Tools for Musicking

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TABLE OF CONTENTS

ABSTRACT

This project aims to unlock musical possibilities through the design of musical tools. Aligning the acts of musicking (the idea that all peripheral acts that contribute to a performance of music are intrinsic to it), making (to enact a potentiality) and design (specifically, discourses around the discipline and its processes) mediated the creation of new musical objects through an intrinsically musical methodology. This approach manifests tools which are innately reflective of this synthesis. The ideas subsumed by these three areas are at times harmonious and otherwise discordant. Ultimately, the nature of these tense relationships is a vital underpinning throughout this project and are acknowledged through its central question: How might divergent approaches to the design of musical tools afford access to new musical possibilities?

An exploratory heuristic methodology directed material enquiry, drawing from heuristics in the arts as well as in design. This identified emergent gains through paired processes and established a workflow which combined low-cost 3D printing with metal foundry practices. Controlling outcomes of this process became an extended improvisational exercise in sculpting the timbre of an aluminium guitar-like instrument - pushing its sound quality into a realm of its own materiality, which stands in contrast to the tones of wooden instruments to which we are accustomed. The princi- ples of free improvisation within musical practice guided the design processes and bounded a framework of post-optimal design. This positions phenomenological elements at the centre, while allowing broad reference in a field-agnostic manner.
In order to realise these ideas in form, analogies were drawn between music as a mode of language (sound, structure and meaning) and evocative representational formwork (point, line and plane). Prototypes were developed whose forms were deeply rooted in these insights regarding the sculpting of sound. Assessing music in this way brought into focus the vast universe of tones and sound relationships outside of conventional reach. The mathematical musicking of microtonal theorists is one such tool that brings the idea of microtonal music closer.

With the guitar form as an inroad, a final instrument was developed which gives its owner control over a set of otherwise walled-off ideas in tandem with a unique timbre and a consistent interface that seeks to convey the intricacies of its internalised musical ideas. The instrument features interchangeable, precision machined microtonal fingerboards, presenting a dynamic that better represent the plasticity of pitch relationships. Additionally, users can design their own string layouts - be it conventional, historical or novel. In this way, musicians can dream up any kind of configuration and then use it to explore the world of microtones. This kind of instrument gives musicians a familiar interface to understand microtonal systems though their own tactile, multi-sensory exploration. It is also hoped that the familiar mecha- nisms of expression enabled by the guitar form factor can be paired in new ways with microtonal systems to develop not just microtonal scores, but new paradigms and genres.

INTRODUCTION

In 1998, Christopher Small coined the term musicking in order to distinguish music as a verb - a process - in opposition to its common designation as a noun - an object or work (Small, 1998). In his book on this topic *Musicking: The Meanings of Performing and Listening* Small expands his perspective on musicking to explain that music as a verb necessitates not only a performer and a receiver but also people involved at various stages of the process of musicking. This perspective opens the scope for what constitutes musicality concentrically - all parties involve are musicking. This includes the performer, composer, audience, editors, lighting technicians, acoustic engineer and architect who designed the space and so on. If this is the case, the design process that gives forth tools for the creation of this music is surely a form of musicking; a musical instrument being a means and a framework for a musical performance and its inceptive deign process being the form of musicking that gives it form. Within this framework of collective musicking, I have connected Ivan Illich's ideas of convivial tools (Illich, 1973). This is a viewport into a kind of tool which extends the capabilities of its user without undermining their expressive freedoms.

It is within this framework that it is asked: musicking can be design, but can design be musical? This project uses elements of musical methodology as a form of divergent design practice to see what kind of a string of tool-to-musical-outcome is created. Derek Bailey's writing and practice in the area of free improvisation lends a steady framework to transition into the field of making. Free improvisation is not experimental - it is tacit and responsive (Bailey, 1993). Using these qualities links back to heuristics in design and the arts - which codifies the importance of learning by doing. This further define the design practice as an extended line of improvisation, adhering to new topics as they move into focus. Ultimately, a microtonal system of customisation and unconventional acoustics emerged through the design of an aluminium guitar like object. This object refers to the fluid nature of tuning and tempering theories of practitioners such as Erv Wilson by giving users control and access to ideas of microtonality in a familiar and tactile paradigm.

Microtonality

There is vast precedent of musical practitioners creating and improving their own tools in order to realise a musical vision or, in some cases elucidate new ones. From Lou Reed's fretless ostrich guitar and tuning that characterised a lot of the sound of The Velvet Underground, to the ubiquity of sampled, spliced and custom coded digital instruments by producers and electronic musicians all over the world. Often overlooked however, is the class of practitioners working towards musical ends from a purely applied version of other specific craft. Mathematicians, engineers, designers, artists and more have used their skills to devise new structures of pitch, rhythm and timbre as well as contextualise humans' historical approach to music making.
The area of microtonality, or alternative tunings, is one such are in which practitioners are often forced to create their own tools and skillsets as a prerequisite of participation. This topic became an important context within which instruments were created, and a fuller understanding of the formation of this field of study is necessary.

Microtonality is a somewhat unique topic in which most of the important voices in its evolution speak in languages other than written or performed music. The term microtonal has come to mean any tuning or tempering system which doesn't resemble the western standard of 12 equal temperament (ET) - the idea that our notes are derived by 12 equal devisions of an octave or the span of a doubling of frequency whereby the two notes are perceptibly the same pith e.g. A 440Hz and A 880Hz. Sometimes the term is used to denote a tuning system in which notes are used with smaller intervals than those used in 12 ET (Schulter, What is microtonality? What is paucitonality?). But in a broader sense, microtonal theory is an endeavour to design collections of musical notes with varying relationships, with which music can then be created and performed (Schulter, What is microtonality? What is paucitonality?).

Joseph Yasser's form of microtonal musicking in this way, was a collection of theories around how microtonal systems might develop popularity in the future. He approached the problem with a mathematic perspective. Part of the theory describes how our tuning systems evolved from few (non-equal) divisions of an octave, to finally settle on 12 notes. He theorises that by following the historical sequence - which saw the number of what he calls 'regular' notes (what we now think of as white keys) being added to the total notes in the system - we can project it forward to derive future viable tuning methods (Yasser, 1932). The outcomes of this simple mathematics points to note values that have not only been theorised, but actually used by composers and musical cultures: 31 notes per octave is a meantone temperament (Zorach, Meantone Tuning) and was actually written about as a viable equal division by Christiaan Huygens in the 1690s (Rasch, 2002). This, like other microtonal endeavour, works towards scales which have as many core just intonation intervals represented as precisely as possible - or intervals of pure ratios. In line with his theories, Yasser wrote music in 19 ET as an exploration in validation of the form. Consciously or otherwise, Yasser's explorations seemed to mostly set his sights on the past in order to contextualise future paradigms. His theories on progressive equally tempered scales aligned with musical instinct of the past but reestablished them for the twentieth century. He even researched an ancient device used in jewish ritual thought to be a musical instrument; according to Yasser's findings however, it was more likely a digging tool whose distinctive sound adopted ritual significance over time (Yasser, 1960). Yasser, in order to untie himself from prevailing thought at the time, cast his mind back to prior watershed moments in our collective musical experiment. This was his method of divergence which allowed him to lay down theory which is yet to be fully realised in popular music, but remains an important building block for our contemporary microtonal discourse.

Wendy Carlos is an example of a practitioner with immense understanding of relevant microtonal precedent but uses her unique perspective and mathematical expertise to question new directions. Most demonstrative of this thought process are her alpha, beta and gamma scales (Carlos, 1987, 42). These three scales are again, equal divisions of an octave however, they forgo the presumed sacrosanct nature of the octave in favour of very precise forms of smaller intervals - as derived from the harmonic series. Therefore the alpha scale consists of roughly 15.3915 notes per octave, meaning an absence of the 2:1 octave ratio in favour qualities such as highly consonant triads.
As an interesting connection, Carlos goes on to validate Yasser's aforementioned progressive tuning theory through a mathematical formula that was designed to ascertain highly applicable divisions of an octave (Ibid, 41). Throughout her career Carlos has certainly integrated various form of musicking across mediums: she was an early user of analogue synthesisers, having performed the album Switched on Bach - the first recording to feature the Moog synthesiser (Miller, 2004). She also integrated her mathematical microtonal theories into studio performance in such albums as Beauty and the Beast. These efforts, complimented by Carlos's scores for film, propelled ideas into the public zeitgeist but mostly in the realm of aesthetic acceptance of the synthesiser (and later, digital music production) (Moog, 1982). The almost alien sounds of electronic instruments become accepted by our ears yet different tuning systems which actually improve the underlying harmony of our music remain out of reach.

An equal approach to intervals is not the only way that our musical palate can be arranged. Harry Partch is a particular notable name in microtonal music through his use of multiple mediums to convey his ideas. Through the written word, a large roster of musical instruments through which he actuated these written ideas, compositions that make use of these instruments and systems, and finally self-produced records were created and distributed. This process was not just self sustaining intellectually, the revenue from record sales also financially enabled further ideas and instruments to be formed. Partch's theories outlined in *Genesis of Music* (1950) eventuate in a tuning system used for the bulk of his compositions, as well as ways to make chords out of these notes. Partch derived a 43 (non-equal) note scale based on natural ratios present in the harmonic series. This was the scale used throughout his somewhat primitive percussive and keyboard instruments and it gave him not just more precise versions of natural harmonics but also ranges of options for each interval. The drawbacks for this kind of tuning system is that it doesn't transpose perfectly to other keys - transposition being one of the reasons for our adoption of 12 ET. The tuning must be relative to a core note and therefore, sonic relationships change as other notes become more central to the music being performed. Using ancient Greek musical practice as a form of precedent, Partch stubbornly stuck to this single idea of microtonality, in his pursuit of pure ratios. It was in his rejection of European musical tradition that Partch attempted to build a new musical culture - the singularity of this vision has garnered great recognition however, the concreteness of his systems did not suit what others saw as the nature of microtonality (Partch, 2000).

Partch's colleague, Erv Wilson - who aided Partch in various elements of his work - had his own vast microtonal practice, centred in the world of mathematics. He use these skills to identify and apply new classes of tunings. Unlike Partch, Wilson saw the possibilities of microtonality as a living system - with fractal analogies borrowed from his love of botany (Narushima, 2017: 6). Throughout his career, Wilson's mathematical intuition and work led him to devise an almost unified theory of deriving microtonal scales from generator values (an interval size that gets transposed beyond the octave and retrieved to derive other related interval sizes) and mapping them onto a hexagonal keyboard interface with any amount of rows and columns. Like Partch these were often unequal scales which preferred pure ratios to flexibility, however, Wilson also researched ideas of equal temperament - such was the scope of his work (Ibid, 136). Unlike Partch's practice Wilson applied his theory to ranges of scales that unfold out of each other and put forward ideas that outlined the characteristics of usable methods for creating musical scales. His attention was split between this area, creating instruments as well as refining his theory towards a method of mapping all scales onto a generalised keyboard design (Ibid, 23). Wilson's hoped that a musical instrument which could manoeuvre the vast array of microtonal possibilities that he could see through his mathematic understanding could be created.

