changed less and less during
the preparation leading up to the performance. From this, we can trace a relationship between finality and power. For a digital musical instrument to change practice it needs to resist change itself. This power to resist can be externally imposed or be a consequence of practical considerations, but it is nevertheless a way for an instrument to assert itself.

The Sound Forest installation is interesting in this regard, as it is to be seen as a fixed platform that in turn allows dynamic content and behaviour. It therefore embodies both rigidity and fluidity. At the time of this writing, it is still awaiting its second commissioned work. However, a project has recently finished where the installation functioned as a platform for students of composition at the Royal College of Music in Stockholm. In the project, composers were given the opportunity to explore how their own music could be reconsidered as interactive in the context of a museum installation, providing them with a fully felt experience. This would have been out of their reach without the Sound Forest installation because of the technical skills and resources required to create the installation space and the technical infrastructure supporting it.

We have seen that crafting is a useful framing for the fusion of technical and artistic sensibilities and skills needed for put forward new DMIs. However, the work of the craftsperson is not done when the instrument ends up in use. On the contrary, repurposing, repairs, upgrades to remain compatible with the surrounding technological ecology, incorporation of new ideas, refitting for new performers, addition of new musical material, are all common activities. Comparing with other more stable musical instruments archetypes from organology that might have had hundreds of years of continuous improvement and adaptation before arriving at a consensus form, the DMIs discussed in the work presented and referenced in this thesis are all comparatively young.

Like the craftsperson, the possibilities for research are not over when we have a working prototype of a new DMI on our workbench in the lab, neither is it over after the first performer is found or the first performance is done. In fact, there is a wealth of information and new questions that populate the myriad of possible futures for the DMI that might follow after that. Especially if we are conscious of how that process can be actively shaped.
5.4 Summary

Sonic interaction design is a useful framing of the work presented in the included papers as it ties together the ongoing aesthetic turn in interaction design with the particularities of the audio modality. Furthermore, crafting is a useful framing of the kind of work presented in the included papers, by virtue of more accurately describing the practical work, the skill set needed, and the role performed in the projects.

Crafting digital musical instruments is to consider and exploit experiential aesthetic knowledge about materialities of different practices and domains. In this work, the presence of the experiential body cannot be overstated. In general, an understanding of experience, embodied aesthetics, must be acknowledged from ideation and onward in DMI crafting.

Only working in a lab setting, from requirements, using superficially strict evaluation, severely limits what questions we can ask using our instruments. DMIs can even be used to explore and change musical practice, but for that to happen much more than the artefacts themselves must be taken into consideration and be designed. Sociomaterial aspects and networked agencies of human and non-human actors contribute to the life of the instruments. Social and institutional scaffolding and infrastructuring determine the trajectories of DMIs that researchers can follow. The degree of perceived rigidity and finality affect how DMIs assert themselves and in turn, to which degree they are allowed to change artistic practice.

A plurality of ways of understanding and even languages used to discuss the same DMI can successfully be cultured in a project. In fact, being too rigid in enforcing a technically accurate understanding of the DMI can be detrimental to the relationships with the DMI. Sometimes, it is a part of the task of the DMI craftsperson to be able to translate between the different worlds of the stakeholders involved, technically, artistically, and conceptually.

This ability to translate an impulse, concept, or statement, from one domain to another is a useful metaphor for what a DMI craftsperson does. The DMI as an actor straddles boundaries and connects practices and practitioners so creating one is in a sense to solidify, to some degree, a connection between concepts and activities in different domains, e.g. body movement and musical performance.
Chapter 6

Conclusions

The work that is included in this thesis is a collection of situated crafting of
digital musical instruments in a variety of contexts. Through the development
of these instruments, as well as through their use, the role of the craftsperson
as well as the artefacts could be further understood. I align myself with other
scholars in saying that the skills and working methods involved in the creation of
digital musical instruments can and should be understood as a crafting practice.
Furthermore, in keeping with contemporary interaction design developments, I
believe an embodied aesthetic perspective to be integral. In fact, the role of the
DMI-craftsperson in the kind of projects described in this thesis can be thought
of as a kind of translator that both needs to be able to communicate between
many different domains during the project work, but also needs to have the
crafting skills necessary to be able to solidify some of these transative connec-
tions into the DMIs. Looking at DMI-crafting as a separated or solitary practice
is reductive. In fact, I would suggest that the very nature of DMI-crafting is
social and sociomaterial. This is my answer to the question of the character-
istics of the role of the craftsperson in multidisciplinary artistic projects where
DMIs are developed. Furthermore, in my work, I have observed that performers
continue to renegotiate their relationship with DMIs regardless of whether the
makers of the DMI consider them finished or not. Therefore, to actively engage
and support that process by keeping instruments in a fluid enough state to ac-
commodate new forms of use adds to the relevance of the instrument and the
time it spends in use. Finally, it is in actual use in contemporary musical practice that the DMIs can be influenced by and in turn influence other central actors like performers and composers. This is how we should explore our instruments, and how we can use them to explore and engage with artistic practice to be a positive force in the development of the arts.

6.1 Future Work

The nuances of the materials used in DMI crafting are very important for the final experience of the DMI, and since new materials are continuously being used in DMIs, it is an ever changing landscape to explore. Between the abstract layer of musical concepts and the engineering specifications and data sheets of electrical components lies a physical reality that could be challenged and charted. How are auditive aesthetics and tactile choices connected? How can we work with or against physical characteristics when shaping our instruments?

Supporting the longevity of our DMIs is not just about putting certain qualities into the instruments themselves, but to create platforms, documentation, and didactic environments around the DMIs. I think there is a strong connection between the ability for a performer to demonstrate and someone else to learn how to play an instrument. Furthermore, I think we could learn much by trying to teach others to play our instruments. Teaching an instrument also highlights the need for repertoire, either aurally traded or represented somehow which in turn leads to notation, traditional or otherwise, all interesting avenues to explore to further our ability to explore new musical ideas with our DMIs.

These new musical ideas could also be interesting to use as a starting point for new DMI development. Even though it is perhaps not uncommon for DMIs to evolve together with one or more musical works, as can be seen also in my own work, it would be interesting to do a more systematic exploration of composition-first DMI crafting. As I have felt in many of the projects presented in this thesis, trying to accommodate other aesthetic goals than my own has helped me to move beyond my habitual modes of working.

Finally, from a research method perspective, I would like to explore the many challenges in exploring and documenting all the moving parts in a complex project where DMI crafting, composition and production all intertwine. Es-
especially in tying together documentation of discussions and insights with source code version control systems. Early tests of this look very promising and could change the way these processes can be understood and reconstructed.

6.2 Crafting Experience

In this thesis, I have written about how we understand digital musical instruments. While it is technically correct to state that a physical interface and a digital core are separate entities that can be looked at individually, in a performance context one cannot rely on that technical fact to define the experience of the performer or the audience. While it is also as true that the strings in a piano can be prepared or retuned, even during or as a performance, the instrument in each moment will also, or in some cases exclusively, be understood holistically. The fact that something has a possibly infinite dynamic capability does not mean that we do not engage with it in its full current complexity. Even though the parts are worthy of study, and might have been created separately, a jump in the level of abstraction takes place in performance and the whole emerges. Thus, instruments can only be understood in performance holistically and as fixed - but must be supported in a more long-term perspective with a much more fluid understanding of what constitutes identity. An instrument that looses its tuning during a performance is considered unreliable, whereas an instrument that can support many different tunings could be considered dynamic and evocative. An instrument must not be static in an engineering sense, but it should present a persistent personality. The underlying technical components can change, but if the aesthetic positioning, the intentionality that the instrument co-produces in its context is stable, the instrument is in a very real sense still there.

The title of this thesis, Crafting Experience, has a dual meaning. It refers to the fact that what I describe is my experience of crafting, but it also points to the insight that what I have been crafting can be understood as multifaceted experiences in themselves, as in the experience of performing with, composing for, or listening to an instrument. The notion of the translating craftsperson is akin to the idea of mapping, where quantities in one domain through a transfer function are mapped to another domain. The reason I chose to refer to the practice as translation, is that I would like to raise the gaze of our community from
the practicalities of our own material and take in the rich complexities that our artefacts serves as a connection between. It is reasonable to acknowledge that experiential domain knowledge is very much in play in the crafting of digital musical instruments. Mapping as such is important but the inputs and outputs are not just the endpoints between which our work is done. On the contrary, how we choose to allow our instruments be influenced by and in turn affect our context is of utmost importance. It is in this wider perspective, looking also at what lies beyond the boundaries of our instruments that the true nature of our craft becomes visible.
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