Ultimately, microtonal theory would become an important set of ideas in the direction of my research. Therefore, inquiry into how one brings these musical ideas to the masses became the key. How might one make musical tools to carry such expansive, living ideas? The expression "music is the universal language" I believe holds some insight on the subject. The progression of language being intertwined with technology lends, through analogy, insights into the means by which concepts take form and enter common usage. Concepts and modalities must be a useful balance of ubiquity and novelty. Human computer interaction (HCI) is one such field that seeks to bridge the current interlanguage between humans and the digital realm, and an eventual natural language which can aid in bringing complex musical ideas (such as microtonality) to the masses.

Novelty (NIME)

Within the world of HCI research there is a slew of technology led tools that change the way we make music. Since the proliferation of Musical Instrument Digital Interface (MIDI) - a universal language for communication between electronic instruments, computers and other instruments - the computer is seen as the centre of musical invention, and as such digital and physical instruments have been created to augment its capabilities (Swift, 1997). The New Interfaces for Musical Expression (NIME) conference has championed the collection of research into this topic for fifteen years and has compiled data in an attempt to determine which paradigms stick and why. As was alluded to earlier, respondents to the survey indicated that the key lies somewhere between referring to existing, familiar ideas, whist still pushing towards new ones. Familiarity seemed to be a key feature - making sure that the instruments hold reliable and understandable references and interface ideas as popular instruments or ideas (Morreale, 2017). Other respondents made clear how important prototypes are for determining these familiar touch-points, but indicated that a line in the participatory nature of some design methodologies, needs to be drawn. Musicians who were not familiar with design processes tended to struggle to be able to imagine the possibilities of features. This saw features being dismissed on a conceptual level but being used repeatedly in a working prototype (Ibid). Although musicians are key to the design and use of musical tools, we should consider the best ways to leverage our individual skillsets. In most cases, designers conceptualise and actualise musicians tools, while musicians conceptualise and actualise their musical realities. Seemingly contrary to this, respondents stressed that instruments need to be unique in some way, they need to stand out in performance and in the market in order to continue to be sought after and used. There is an element of aspiration in the greater interaction surrounding musical performance. New instruments need to distinguish themselves as the harbingers of new ideas visually, through design approaches. This also relates to the quality of construction. There was a noted correlation between the physical quality of an instrument and its continued use. Perhaps this is also an indication that deeply conceived ideas will be executed with greater quality. Finally, throughout this investigation into the use of past musical instrument designs, there has been subdued references to subtle qualities as well as tacit or intuitive understandings that designers place within their works and indeed musicians derive from their use. While these outcomes form useful general insights into musical instrument design process, it should be noted the extent to which this is a point of view from a niche sample. The vast majority of work in this area is presently undertaken in conventional design firms or in house design teams rather than academia.

NIME research also uses more traditional mediums as a framework for future designs. Violin luthiers were targeted for another study in order to deepen our understanding on what makes one instrument great and another (although very similar in design) average. This study similarly confirms the limits of participation by musicians but reaffirms how sensitive they are to tacit realities embedded within musical artefact (Armitage, Morreale, McPherson, 2017). The authors distinguish this from testing but, musicians seemed to have different kinds of sensitivities to the designers and as such could not evaluate the effectiveness of the approach - only the raw outcomes (Ibid). To then recover a players' response to an instrument also proves difficult as there is a limited vocabulary to describe subtle details of sound and physicality; many terms hold too subjective interpretations. Overall, it is stressed that tacit knowledge plays a dramatic role in the quality of a musical instrument and that designers' senses in this way can only be improved by creating and evaluating. Additionally, it is noted that scientific tools for analysis diminish the application of a designer's embodied knowledge, despite scientific concepts being a boon when integrated into the designers cognitive frameworks.

Practitioners that participate in NIME proceedings usually come from a HCI background and as such, the bulk of instruments created in association with the conference are in some way digital. In recognition of this Magnusson and Mendieta conduced a survey to determine musicians attitudes towards acoustic and digital musical instruments and how they figure into their creative processes. The respondents articulate a dynamic whereby the strengths and weaknesses of digital and acoustic instruments appear to be fixed (Magnusson, Mendieta, 2007). Digital instruments are moulded to a task or sets of tasks while acoustic instruments sit staunch to their function, to which to player must reshape through extensive practice and training. The idea that either class of instrument is fixed, yet again demonstrates the musicians zeal to incorporate new tools when appropriate but lack of speculative vision into how tools might mould to people or functions. Respondents really appreciated the customisation often enabled by digital instruments but were frustrated by either a lack of depth or the tool's fragmented attention - fulfilling too many tasks poorly as opposed to one with nuance and depth. A great deal of NIME research takes place in attempting to capture the embodied and expressive possibilities of traditional or acoustic instruments, in a digital format in order to expand their possibilities through modern computers . Perhaps there is scope of inquiry whereby notions of interaction, customisation as well as shorter iteration cycles enabled by computers can be fed back into the design of acoustic instruments (Tzanetakis, Fels and Lyons, 2013; Mainsbridge and Beiharz, 2014). By going beyond simply combining physical properties we can move forward into synthesising paradigms that better represent current musical experience.

Ubiquity (The Guitar as a Symbol)

As discussed in previous sections, there is a certain amount of relevant context needed (to illicit a sense of familiarity) as an shortcut to smuggle new ideas and paradigms into musical circulation. At a certain point my work in casting crossed over with the world of guitars - one of the most commonplace musical instruments perhaps behind the piano. There is a vast modern ecosystem of guitars available to the consumer, each with varying philosophies, quality, semiotics, string scales and even materials.
The modern acoustic guitar begins to take form in Europe in line with the popularisation of lute like plucked string instruments. It starts life as the Vihuela in Spain and varies in refinement, form, string number and construction (Wade, 2010: 63). Originally settling on four courses (four pairs of strings) the guitar eventually gets a fifth added and then a sixth - an increase in forces on the body was counteracted by the advancement of fanned internal bracing that are commonplace today at the end of the 18th century (Turnbull, 1991: 62). In order to grapple with variability in tunings that were musically common in the west before widespread adoption of equal temperament, the progenitors of the modern guitar originally had no fixed frets, but instead were bound with lengths of gut (Ibid, 15). These frets could be untied and repositioned to accomodate different tunings.
The exact time an place in which the guitar as we know it today emerged not totally clear. Exisiting specimens span from Spain, France and Italy (Ibid, 64) . It did however generate a swath of compositions (Ibid, 88). It was also at this time and perhaps for this purpose that writing for the guitar transitioned from tablature style to the use of a musical staff. Similarly, single strings became popular instead of courses for reasons of simplicity - more primitive strings and pegs presented much more of a chore in keeping in tune. It was during the 19th century that the guitar, although not completely designed

to a consensus, resembles in most part the guitars of today - metal strings, frets and machine heads, fanned bracing, large body and long neck (Wade, 2010: 66). Fixed frets now extended well into the higher register. With this new reliability and versatility guitarists could now rethink the musical role of the instrument and push it to take a place of prominence in performance an ultimately in the musical zeitgeist.

A swath of musical traditions that emerged through the 20th century had the guitar at some capacity, at its centre. Most notably this is true of the genres that emerge out of the advent of the electric guitar (Millard, 2004: 78). This is the icon of interest. Much as the piano keyboard interface served as a useful abstraction of its underlying complexity, so too does the guitar have a layer of social abstraction which bring to it a sense of understanding and musical ubiquity. There are a few companies who are taking this idea of the ubiquitous and either moving to perfect it or augment it. Paul Reed Smith, the founder and namesake of his guitar company, seeks to enrich and maintain pure tones through his subtractive theory (Smith, 2013). The theory illustrates a dynamic in which the vibrations of the strings before any real world impedance are pure and have optimal sound characteristics. From there the materials and design of the infrastructure only act to diminish these qualities. The best a guitar maker can do therefore, is create bridges and nuts that offer the least impedance to the transfer of vibrations. According to his theory, the use of appropriate acoustic materials is the key to a perfect guitar (Ibid).
In contrast to this, the instruments of the Strandberg company seek to perfect the guitar in terms of its relationship to the body. The company's approach comes from the perspective that ergonomic improvement increases comfort which rolls onto all other aspects of playing: enjoyment, increased practice time, clarity of play style etc. (Orpheo, 2013). This even continues through to their innovation in extended range instruments. Extended range refers to the addition of extra strings, usually tuned below the existing six-strings four on a guitar (Gil, 2014). The functional gains found in the designs of the Strandberg company allowed for the addition of extra strings without compromising playability. Other companies have similarly offered extended range instruments - most notably Ibanez (Ibid). These extended range instruments mirror watershed moments in the development of the modern guitar. Once the addition of strings is made possible by technical advances, the resultant instrument its not simple the product of addition, its capabilities are augmented. An extended range guitar can now cross into the bass clef, edging in on territory comfortably held by the bass guitar and drums. Within this dynamic the status quo in modern rock is melding, so much so that new mixing techniques need to be considered in dealing with the new music being created through extended range (Ibid). It is already true that new corners of the heavy metal genre rely on these new instruments (Alvarado, 2011). Could it be that extended range guitars are the next articulation in the evolution of the instrument?

CONTEXT

While exploring the design of new musical instruments, one is faced with a somewhat dissonant discourse between classical musical thought and cyclical design discourses. Musical instruments may lose and gain pertinence through cultural shifts without changing the way they sound or behave. In this way, (as tools for creativity) musical instruments must be assessed on the basis of their encoded social meaning and messaging; measures such as accuracy and usability compose a useful subjectivism that must not be regarded as objective waypoints in the scope of musicality. We must articulate current ideas and philosophies through the design of these tools in order for them to be useful for musical creatives. Understanding of the nature of tools, how to convey philosophy through form and function is fundamentally important to aligning idea with action. Beyond this, working towards preserving this form of authorial intent is also central. However, tempering these two principles with realities imposed by diverse and global user groups is the process which can deny validity and effectiveness to even the most sincere and insightful scheme.

How do we use the tools of technology to unpick the mess of ancient, unverified accepted norms? These norms get trapped in the zeitgeist as a technology transitions into accepted realities. They slowly calcify into an un-interrogatable form. How can a modern musical instrument retain its ethos in the face of diverging considerations? We first must understand the social significance of tools.

While discussing the role and power of tools more generally, Ivan Illich describes the importance of the implicit (and often encoded) nature of tools in society. He frames these concepts around the phrase "conviviality". Illich adapts the term from the interpersonal to start to describe a relationship with artefacts and (more centrally) systems in which the human element is respectfully maintained and the user retains an expression of agency - without the risk of the system or object rejecting them. This lends interpretation towards approaching the design of tools - and indeed, creative interfaces. Throughout *Tools for Conviviality* Illich renders an image of societal and institutional tendencies towards monopolisation and exclusion. He argues that these expressions manifest through the erosion of conviviality within an assortment of our shared constructions - or tools (Illich 1973, 19). He links this with specialisation and centralisation - the narrowing of the function and accessibility of a tool system.

Illich points this argument towards the medical industrial complex. He argues that through its non-convivial formation and formalisation, medicine and health practices have undergone a process whereby the human is removed from its centre (Illich 1973, 8). Although it is easiest to identify these patterns within core institutions of the modern age, capitalistic signifiers bloom within our creative industry - especially those linked to commerce. The music industry (both music itself and the various systems that govern its creation and distribution) is in no way exempt from this.

Incorporating this understanding of the nature of tools with existing thought in the musical sphere is key to expanding tools beyond a confined use case. The New Interfaces for Musical Expression (NIME) group works (in a simplistic sense) to blend new technologies with music and validate the results through an ecological, performance approach (Jensenius and Lyons, 2017: 799). This is a useful paradigm that begins to bring a musical and design approach together. There are however many other dissonances between the two fields that need to be addressed in order to pass through a considered design process to ultimately be evaluated in the musical realm and face iteration.

Having progressed well beyond two discrete watersheds, the industry has come to suppress the divergent and indeed, the elemental. Monopolisation, codification and the elevation of such terms as musician, composer, producer beyond their egalitarian significance has contributed to factionalism - in an area that otherwise represents some level of participation across the planet. According to Illich these lumbering oligarchies are the result of a removal of agency through closed practices and employ tools that in effect, use the user rather than enabling expressions of agency. "Individuals relate to their society through the way they use their tools" (Illich, 1973: 18) and similarly, musicians scope of interaction and expression is defined by these tools. There is a level of determinism encoded into the electric guitar that enforces it as a tool for high pitched, distortion laden rock solos while a concert harp remains in its place within a classical orchestra. Subverting this by supplanting these highly encoded sounds - or the mechanisms that produce their timbre (materials, interaction paradigms, manufacturing processes etc.) could bring about new musical possibilities.

How does one continue to engage with their society through a period of rapid globalisation? We now live in a global society and certain convivial creative tools have developed, but mostly in the visual world. In the aural world however, stagnant paradigms and tools give rise to fundamentally racist designations such as 'world music' and limit the rights and benefits for a musician to interact globally. Systems that lack intersectionality in a global age cannot be convivial. Global tools allow all "user[s to] expresses meaning through action" while codified and biased tools perpetuate creative segregation and cement adverse power structures.

In a world of ever-frequent watersheds, only careful crafting and revisionism can create tools with the least means of control over the user - "the most autonomous action by means of tools least controlled by others" (Illich ,1973: 17).

Why is the implementation of these values pertinent to design discourse? Verbal arguments to the socialising of music flash, fade and augment, while "powerful tools created to achieve [the same] abstractly conceived social goals, inevitably deliver their output in quanta that are beyond the reach of a majority"(Illich. 1973: 28). Imbuing global and social musical perspectives into the design of an instrument works towards realising these goals through a combination of strength and fluidity - ultimately working towards sustainability. Positive zeitgeist need not be explicit, or indeed verbal. It must, however, be suited to the medium and its practice - it can only exist in conjunction with effective convivial tools (Illich, 1973: 38).

Kettley agrees with Illich's outlook on tools from a design perspective but criticises his lack of attention to replacement power structures. She argues that some of his approaches constitute dictatorship and that in itself is non-convivial (Kettley, 2012: 68). Kettley offers a means to ensure a flow on of agency through securing participation and authorship within the design process of such tools (Kettley, 2012: 70). In addition she takes issue with a perspective of hyper-functionality being the goal for design (Kettley, 2012: 68). Kettley reasons that sometimes ambiguity and poeticisms are key to allowing self expression - a tool should have metaphorical porosity to facilitate the diffusion of the user's character (Kettley, 2012: 69-70).

This insight is what Kettley feels is most important in turning Tools for Conviviality from theory to practice. Along with this she insists that a designer-centric system be in place where "designers must also reinstate themselves as authors" (Kettley, 2012: 70). Kettley contends that "the disappearance of the designer in the industrial system is a central problem for the production of tools for conviviality" (Kettley, 2012: 71). Kettley's interpretation, uses Illich's philosophy as a convivial tool; by using it to achieve an outcome whilst conforming it to her personhood. Illich, however, would see a designer-centric system as contrary to an egalitarian system. Strict control of use through design of an object can indeed erode convivial agency, while Kettley argues that strict control of a system to the same degree, constitutes dictatorship. Even positive ideals can be corrupted by strict control just as a verbal argument can decay through its transmittal. Designers should be responsible and embedded in creating for a community with open channels keeps designers and musicians in check through mutual assurance. The lutherie trade exemplifies such values where the craftsperson is inextricably linked with a musical culture. The luthier adjusts the thickness of the fingerboard, changes strings, and maintains the instruments well after they've left their hands and entered the world. This relationship tempers the craftsperson's ideals and allows them to fully perceive the

effect of their work. This relationship embeds the luthier and their work in the musical world and enables a multifaceted first hand perspective. It allows them to adjust their practices through what is in effect a circular design development process. Of course luthiers are not concerned necessarily with innovation or divergence. The craft deals with incremental progression in order to uphold tradition. Divergence gives them no initial advantage. The designer must inhabit multiple roles; they must be embedded with a sense of tradition whilst being principally preoccupied with human centred innovation. Additionally within the domain of this research, there are two faces to the researcher (musician and designer) and indeed two styles of making that do not take responsibility for the other. Perhaps by integrating these two faces - both within the researcher and within the greater design/ music community - tools with pointed ethics and keen insight can be developed to help practitioners articulate the realities of the day.
Design could borrow from real world Illichian scenarios by understanding the ways people interact and rely on their communities. Ultimately, designers need to keep looking forward and not be bound by preconceptions of demographics and established paradigms in order to get a broader deeper view of what people want and need.
In essence, the type of tools described are what we need to unpick the musical mess. That's all well and good in an idealised form but how do we implement real world design processes to maintain the integrity of these principles?
Various design thinkers have indicated that a step away from traditional user centred design may be necessary (Saunders and Stappers, 2008). The umbrella term 'Co-creation' is used to signify collaborative, inclusive approaches, much in the image of Illich. They rightfully argue that speculation and generalisation in understanding users are irrelevant in a digital age (Saunders and Stappers, 2008: 6). Although elevating users to the level of designers has an inclusive tint, a power imbalance is still present and acts to undermine a true collaboration.
When undertaking collaborative design there is an obvious discrepancy in skill sets, perspectives and confidences between designers and non-designers. To counter this, collaborative design need not be explicitly designerly. New languages and forms of communication are the real challenge of inclusive design (Saunders, 2002: 4). How do we give the determinism of tools to musicians?
Within the musical field, non designers have, in the past, been at the forefront of opening up sonic possibilities, diverging use cases and expanding the scope of the term musician. The common theme amongst these practitioners is that their work is rarely concerned directly with the creation of music. Erv Wilson for example, chose to concentrate his work on mathematically mapping new methods of tuning - deciding which sound frequencies will be arranged to form the palette that musicians then create music from (Narushima, 2017: 3). His formulas and illustrations truly reflect a mind in its element but are little use to the non-mathematician. Conversely, the early synth builders Don Buchla and Robert Moog gave new universes of timbre control (as well and fundamentally new ways of composing and enacting music) to non-craftspeople for the first time when they created more affordable, modular systems (Pejrolo and Metcalfe, 2017: 11). These efforts were tacitly imbued with principles of inclusivity and experimentation, whose monumental importance would remain supreme until the home computing revolution.
Designers, however, argue for co-designing and active participation. By leveraging the skills and insights of both participants to carry musical ideas through rigorous design practice, designers in the field with musicians can create new shared communication techniques and associated vocabularies and expressions.
Saunders argues that effective shared discourse and collective generatively relies on "visual literacy… [being in] balance with verbal literacy" (Saunders, 2002: 5). This can of course be generalised to other relevant senses in their fields. It is expected that in a design led environment, the non-designers adjust their expression to be more conscious of the elements of design - form and function. Perhaps in the contexts like music, with

a rich extant language not only available but central to the design problem, designers should concern themselves with participation in musical literacy. Saunders argues for "direct and active participation of all stakeholders in the design development process" which necessitates both an engagement in new areas and a reconstructionist view of entrenched ones (Saunders, 2002: 6). In any case, holding the physical form as central to the design problem can often serve to diminish the effect of the solutions. Collaborators must focus on harbouring a "language built on aesthetics of experience rather than aesthetics of form" (Saunders, 2002: 4); with the aim of universality of experience. Saunders along with Stappers frames contexts for this kind of collaborative exploratory design work around facilitation. In effect the designer selects participants and enables them throughout the process through four key responsibilities: lead, guide, provide scaffold and offer a clean slate (Saunders and Stappers, 2008: 14). Although the formal skills of a designer are pivotal to the realisation of an object or service (or both), a professionals proficiencies can limit the overall scope of a project. They can create shifting borders through bias. This dynamic can manifest in the designer's selection of tools chosen for the user to engage and express their insights within the project. Instead of the designer creating tools to uncover 'expert' information from the collaborative user, the designer should consider embracing existing tools that the user already knows and relies on. An expression from a 'home soil' of sorts, is useful in its purity. It can also be shed insights through methods of contrast; by interrogating the preferences and biases exemplified by the users choice of tool, the designer has an opportunity to understand the issue from a birds-eye view. This view can then be fed back into discussion and further dissected. An example, as it relates to this research, can be found in the theory surround microtonal music - a field rich with theory but underrepresented in actual creation and consumption of this music. Designing tools to deal with greater sound spectrums would fall short if the designers do not immerse themselves in extant musical theory and practice on the subject.

Saunders indicated that a key boon in the participatory design approach is the preservation of emotionality in the finished product. By working collaboratively instead of simply interrogating a broad sample of users, you are able to gain design insights beyond the explicit (Saunders, 2002: 3). This taps into deeply human attributes and draw links to design for an intrinsically emotional field.

Musical preference is often a statement of cultural allegiance on the surface, while musical expression can be seen as an articulation of tacit knowledge (Saunders, 2002: 3). The role of collaborative design is to better understand tacit knowledge in order to begin to assemble an image of latent needs - which in turn direct design goals and show us where to apply (what Illich would call) constructive technology (Illich, 1973: 12). On the topic of latent needs, Saunders muses that "seeing and appreciating what people dream shows us how their future could change for the better". Designing for this core level of human existence is deeply important to creative mediums (Saunders, 2002: 3). The impact - and ability to spread ideas and shift the zietgeist - of such designs is unfortunately linked to more simplistic interrogations. False analogues of 'performance' and 'cool' cement the status quo in our musical structure. Collaborative design must be used to intelligently incorporate ideas of use, form, social philosophy and cultural insight to make tacit and latent ideas comprehensible to a wider field of creative users.

These concepts are carried forward in the musical space through the lens of "post- optimal aesthetics" by practitioners surveyed by Ezra Teboul (Teboul, 2015: 5). It is in this space of electronic instrument design that Teboul illustrates a movement away from "engineering methodologies" in order to articulate the practice of silicon luthiers to create instruments "that curate more satisfying interactions" (Teboul, 2015). He shows the boon associated with a kind of practical agency that arrises from instruments that "blur the line between composition and design" (Teboul, 2015: 6). These humanist tendencies seem to be key in developing freeing musical ecosystems. Focusing in on the tacit side

of interaction is key but it no doubt needs directed intention in order to retain principles from conception to execution.
Small's inclusive ideas of Musicking (Small, 1998) bring a specific system level view of the creation of music, bringing with it key insights into maintaining the expression of agency and accountability in a musical community. Small attempts to reframe the social understanding of what constitutes music making but expanding the endeavour to all supporting roles - musicians, producers, instrument makers and indeed audience members are all participating in the act that he calls musicking (Small, 1998: 11). Perhaps this idea is useful as a tool to bring all invested parties together, operating towards a single goal.
Lee, Harada and Stappers offer specific methods for creating the necessary languages and facilitators to achieve meaningful blends of accuracy and poeticism within the scope of creating artefacts. They colour their method with the distinct tint of a Japanese concept of Kansei. Kansei is a layer of emotion "which exists beneath human behaviors"; for example: "the attitude of a person in front of art work and design is not based on logic but on Kansei"(Lee, Harada and Stappers, 2002: 2). The group suggests that by tapping into this lens of experience, it is possible to dredge hidden user knowledge. Their method entails a distillation of tone and character into thumbnail images and 3D models to use as reference and form reference when developing a product (Lee, Harada and Stappers, 2002: 5). This procedure helps to deepen the impact of tonal intent on the final outcome through various means: by keeping the conversation about tone and emotion as it relates to form and function, it holds those ideas pivotal. It also grounds the perception of the skills required to remain critical of the work. By talking about tangible relationships and lines and forms rather than high concept, the non-professional is encouraged to engage. Finally the method is proven useful through the authors empirical study into the importance of tactile experience (Lee, Harada and Stappers, 2002: 7-9). The authors noted marked increase in sensitivity to the experiential qualities of a product under the conditions of closest contact (viewing images, seeing the actual object and seeing and being able to hold the object). This shows how creation and iteration aids the discourse not just through shared languages but by a deepening of experiential understanding between the designer, user groups and the objects they are developing. To expand this insight: musical instruments require collaboration, music creation and performance in order to support a form of entrainment fundamental to an effective, wholistic design process.
The group's Kansei method proves efficient in capturing the principles important to creating convivial tools, but it falls short in capturing the soul of the problem through rigidity. The authors themselves admit that Kansei is a concept of dynamism and ephemera, therefor active members should seek to find meaning in all interactions across mediums. It is possible to encourage iterative creation as a dialogue. Varied methods best attend to notions of Kansei, which "implies that human behaviours can change dynamically, and indicates flexible and dynamic approaches are needed in the various fields of study" (Lee, Harada and Stappers, 2002: 3). In the field of musical instrument design for example, improvised musical communication may aid in one stream of enquiry but prove too conceptual for another. Sculpting from music and discussing the sculptures is an example of a dynamic approach which leverages shared languages and sporadicisms in designing integrated poetic and practical solutions.
Gleaned from these discussions are a set of my own convivial tools used to direct the creation of further musical tools. They are as follows:

Convivial template - a framework that focuses the design work to principles of adaptability, inclusivity (through access, ergonomics) and customisability. This prioritises maintaining user agency in this case to allow for maximally creative uses for these musical tools. This necessitates navigating the balance between open and closed systems. The convivial template serves to reorient priorities in this kind of design endeavour away from conventional metrics.
Shared perspectives - interrogate existing tools in the field in order to integrate the musical and design mind. Leverage the wealth of existing institutional and embedded knowledge in each field, leading to a synthesis in which new shared perspectives emerge.
Allow for ambiguity - allow a level of malleability for the user to adapt the tool to their idiosyncrasies. This will help elucidate tacit human realities and needs beyond the explicit and give voice to the relationship between the musician and instrument beyond the intention of the designer.
Coss-sensory jamming - improvised music making is an excellent way for musicians to communicate musical ideas that are complex to verbalise. Similarly in the physical world, model making, sculpting, drawing etc. can be invaluable forms of direct communication. These are the scaffolds of common languages, a form of entrainment that can bridge divides.

METHODOLOGY

This research comes off the back of a honours project that investigated ways of producing interfaces for digital music production that closer resembled a musical or sensorial process rather than a scientific or engineering sense of precise control. That project was the culmination of a long relationship with music - a relationship that has seen a continued shift in dynamic from recipient of a methodology to agent creator. It began with Suzuki method violin as a child, eventually supplanted by bass guitar lessons as a teenager. Buying instruments and gear at that point began to teach me ways in which the instrument was a tool that belonged to me and my thoughts, and needed not to conform to any other players. The electronic side of the bass guitar then introduced me to the concepts of tailoring the instrument sonically, though pedals, amp settings and DIY electronics. Creating custom pickups for looping setups and other such projects then led to my honours project, which instead of asking "how do I…?" it asked "what happens if…?". Having felt like I had the opportunity to answer that question in one way, I was still itching to have it asked again - and answer within a larger, higher resourced format, enabled by my new skills and insights around making physical objects. How might I go about creating more tools and objects that create new dynamics for myself and other musicians?

New musical instruments are created all the time. Physical interfaces that control production software or enable live performance, purely digital instruments and the broad range of acoustic instruments (see the litany of new guitar companies that pop up and disappear every year) are all perpetually being iterated and refined. This certainly takes place within garages and the confines of research (such as this one) but ultimately the bulk of these exercises take place within established companies or brands - be it a consumer electronics giant like Apple, long time contenders in the field like Korg or even celebrity musicians such as Tosin Abasi or even Les Paul. It's difficult to properly ascertain the methods used across the industry in designing this broad spectrum of musical tools - although, they seem to fall somewhat in line with the broad and amorphous world of design thinking, that is to say, a form of human centred design. In a simplistic sense it is a process whereby problems, shortcomings or areas of opportunity are identified and designed for. They aim to fill a definable need (Rowe, 1991:39).

The project seeks to identify the effect of musical artefact, created from a particular perspective, on the ways we enact musicking. This will also see the creation of a set of practices that will guide others in pursuing interdisciplinary musical creation. By nature the resultant practices will need to be generalisable between a variety of practitioners. This necessitates an inceptive procedure of self disclosure (Jourard, 1971, 19) and the mediation of continuing research on the basis of such a practice. As Moustakas indicates in relation to the heuristic process: "the research question and methodology flow out of inner awareness, meaning and inspiration" (1990, 2). Therefor a formative component of the research is based in immersion in the topic. Such practices are common - in different forms - amongst a variety of methodological practices and, by synthesising a variance in practical applications the design practice can take on a form of manoeuvrability (Berg and Derlaga, 2013). This plasticity in research is vital when focussing on an area such as music, which is composed of a rich and diverse ethnographic and cultural history as well as a continuing fast paced and progression (Bohlman, 2013).

These processes of self disclosure not only includes acknowledging the personal basis by which decisions will be made in research, but also works towards exposing new biases that otherwise would form an invisible framework that can hinder breadth or accuracy in research (Moustakas, 1990). Including a deep and flexible image of the role of the researcher's personal identity can broaden research in a number of ways. It is also important to remain flexible when interacting with a deeply collaborative area such as music. Additionally, key insights can be missed if the area is not practically understood, an interpretive model must be employed to help achieve this. Interpretive models reject positivist outlooks that dictate that importance of a piece of information is relative to the objectivity to the way it is measured (Hennink, 2010, 14). It is in this way that post-positivism is related to post-optimality in musical instrument design. Methods to understand the emic realities of music making must involve native participation. The process of acknowledging the researcher's philosophical predispositions extends far deeper into the research and dictates an awareness of more abstract potential influences on authenticity of results. By accepting these factors and folding them into the research practice we become open to the influence of tacit possibilities (Polanyi, 1983) which is often the realm where musical creation can arise. Participation can be a key force in balancing forms of literacy (Sanders, 2002). In this case the major languages are form, function, sound and emotion. By designing for user groups, it becomes harder to practice literacy in more abstract areas - let alone maintaining a musical practice. To avoid this, the exercise of creating these instruments is not seen as a user centred endeavour, but rather a personal expression - a mastery over a subject with a final point of view put forward in the form of a musical tool.

The studio practice component follows a string of action and analysis, whist constantly being mediated by emotional insight and ultimately working towards being validated musically - in order to lead to more action. Due to the complex relationships between each stage of action, it was important to document the progression and links that arise thereof. This also gives a way to continually define a reactive methodology as it changes through various tasks, insights and roadblocks. By defining methods in practical, chronological accounts, it allows the research to remain agile and truly reactive - or (as it would later become clear) freely improvisational. This also allowed me to mediate conforming and diverging from the interconnected roles inherent to this project: design, maker and musician.

In order to correct potentially closed design loops, methodologies from the musical world were incorporated as a means of applying native musical perspective. Interrogating practice from a musical perspective can be an effective tool for calibrating the translation of intended ideas through to form and function. Especially through layers of abstraction ideas can begin to illicit useful emotional responses (Lee, 2002). Integrating a musical perspective into the design process does more than simply prove or disprove effectiveness or optimality of outcomes - by practising object making as an act of music making, the researcher can absorb methods and languages and ultimately hope to foster the onset of an interlanguage between mediums. The concept of a linguistic interlanguage (an informal hybrid language used instinctively by non-native speakers in learning a new language) also an important framework for understanding how expert groups communicate about important ideas (Bardovi-Harlig, 2010) - in this case between design and music. Upholding a material relationship between design and musical practice also helps to test the effect of this kind of design on the very structure of music making - instead of simply slotting new ideas into existing paradigms.

With the widespread use of computers for all forms of tasks in the composition and performance space, and even from the birth of the phonograph, the changing role of a musician has been a topic of debate and interest (Foss, 1963). This is especially true as composer to performer paradigm continues to draw layers of complexity and musical labour continues to be divided. The inclusion of a practitioner into the musical family relies on the idea that the practice adds utility to the journey or destination of a vision. These methods of inclusion seek to justify the luthier's tools as musical, which, in turn justify all manner of applied design regimes as being part of a musical process.

Small, in arguing for his concept of musicking, admits that the score oriented musical paradigm (or music as a noun) does not align with his entire lived experience of music (Small, 2011). Similarly I find the idea that musical progression lies beyond the hurdles of functional impedance to not be reminiscent of my experience. The piano for example as an interface, has fundamental ergonomic issues, frequently leading to long term injury from the cumulative trauma of repetitive practice (Allsop, Lili and Ackland, 2010); yet this does not diminish its importance in our contemporary music culture. Ergonomics aside, there is a notion embedded within the consumer electronics portion of the market that making things easier is better - simplicity of the interface is evaluated rather than deeper possible human interactions (Nielson, Jacob and Molich, 1990). This may be a goal of the consumer, and access in general is a boon to our global collective musical experiment, but there are surely expressions only found in adversity, or only pronounced through endless trial (Lewis, 2015:13). I am interested to see what exists to the flanks of optimal designs and the fulfilment of user needs - what can challenge musical paradigms functionally, sensorially and socially.

The questions ask what can be achieved musically by a measure of unvarnished improvisation? What happens when we regard the possible outcomes as so low risk that any creative output is possible? This means moving away from datum points of optimality by creating experiments that point towards less well represented ideas. A natural starting point in ascertaining a fitting methodological framework is in the realm of design thinking. Cross's distinction that designers solve problems through synthesis has been underscored by thinkers to follow with procedures that often begin with a phase of divergence or free thinking. This is regarded as the time to cast the net wide, draw in far reaching ideas in order to better understand the problem, and the tools at our disposal (Brown, 2009). Instead of passing through this phase and refining findings from within it, I passed various insights from my diverse investigations through to various stages of completion - each learning from the other - and continued to ideate for most of the process. The mind's capacity to understand and synthesise is forever broadening; by continuing to act on divergent design ideas or notions, new realities were brought to the gamut.

Ultimately these processes seek to optimise the translation of a deeply personal perspective into musical artefact whist finding ways to make the results intelligible, interesting and relevant to musickers. This is why my methodology points firmly towards free improvisation. It is by intersecting my somewhat closed generative cycles with the similarly closed musical cycles that both can experience contextual insight and shift their focus in a mutually beneficial direction.
If we view the act of creating a musical instrument more sincerely as a method of creating music itself (or indeed musicking) then it becomes much more difficult to derive a framework by which to assess the usefulness of its outcomes. It does however open us up to a world of expressive and responsive methodology. These methodologies that, aligned with my designerly investigation, come from the world of musical creation and thus can be viewed through lens of popular musical parlance. The expressive methodologies associated with songwriting often involve elements of introspection and personal contextualisation. They present a dynamic where by the work (a song, performance or in this case, by analogy, design) is only extant as an extension of the creator and their context. A song cannot be disembodied the way research is often instructed to be. As such, key to this investigation was maintaining methods that keep the designer at the core by various means, drawing from musical methodology and beyond. Firstly, this started from a deeply personal and reactive place. There is an element of instinct in musical practice that I allowed to guide my design practice. The feeling of a latent musical

reality, almost like a phantom limb would push me to realise that idea in form. For example, the subtleties in overtones that occur while I work with raw bronze casts led me to explore their relationship of complexity of form and aleatoric forms - all newly enabled by the repeatability and precision granted by low-cost rapid prototyping techniques. Responding to input in this way extended beyond the direct confines of research and directly into daily life, leading to diverse explorations of medium and theme.

The approaches and dynamics associated with free improvisational music practices formed a basis for a methodological framework that would govern this kind of investigation. The distinction between improvisation and experimentation reveals the breadth of improvisational methods and is prone to conflation. An experiment pits an action against a hypothesis with a specific methodology - and although this mode of music making has coalesced into an aesthetic or genre, hypothesis still remains central to the endeavour (Duch, 2010). Free improvisation on the other hand, tackles a momentary scenario with purely a practitioners reflexes and intuitions (Bailey, 1992). It implies a value that prioritises tacit and embodied knowledges as material resources. Staying true to these ideals, the field of improvisation should and has responded to the self and the world differently as contexts and relationships change. Burgeoning practice in the 60's saw aleatoric scores morph into frameworks for musicians to interpret and practice free response by means such as graphical scores (Duch, 2010). The multi-sensory nature of this interaction is another clue to the nature of improvisation and offers clues as to how to apply a free improvisation methodology to non-musical exercises. Typically, the pace of decision making in musical forms of improvisation is so fast that experience and preparation morph in the moment. How can free improvisation maintain the importance of tacit responses at the centre of a design project that spans two years of decision making? The constituent elements of the practice are no coincident or improvisational flourish; tacit attentions and multi-sensory engagement are the only means by which to realise free improvisation within any field. Borgo delineates two modes of improvisation: Afrological and Eurological, or "emphasis on personal narrative and the harmonisation of one's musical personality with social environments, both actual and possible" and "absolute freedom from personal narrative, culture and conventions – an autonomy of the aesthetic object" (Borgo, 2004:4). Put simply, these two categories are defined by a practitioners entrainment or departure from their cultural context. Duch points out that a musician can have elements of either and both (Duch, 2010). It is important to my research to attend to these styles, realising how this work can reflect elements of the self in isolation whilst also relating to and commenting on elements of my context.

In search of this cross-disciplinary, improvisation time was spent learning an expressive weaving technique called Saori in Japan. This experiment arose out of a graphical exercise used to discuss sound and music, and the feeling that I needed more tactile ways to express insights. The 5 day stay culminated in a 9 hour interpretive weaving exercise, whereby I wove a single continuous piece of textile while responding to a single bands discography chronologically. Analogous colours were used in line with the album art while adjustments in these colours and textures were made in accordance to my response to the music. Divergences, such as a weaving exercise in a music design research project, are not intended to have literal outcomes but they do aid in my understanding of a subject and train new improvisational realities. Experiencing music in this way, for example, led me to experientially understand the constituent parts of music as being independently continuous. This eventually led me to the topic of microtonality - a concept which ended up being central to my outcomes.

STUDIO PRACTICE

Aluminium

Investment casting methods have been practiced over the centuries, mainly in service to the creation of bronze objects (Lapatin, 2014). Modern, hand made investment casts are mostly geared towards the creation of bronze artwork, while industrial processes are used to make a multitude of objects in increasingly specific alloys. It is even now possible to cast titanium in a form of sacrificial mould. My experience in metal casting sits in the former category - preparing bronze casts of single, sculptural objects. I was led to incorporate this process into this musical practice because of the unique aesthetic quality as well as the functional possibilities that investment casting can bring to an object. There is a relationship between this form of casting and 3D printing. Both these procedures are capable of creating very complex objects through careful crafting and mitigation of the force of gravity. It seemed all too logical to blend these methods together and use this fusion towards realising new musical objects. After testing the reality of the workflow, a set of bronze bells were made directly from 3D prints (figures 25 and 26). The process of creating and sharing these bells with people fully articulated the sense of weight associated with bronze as a material. Physically, it become unwieldy at the size where instruments begin to become functional. Perhaps more important than this, bronze has an immense cultural weight, expressing itself as a museum material - to be seen and not touched. This cultural connotation dates back to the immense cost of production in prehistoric times and was carried through to the present day through a close connection between the material and the body - from tools to jewellery and finally representational sculpture (Tilley, 2006:436). Although relationships with the body are of interest to this project, the sacrosanct connotation that bronze brings to a form is less than desirable in enabling creative outcomes. Spurred by the conflicting properties identified, experiments would hereafter be carried out in another metal common to casting: aluminium. This offered a great solution in terms of the materials cultural currency.

Aluminium isn't a new material within the musical instrument market; elements of stringed instruments have been made from the material since its widespread commercial use. In fact, musical instruments were one of the first commercial uses of aluminium and a whole range of partly aluminium instruments (including guitars, mandolins, zithers, banjos and fiddles) were available from the Merrill company in the 1890s (Holmes, 1997). Today, aluminium is a ubiquitous material that comprises a large array of consumer electronics, including those within the musical world. Analogue and digital electronic hardware is often encased in rugged extruded, machined or die-cast aluminium shells to protect the delicate components and mechanisms. Eurorack synth standards conform to a standard extrusion of aluminium, giving synthesists full control over the composition of their modular system. As a material, aluminium has become encoded with ideas antithetical or at least in contrast to that of wood and bronze (Worden, 2009: 153). Perhaps partly responsible for this is its natural stability and malleability. While bronze oxidises to blacks, browns and greens when exposed to the air aluminium develops a very thin, clear and strong oxide layer which can be induced and coloured through anodisation (Sheasby, 1987). Similarly, wood requires immense skill and attention in order to protect it from the elements. Musical instruments composed of it must be coated in lacquer and varnish, and reinforced with steel and extra bracing in order to repress the effects of the forces inherent to the instrument. Additionally these instruments are constantly under threat purely from an earthly atmosphere which shifts in temperature and humidity - historically, wooden instruments have been difficult to make and fragile (Holmes,1997). This is not to denigrate its incredible usefulness in creating quality and evocative musical instruments; the communities and skills that have developed around the process of creating wooden musical instruments is an incredible thing.

We are however in a new era of materiality, not just in the introduction of the digital realm, but in the way that digital means offer new possibilities for real world materials.

Materials ubiquitous to a time carry the pace and ideals of the era (Hughes, 1997: 138). From the bone flutes and rock gongs of early humans, percussive clay jars and bells of the Bronze Age, mass proliferation of wooden instruments during the development of wide-spread trade as well as gut strings as a result of animal rearing, through to the synthesisers of the silicon era, followed by democratised digital audio engineering and production brought by a connected world - the design of musical instruments has carried out material principles. What material can form the means of music making in a world of distributed manufacturing and heightened access?

By having the freeness of form granted by the marriage of 3D printing and casting in aluminium, several design realities can be achieved. This form of design and manufacturing allows for an instrument whereby key components (which hold the strings in correct orientation and transmit vibrations) can be fully integrated into the whole. Typically, on this type of instrument, strings would be suspended on a bridge on one end and a nut on the other. These are crafted separately from the instruments body out of wood, metal, plastic and sometimes bone. Eliminating glue joints, points of contact and other impedances ideally allows the tone of the strings to ring out with high sustain and rich overtones. It also affords a treatment where these integral parts of the instrument are crafted with consistent form language in order to code new musician-instrument understandings and interactions. By asserting a consistent use of form in suspending strings so they are musically of use and positioning them to the body, boundaries can be drawn within which, ideas expressed by the interface elements can relate to the user in question and to a wider musical culture. It is an opportunity to frame this act of musicking within a viewpoint that articulates the role of its constituent parts in our experience of it.
Its not just the variety of form that aluminium affords a slew of functional elements are now possible. With a relatively high capability of strength, at a variety of shapes and thicknesses, this material can be designed to bare loads at any conceivable point (regardless of direction). From this perspective aluminium is an attractive material with which to create functional objects (Tański, 2014: 202). Due to this an aluminium instrument can be worked in many ways to interface directly with fasteners and other forms of ancillary components such as electronics.

Functionally, aluminium exhibits a set of behaviours which will also bring some specific characteristics to musical instruments. The inherent beauty and intricacy of wood, paired with the practicalities of creating musical objects with it, can sometimes force the patina of age or use into a form of unwanted contrast. A personal instrument made out of aluminium would be composed of homogenous material, allowing forms of texture and finish created through its creation and use to speak harmoniously of the instruments nature. It is a relatively soft metal which can be easily worked and customised. Instrumentalists could benefit from this level of non-expert customisability by removing unwanted material or indeed by adding to the instrument by welding. This high degree of user facing flexibility that aluminium unlocks, can create a framework for tools that are useful and perhaps in a Illichian way, convivial.
The timbre of aluminium is not often regarded as ideal for musical instruments. While resonant, it lacks the richness of more widely used materials. Throughout this project, the sonic nature of aluminium has attempted to be refined through various means. Initially, cast resonators were designed with small fins connected within, in order to ‘program’ specific timbre profiles for each iteration. While resonating, the fins would hijack some of the energy to produce a single distinct overtone, perhaps adding some unusu-

al complexity to the sound of the instrument. Later, a series of fins were designed more specifically to carry a vast spectrum of overtones, in order for individual notes played on the instrument to hopefully have a corresponding harmonic fin sing out in response - similarly confounding the pitchy timbre of the aluminium.
These approaches to material sought to morph its sonic behaviour purely through treatment of the material itself - that is, controlling the qualities of aluminium through careful and contextual assignment of form through various processes. As this idea moves from a collection of discrete ideas to a functioning whole instrument, new approaches using external mediums and techniques from borrowed contexts would pave the way forward.

The resultant aluminium instruments, while totally functional remain thematically prototypical. The greater relationships of form and function with musical performance are yet to be tested and validated broadly. Through the use of aluminium, I was able to carefully control intricate and light forms, on which a kind of musical philosophy was moulded. The aluminium imparts a soft, cool and snappy flavour to the innate sound qualities of given strings. It's cold to the touch but soon takes on the warmth of the player. Interacting with aluminium in this way and in this context certainly gives me the impression that it's a totally new kind of material, with a sonic palette that seems to invert the balance found in timber instruments of a similar style.

Skin

Another experiment in augmenting the sonic possibilities of an aluminium instrument revolved around the use of tensioned membranes. Goat's skin was stretched over voids in the resonator to augment it into a drum-like body. There are precedents of this kind of amplification, namely, instruments of the banjo family and their lesser known African ancestors such as the kora. Instruments of this kind sit the string-bearing bridge on top of the tensioned membrane, leading the sound to transfer directly into the drum while the subtle vibration in the drum head shifts the bridge up and down, giving this kind of instrument its unique timbre. These experiments in skinned aluminium however, have the membrane sitting perpendicular to the strings and not in direct contact. In this way, the drum head acts as a secondary resonator, pulling out warm tones from within the otherwise harsh environment of the aluminium resonator. Another differentiating factor is that the skin itself runs the non-circular profile of the body, making it a somewhat misshapen drum head. While a circle is an ideal shape for creating a drum with a clear and loud tone, a widening shape such as the one created by these experiments, creates a continually pitched environment. That is to say that instead of creating one fundamental pitch when struck and slightly changing the nature of the overtones depending on the location of impact, this drum can create different pitches entirely, depending on where it's stuck. This distinct phenomenon has been noticed and constructed into an instrument before. The composer Karlheinz Stockhausen stumbled across a kidney-shaped glissando drum at trade show made by Kolberg - a simpler version is still made today. The drum was incorporated into the Momente composition to achieve a percussive effect that sits between worlds (Stockhausen-Verlang, 2013)

The continuous nature of its tuning also means that any form of microtone (between the highest and lowest pitch that the drum is capable of producing) is represented. This form of resonator would prove an interesting form of timbre accompaniment for the tinny homogeneity of an aluminium instrument. Also, given the variability of pitch accounted for, it would suit the ability to produce various microtones that arose out of this project.

There are very few examples of a non-circular drum in existence today. The company that produced Stockhausen's drum, no longer produces continually pitched percussive instruments in non-round formats. The Japanese shamisen consists of a long, slender, fretless neck, doweled into a body with a rounded square profile which is then faced in a thin stretched skin, on which the bridge then sits. Its non-round resonator gives some insight into methods of achieving such a form in stretched skin. During a trip to Japan I stopped by a shamisen store to see first hand how these craftsmen deal with such a complex skinning procedure (and to pick up some beautiful dyed silk strings). The owner was kind enough to have me sit in and watch as his apprentice used a paste of finely milled rice and water to carefully apply the thin cat skin to the wooden body. Using a wooden tool, he both mixed the paste, applied it and smoothed the skin down, displacing any air bubbles. The shape of the skin was then guided into position and tension by a jig consisting of wooden frames and wedge shaped blocks that apply tension across each edge. Once dried in the jig it is then trimmed, leaving a fair margin up onto the sides of the wooden body.

Back home I made an attempt at skinning one of the aluminium forms using clamps to hold onto the skin, bound together with twine and wooden blocks to wedge tension into the string. As most first attempts are, it was far from the best method. Despite this the goat skin dried in shape. At first I tried the rice glue recipe but it didn't stick to aluminium. I then turned to a contact cement. Glue was applied to both contacting surfaces, to dry for a few minutes and then firmly pressed together. This left a very strong bond that survived the skin creeping together the next few days as its forces balanced out. The skin was trimmed to the flat edge of the instrument.
The second attempt was much like the first except for the use of ratchet straps to achieve tension, over the manual method. Moving forward, it became clear that I needed a more robust method for dealing with complex skin shapes as future designs became non-flat as well as non-round. An ABS printed jig was made to give the skin its form. This then made gluing much simpler. Clamping the form after gluing additionally gave the desired shape after the forces all equalised. The main breakthrough with this technique was a simple element that had been overlooked previously. The shamisen skin doesn't just end at the flat face, its formed over the sides to give extra support. By gluing the skin further up the sides of the aluminium body, the drum head had much better support and was able to be much tighter. This also gave a styling opportunity for the skin to play into the three-dimensional intricacies of the cast form. Sonically, this use of skin as a secondary resonator rounds out some of the flat sonic qualities associated with aluminium while providing a natural delay and sustain. Skin proved to be an inherently paradoxical solution to the seemingly straightforward issues that aluminium presented as a sonic medium. Ultimately, it was in the combination of polar ideas that this new reality arose: homogenous metal paired with textured and patterned animal skin, the traditional craft of skinning a ceremonial instrument augmented through rapid prototyping and the tried and tested margins required for a strong bond, strengthened further by high strength modern glues.

Sawari/Jivari

The first time strings were attached to my cast aluminium resonators, the instrument was brought to life and a new sound brought forward. In analysing the qualities of this sound - sometimes juxtaposing it to conventional timber guitars - there was a definitive buzz detected in the timbre of the instrument. This buzz didn't feel like a form of interference, like crossing radio stations, but rather a constituent, valuable component of the character of these new instruments. I later became aware that this quality is known to other musical cultures specifically and is often referred to as sawari. Discovery of this phenomena natively within my making imparted a drive to inform my sonic and aesthetic understanding of this phenomena with a textual understanding of its use in musical cultures other than my own.

In its simplest from, sawari and jivari is a component of buzz present within an instruments timbre, and therefore a factor within the creation of music (Taguti, 2008). Beyond this the concept of sawari and jivari runs much deeper, mechanically, culturally and in terms of aesthetics within Japanese and Indian musical cultures respectively. The pair also further distinguishes themselves through contrast. In Indian classical music, jivari is achieved through a specially designed bridge . The crafting of jivari enducing hardware is said to be a precise art in balancing its qualities (Caudhurī, 2000: 51). The buzz is sounded by the string lapping against the face of the bridge that gently curves away from the position in which the strings are held. This is one of the factors that gives instruments such as the sitar, its very recognisable sound quality, and is deeply paired with our outsider understanding of Indian musical cultures. By contrast, sawari is created at the far end of the neck by either: the omission of a nut - which would give the string a more discrete endpoint - allowing the string to buzz freely on the curved geometry of the beginning of the headstock (in a similar fashion to the jivari creating bridge), or with a specific 'sawari' mechanism. A threaded brass piece with a carved top is inlayed into the fingerboard. A thumbscrew can be turned to raise or lower the brass piece in relation to the string. In this way, a player can increase or decrease the effect of sawari, an effect which changes its overall quality rather than just its amount (Sakata, 1966). Both methods create an overtone rich timbre with a reinforced high frequency component (Van Walstijn and Chatziioannau, 2014).
It is said that sawari brings a from of sound to an instrument and is a core aesthetic within several genres of traditional Japanese musical performance (Malm, 1963: 57). Although the shakuhachi doesn't have strings, it too produces sawari, in somewhat a similar manner to reeded instruments. Jikken Kobo explains essence of sawari as a reclamation of musical sound by the forces of the material world: "the shakuhachi master thinks it would be wonderful to create in his own performance the natural sound that emanates from the wind blowing through an old bamboo grove and sticking its roots" (Corona, Ignacio and Madrid, 2007: 54). This idea is not totally foreign to European musical tradition. As experienced through the electronic synthesis of sound, a pure sin wave is abrasive and rarely musically fertile. Control over the complex interplay of vast families of instruments (with conflicting materiality) is a key pursuit of the European orchestral tradition.
In this way, sawari is similar to the sixth flavour sensation umami - although an understanding of it is present in prevailing western traditions, it is rarely understood as a distinct, malleable and useful pillar of the craft.
The effect of sawari entered the project in quantifying the material effect that my instruments form language would have on sound. The integrated curved bridge produced this subtle buzz which was the first element that distinguished the aluminium prototypes and their own musical entity. This buzz created has a relationship with existing guitar culture. The electric guitar is often paired with elements of distortion or other effects which produce overtone rich compliments. By embedding this point of difference - linked to a complex Japanese aesthetic philosophy - makes it less and less possible for musicians to practice the same kind of music on this instrument. This flourish engenders further improvisation on the part of the performer.
Additionally, the notion of sawari relates to the participatory nature of musicking: "Sawari and Ma suggest an approach to listening that equalises the contributions of composer, performer and audience" (Corona and Madrid, 2007:54). The concept of sawari when paired with the complimentary silence of Ma, evokes and highlights the natural acoustic textures in nature and indeed surrounding the music being performed - entraining the audience into musical creation.

Point, Line, Plane, Volume

While working in software to ideate and develop prototypes, the workflows and analogies in these tools began to shed light on latent metaphors within the work. 2D and 3D programs often rely on vectors - a point in space with its own direction and force. Vector points are joined together into lines. Building objects based on lines from my sketches and realising them in 3D formed links between the idea of line and the things I wished to represent and cater for. Lines can be used to represent a guitar string, it can be broken up and morphed to show where the notes are along this string. It can be further subdivided to reveal microtones. Four lines can be connected in 3D space and lofted to create a plane - and when planes enclose a volume form is created. From point to line to plane and finally volume - these first principles of design are the tools of representing not just musical ideas, but also ideas about how sound can relate to us: the ergonomics of sound. Traditionally, measurements along a timber fretboard are carved and a metal fret is inlaid. The precision and accuracy of this method is unquestionable. It does however imply a single static dynamic and doesn't recognise the continuous nature of the string as an interface.

The phenomenological or experiential models of music are of prime importance to this research. Within those concepts comes alternate modes of interrogating musical activity - namely, music as a language as mediated through social anthropology (Feld, 1994). If the elements of form are to be used as a design scheme, they require analogous elements to speak of. This is where the elements of music as a language come in: sound, structure and meaning.

Sound: pitch created by a guitar string changes along its length (given its tension, diameter and material) (Fletcher and Rossing, 2012: 243). Although we usually only have access to twelve discrete pitches, a guitar string is capable of producing mostly any audible pitch within its extremes. This microtonal spectrum is what I wish to convey through the instruments interface. A continuous line forms the fretboard. This line undulated in such a way that its peaks come to meet the players finger and afford access to that note. In this interface dynamic, strings represent a continuous spectrum of pitch possibilities, while frets represent a discrete point on that spectrum.

Wilson saw pitch relationships through a specific mathematic lens; he used this to create diagrams, models and instruments to illustrate scales (Narushima, 2017: 4). This is my method to abstract utile sound as I see it and offer it in a format that can directly be used to create music. This approach is to strategically embed representational ideas within the instrument itself.

Structure: broadly, the structure of music can be said to include the arrangement and relationships of sound elements in time and space. The guitar like instruments created through this project loosely use individual planes to position the instrument to the user. Soft, general and nonrestrictive shapes hint, without prescribing, ways in which the instrument can relate to the body. Additionally, fretboards and stings can be changed and configured by the user, positional abstract structural elements of music within the reach of a musicians agency.

Meaning: musical meanings are complex and subjective (Watson, 1942). There are elements which are said to be intrinsic but much more often musical meaning is assembled extrinsically - much like language (Cross, 2011). In cultures all over the world the meanings evoked by music and the act of music making may hold greater importance than the lyrical or sung content (Levman, 1992: 164). The use of an unusual material through a process which imparts unique texture and material artefacts is an attempt to insinuate the possibility of new meanings. By standing in contrast to timber acoustic guitars and the high gloss aesthetic of electric guitars we can provoke an investigation into new forms of meaning. The instruments can be seen as a series of prompts expressed through their use and interpretation.

This alignment of constituent elements forms a consistent interface by which musicians can access microtonal musicking. This treatment transforms the linearity of the guitar string into a core interface dynamic - embodying the continuousness of pitch. As the string is suspended in space, undulations of the guitar form come to meet it and dance around it in various ways. The resultant fingerboard designs plays on the knowledge held by the straight string. Waves come to meet the string, illustrating areas where individual pitches can be created as well as articulating relationships between pitches and the total length of the string (figure 138). Similarly, the back of the instrument curves to embrace the body of the player (figure 139), their hands and eyes then are appropriately positioned (figure 141). Opposite this, a large swoop comes to hold the strings and acts as a bridge, while negative space in between fulfils a core functionality: amplification (figure 139). These shapes acknowledge the player's body as part of the interface and function of the instrument. These eventualities were only possible through an experiential process, which was mediated through an improvisational framework. This allowed post optimal notions to emerge, placing importance in divergence and hopefully passing this insight to the player.

Making

The practical elements in this project are seen as an extended improvisation. Much like in musical improvisation, each phase and artefact emerges out of the successes and failures of the former; adapting to and shaping each part of the expression. In order to convey this progression, practice will be recounted chronologically. It is hoped that this will give a fuller understanding of how disparate elements come to inform the main outcomes.

Studio practice begun with the creation of a range of worry stones (figures 1-5). This exercise attended to my compulsion for making and expressing through process and form and also, to keep me tangibly in touch with my personal emotional dimension. These evocative objects were designed digitally and 3D printed for lost plastic casting (figure 1). The forms were attached to sprue to allow molten bronze to flow into mould cavities (figure 2). This process involved my first ever attempt at patination - the process by which chemicals induce a coloured oxide layer to the bronze (figure 3). Patinas can also arise naturally and several of these objects have since taken on new finishes through use. Final forms were smoothed and patina applied (figure 4 and 5).
This exercise set a formative tone for my research whist showing me how effective the 3D printing to investment casting pipeline can be for quick, tangible and complex ideation.

Based on the success of prior casts and in conjunction with research into musical instrument history and acoustics, a set of three bells were designed and printed on a home 3D printer (figures 6-8). The prototypes each make use of the manufacturing process in a different way. The 'double bell' (figure 6) for example, would typically be hard to manufacture with traditional methods. Another bell (figure 10) features three distinct 'nodes' that would theoretically create a distinct pitch each. The three pitches would then create new dynamics as they compete. This process lends itself to very precise forms of iteration - comparing one bell to future iterations of itself sonically can perhaps lead to creating and controlling complex timbres or tone profiles.

The final bell (figure 8) sought to create something that would be close to impossible to manufacture with traditional bell foundry techniques.

Figures 12-24 illustrate the investment casting process. The printed forms are equiped with 'runners' and 'airs' - a series of carefully placed tubes that would allow molten metal to flow in and out of the mould cavity fluidly whilst capturing the detail and expelling any remaining contaminants (figures 9-11). A special mix of crushed refractory and investment (a plaster like substance) is flung onto the surface. This techniques allows us to capture as much detail as possible. This is repeated layer by layer until there is a stable tick form (figure 12). The tips of the wax tubes that will allow air to escape are excavated from the investment and extended with a foam tube pinned to the mould. At this time, loose and excessive material is trimmed (figure 13). A thick batch of investment is mixed and applied to the tops, flattened with a board and left to dry to form a stable foot (figures 14 and 15). The mould is then flipped and remaining sprue are attached with a cup to act as a funnel during the metal pour (figures 16 and 17). The mould is then placed in a plastic tube with a fence of chicken wire for strength - the tube is filled with more investment mixture that includes the crushed up remains of old moulds as filler. At this time the bell cavity is filled simultaneously (figures 18-21). Cylindrical moulds are then stacked inside the kiln upside-down (figure 22). As the kiln heats, the ceramic components harden as the wax and plastic melts out - avoiding the build up of contaminants, which when trapped in the metal cast are called inclusion. This leaves a clean, continuous cavity in which molten material will be poured and take shape.
After a week in the kiln, moulds are arranged, given a final wrap in paster bandage and filled with molten metal with the use of a crane (figure 23). When the casts have sufficiently cooled, the moulds are broken open with hammers (figure 24).

Using water to remove the last traces of the chalky mould material revealed a nearly perfect surface (figure 25). There is an array of aberrations and faults which can arise through the casting process. A crack in the mould, which can easily from the expansion and contraction that large temperature changes bring, would then fill with metal to create a fin of flashing (figure 28). The ease at which 3D printed parts were cast presented many possibilities at this scale. Of note too is the interesting effects granted by the casting medium, both in the precision of some forms and the natural aberrations in others (figures 27-30). Playing on this idea of finding a kind of beauty in the flaws of casting, a necklace was made as the results of tests design to illicit faults in a bronze cast (figure 31). Other forms create through this experiment (figure 29) had notably interesting sonic qualities to them - an idea which would be picked up later in aluminium.

Success in the 3D printing to investment casting process led me to consider forms that might otherwise be impossible to manufacture without this technological pairing.
Drum shaped meshes were produced (figures 32 and 33) and subsequently turned into lattice structures (figures 34-39), which could then be printed and cast. Figure 39 shows brainstorming the best placement for sprue. These would eventually be skinned to become percussive instruments.

Part of the research led through ideas of interface and spurred the creation of a visual language that deal with ideas related to sound (figures 40 and 41). Illustration was selected as a tool to translate the understandings of sound endemic to different musical traditions. Some of these ideas then transition into form (figures 42-46). This began to interrogate whether the visual analogies were in any way beneficial and formed the basis of my work into evocative interfaces. The forms were modelled digitally and 3D printed (figure 42), reproduced via a simple silicone mould and cast repeatedly in wax to form a continuous landscape (figure 43). This exercise was refocused on creating an

interface analogy for musical pitch that focused mainly on the phenomenon as a sensation. After iterations a layout was created that fulfilled fundamental criteria, laid out by the piano keyboard interface, with the hopes of surpassing it in certain areas (figures 47-49). A wide bandwidth of hand sizes should be able to span a single octave, each individual 'key' should be of a suitable size so as to mitigate variance in player accuracy, it should be possible to play neighbouring simultaneously while it should be similarly simple to play a variety of chords.
These rules were then combined with research into exiting control surfaces. This resulted in the final spans and sizes of keys across three octaves. A simple algorithm was devised to dictate the curves which then revolved to make a 'key'. Three variables - the vector of the cure at the top and bottom and the vertical height - were calculated to all increase and decrease at nonlinear rates. This emulates the exponential relationships present in sound waves within a functional degree (figure 50). Linearly transitioning forms was attempted and the forms did not reflect as engaging, tactile, naturalistic or evocative. A final model was created and machined in ABS plastic - to then be cast in silicone - in order to further validate the effectiveness of the scheme (figure 51). A larger 'landscape' was created using the previous model, repeated in another axis to give a user access to microtonal tunings (figures 52 and 53). The microtonal elements were stylised with different wavy surfaces which sought to represent the interference beats created by to similar pitches. Inspiration was sought in the way in which these patterns behave when different pitches clash across different intervals.

Retuning to themes of emotion and self discovery in design, I was lucky enough to attend a weaving workshop, Saori, for a week in Japan (figures 54-64). Saori weaving is based on ideas of kansei: innate nature, sensitivity and intuition. The practice is meant to act as a design process that flows out of intuition - tacit design rather than explicit design thinking. Some of my previously hand made glass beads were incorporated into the designs (figures 57 and 59). During an all night weaving event,I took this opportunity to weave continuously for 9 hours to the discography of a single band, interpreting musical themes and timbres and structures in my weaving as I went. I used colours from the group's album art as inspiration for each section. Using that palate and the various weaving techniques it became clear that representations were emerging from what I was hearing but more importantly how I was feeling in response (figures 62 an 63).
I also had the opportunity to lean some bamboo weaving skills from one of the foremost weavers in Japan (figures 65-67). I learnt some basic weaves as well as sets of techniques for more free-form weaving. Most importantly I learnt the processes for splitting and cutting bamboo to an amazing variety of shapes and sizes (figure 67). This is for sure an incredibly useful and potentially underrepresented material in musical instrument design. It also seemed very amenable to being worked in a variety of different ways.
While in Tokyo, I was taken by a friend to a flea market where I ended up picking up a hundred year old shamisen. This made a good excuse to visit local artisans and watch how they service these instruments. Watching them skin the resonator section by hand was so different to any skinning tradition I had seen before (figure 68) and while their jigs for applying tension to the head (figure 69) seemed almost improvised, it also seemed incredibly clever. This planted a seed which would eventually lead to my own skinning experiments.

Returning home saw a continued effort into realising cast designs in metal. A drum was designed which incorporated the sprue section of an investment cast into the actual body of the instrument (figure 70). The design was also created in such a way that it could be printed in one piece (figure 70) - print to cast with little to no intervention.

The next object to come into existence was an aluminium guitar body (figure 72). This arose out of an interplay of sketching (see collage of sketches figure 145) and textual realisations. The resonator body would be cast in aluminium while the internals will be cast in such a way to produce fins of flashing - thereby granting each incarnation potentially unique sound profiles. Thin wax sheets were made an applied to create vulnerable areas for flashing to occur (figure 76-78).
The same casting procedures (figures 74, 75, 78, 79. 80) were undertaken for this batch except for in a few instances: complex lattice shapes were not sprayed with investment, but just stood in a plastic tube with the material poured over them (figures 83 and 84). The cavity in the guitar forms were enclosed with wax-soaked paper and then filled with a thin mix of refractory (figure 81). Finally the batch was cast in aluminium instead of bronze. The casts again, came out really clean and were able to be fit with guitar necks (figure 93).

A previous interface concept was cast in silicone and attached to plastic base with push buttons underneath as a proof of concept (figures 95 and 96). A rainbow graphic was create as a method of mapping pitch values to the keys. The association of pitch with colour also draws a link between existing colour theory to interval relationships.

Returning to work on the aluminium guitar bodies, a piezo pickup system attached and installed (figure 97). These pickups transduce electrical information through contact and pick up some intricate reverberations and partials present in the aluminium. Three piezo pickups were mounted in total: one under the bride, one near some large fins and one under the neck attachment. With an instrument complete and playable it was now time to interact with it musically, allowing new ideas and insights to emerge. Folding functional and musical insights from this testing was key. It became clear that I could shave back some material thickness to save on weight an increase resonance. I also loved the aesthetic of the random fins (figure 97) but they didn't propagate as freely as I would have liked. It was decided that I would design the next fins digitally and embed them into the cast (figure 101). The shape offered an interesting bend effect when you put pressure on the back of the body. This was an interesting effect musically, but might mean the aluminium would fatigue over time and break.

The next body design was cast by an external foundry, to a higher degree of accuracy and efficiency. In line with prior insights, material thickness was reduced and the body was closed at the far end to increase structural integrity and to increase resonance. Two bodies were cast: one with sympathetic fins (figure 101) and one without (figure 100) in order to provide contrast and evaluate their importance. Unfortunately the aluminium struggled to flow into the fin cavities figure 101) which was most likely due to pressure flowing perpendicular to the cavities, drawing pressure, and material away.
Standard Fender guitar style necks were sourced for these casts so that their utile nature might allow for the body to be the feature (figure 102). The next innovation formed at the confluence of several inquiries. Weaving and representational graphics exercises guided me through the perception of not just musical pitch as a spectrum but all principles of music being different interplays of frequency. This also pointed more substantially to readings on microtonal theory. How to "access these ideas through interface" was the central notion that mediated the creation of this machined aluminium 48 equal temperament fretboard figures (figures 102 and 103) which plays on this notion of spectrum by contrasting the line of the string against the unbroken undulation of the fretboard. This fretboard has 48 notes per octave, meaning that it is effectively the 12 notes that we are used to, plus the ability to adjust pitches by a quarter. This design was conceptualised prior to a full understanding of the nature of microtonal theory. Ratios between notes are at the heart of tuning theories. Although this system doesn't offer

much more access to pure ratios, through playing I have discovered that it unlocks other play styles and timbres. This is a good example of the way that heuristic endeavour can augment theory.

Noticing that covering one edge while playing increased the volume of the instrument I decided to apply tensioned skin that open face. Having had the opportunity to watch a craftsman in Tokyo skinning shamisen, I created a crude setup to create a similar outcome - using goatskin, sourced form an African drumming store. The skin is first soaked in water to become pliable. Folding the skin over a rod and attaching a clamp to pull against the enclosed rod was the best way I found to get a good grip of the material. String was then tied between the clamps while wooded scraps were wedged against it and the table to tensions the system (figures 104-106). I found this to be a failure prone method. A usable result was achieved in the end, but a better method needed to be developed.

In comparing both bodies with and without the fins it became clear that their benefit is hard to detect. They do add some interesting sympathetic resonances but only selectively - creating a broad enough range within a cast body might be technically difficult and heavy. They do (for some reason) appear to increase the volume of the instrument. At this point, reflecting on making four guitars so far, I realise how much practical knowledge I have accumulated in regards to setting up a quality instrument. The position and angle of the frets to the strings is an interesting balancing act. Preferably strings should be mounted so they sit close to the frets to enable fast and fluent play-styles with greater ease. If the strings are too close, however, the following frets can cause interference and excessive buzzing. A steep angle between the plane of the frets and the strings can stave off buzzing but increases the degree to which the strings become higher along the length of the fretboard. In the case of the highly frequent frets on microtonal instruments, this buzzing risk is heightened. Finding a compromise between these factors is complicated by the user preference. Every player has a different expectation of how a guitar for example, should feel.

Continuing in this endeavour, I began conceiving of a single part aluminium stringed instrument that leverages running ideas and theories in combination with experience gleaned within this project. The first digital iteration was 3D printed and assembled in order to better evaluate scale, feasibility and ergonomic factors (figures 110-115). A track was designed into the neck cavity along with perpendicular holes to accept grub screws. This infrastructure is designed to accept and secure custom machined fretboards (figures 111 and 112). This system allows you to swap out different tuning systems and scale lengths. It also grants users control over string action - or how high and at what angle the strings stand suspended off the fretboard. Testing this mechanism in plastic validated the concept structurally enough to warrant the investment in such a large and complex metal cast. This first printed prototype however, needed some revision. Both the back of the body, the rail system and the headstock would be redesigned for casting.
The design was finalised and delivered to the foundry. Unfortunatley during the casting process the form split in two (figure 119). This would have been mainly due to the difference in material thickness across that section - aided by the thick sprue at the back. The larger mass would draw material from the smaller as it cools, causing failure. The foundry did a great job repairing it, mostly to specification (figure 122). The final part was a little askew, resulting in a limitation in string configurations. In this case it was decided to proceed to making it playable in order to not waste precious playing time. Finally, tuners could be installed (figures 120 and 121) and thanks to the accuracy clearance stayed very similar from printed to cast part - meaning very little shrinkage occurred. Addi-

tionally a 31 equal temperament fretboard was machined at a scale length of 710mm, which is larger than regular guitar scale lengths (figure 138). The rationale for using this as the first test is that it's not too different from common 12 equal temperament in terms of available just intonation intervals, but it does offer a wide variety of new microtones with which to experiment.

Having cleaned up previous aluminium drum casts (figures 116 and 117) they were now sent to the African drum shop to receive their drum head using specialty tying techniques.
The drums all feature a main circular playing surface as well as smaller voids formed in the lattice. When the skin is stretched over the form it creates its own acoustic chamber with multiple smaller playable areas (figure 124). Playing these drums and evaluating them as instruments lead to the next design which sought to maximise the extra edge surface with a taller form and thinner rim (figure 125).

Returning to skinning my stringed instruments this time, I had a more realistic plan. I decided to use ratchet straps instead of wooden chocks to achieve tension (figure 129). Additionally a jig was printed to conform the skin to the body with a margin that overlaped the main face (figures 129-135). Firstly this allowed the skin to take on a compound curve across its tensioned face, secondly the margin gave greater surface area wherein glue made contact.

This long necked aluminium stringed instrument would be the final outcomes of this process of making (figures 136 -141). It offers familiar gestures and play styles associated with plucked string instrument traditions while augmenting this familiarity with unusual timbres and a level of customisation which better reflects the complex dynamic within the world of microtonal theory.

IMPACT

This research has produced two distinct forms of outcome: an array of prototypes and instruments that seek to expand our expressive potential, and a framework for realising design research as a kind of musical endeavour. The latter was explored from the a perspective that interrogates the role of divergence in this musical/ design process, and assesses the links between this approach and creating new musical outcomes. Derek Bailey's book on the topic of improvisation, chronicles its practice across genre and the globe but he takes the time to remind the reader of the ubiquitous and formative nature of the exercise (Bailey, 1993). Free improvisation can be a means for new genres to emerge out of old ones, and new practices take root. This dynamic is true in design. In a microcosmic sense, design inquiry begins with a broad improvisational exploration to better know the issue (Brown, 2009). In a larger historical sense, design as a formalised discipline is a product various forms of improvisation.

In a larger historical sense, design as a formalised discipline is a product various forms of improvisation. Within the context of this project, free-associative elements in my practice have allowed me to maintain musicality within the physical design of my instruments - coalesced into functional insights. Wood, in his article in *The Musical Times* posits that "the evolution of acoustic microtonal instruments has faltered because … composers are not writing for microtonal instruments because they are not available; performers are not building them because there is no music" (Wood, 1986). It is as if there are two ongoing conversations with one interlocutor each. Within the world of free improvisation, there need not be a score to necessitate an instrument; both devices are subservient to intent and expression. Similarly, in design, the aesthetic and philosophical intent of the object can be means enough to propagate its existence. In writing about Erv Wilson - a practitioner who has advanced the microtonal theory substantially through his work - Narushima marks the needs for a next step: to turn theory to music.

Wilson was musicking through maths, Narushima is musicking through her conscience and approachable explanation of Wilson's theories (as well as her own compositional practice). Beyond his theory comes "the search for an instrument capable of playing music in different tunings" and "finding a single interface that can accommodate more than one tuning system" (Narushima, 2017). This effort has largely, in the past, been focused on keyboard interfaces of various layouts and dimensions. Although from a technical perspective, modern MIDI devices seem the perfect candidate to accept multiple tunings, from an interface design perspective the shortcomings are more clear. Discoverability is key to an interfaces success (Norman, 2013). Sure, there is an element of pre-gleaned information when approaching a regular piano keyboard interface, but the static nature of layouts suggests static relationships. This is why this interface has been so successful in controlling various timbres through software and synthesisers, while the equally tempered pitch relationships stay the same. The string on the other hand, is an interface which has embedded discoverability. Comparative lengths created by fretting at a point along the string while playing links gesture, ratios and sound into one cognitive slice. Designing to the string as an interface, with the creation of microtonal fretboards, unlocks not just the functional access to microtonality, but draws a bridge to its concepts. Beyond this, affording access to these theoretical pitch relationships in a real world setting paves a smooth inroad to microtonality for a guitar obsessed culture. The 48ET fretboard has surprised me in this way. As a scale 48ET offers very few additional pure ratios. Playing it, however has revealed all kinds of new styles of play that is available when you can move across what is effectively a conventional fretboard with greater granularity. It is hoped that these instruments can fill the vacuum of approachable microtonal instruments by remaining distinct in their material and design approach, but familiar in their interface and concepts.

CONCLUSION

This research has produced two distinct forms of outcome: an array of prototypes and instruments that seek to expand our expressive potential, and a framework for realising design research as a kind of musical endeavour. The latter was explored from the a perspective that interrogates the role of divergence in this musical/ design process, and assesses the links between this approach and creating new musical outcomes. Derek Bailey's book on the topic of improvisation, chronicles its practice across genre and the globe but he takes the time to remind the reader of the ubiquitous and formative nature of the exercise (Bailey, 1993). Free improvisation can be a means for new genres to emerge out of old ones, and new practices take root. This dynamic is true in design. In a microcosmic sense, design inquiry begins with a broad improvisational exploration to better know the issue (Brown, 2009). In a larger historical sense, design as a formalised discipline is a product various forms of improvisation.

The project emerges from vast musical precedent in which practitioners create and improve their own tools in order to realise a musical vision. In this case however, the focus was shifted towards a mostly applied perspective in which this field of inquiry - making and design - was leveraged in order to contextualise structures and promote new approaches. The field of microtonality was identified as being ripe with potential when explored with new technological and social possibilities. Much as Yasser looks to the history of tuning to project possibilities in the future I use the history of tools and design to give form to microtonal ideas as a projection of emergent musical realities.

Drawing on this kind of applied musicker of the past formed a theoretical foundation. Erv Wilson for example, saw tuning as a vast living system and hoped for an instrument that could actualise this perspective into music (Narushima, 2017). And from there theorists like Ivan Illitch offer clues towards reasoning what properties a tool will need to effectively afford access to such ideas.
Further influence was found in the interrogation of the relationship between aforementioned fields and the ontology of language as a technology. This crosses back with the worlds of human-computer interface and insights from computer music. The role that software instruments play in understanding the limitations of analogue tools and set a framework in which a useful modern tool could be formed. Key to this was relationships to prior reference and the familiar paradigms that this forms. Creating prototypes was one means by which ideas to this end could be evaluated, along the way finding how to cater to tacit and intuitive understandings.

The idea of customisation as a mode of user control distinguished itself as an important device trough its relevance to several areas or research - convivial tools as well as research conducted for NIME that sought to contrast musicians' use of digital and acoustic instruments. Digital instruments are shaped by the user to sets of tasks, whereas acoustic instruments demand that the user adapt to the instruments mechanics whole heartedly (Magnusson, Mendieta, 2007). Pairing the depth of interaction and expression that acoustic instruments offer with the customisation of digital instruments would create a dynamic whereby complex musical ideas can be explored.

The guitar was selected as both a format and a symbol on which to build ideas of microtonality and conviviality. This provides a certain amount of relevant context needed to smuggle new ideas and paradigms into musical circulation. Taking this format and applying a specific philosophy or quality has been achieved in the past through various combinations of semiotics, strings, scales and materials. Extended range guitars is one such example which allows the instrument to span greater pitch ranges and therefore

craft new sonic possibilities - this has contributed to the development of a collection of progressive genres.
While the piano keyboard interface has proven its worth in serving as an interface which can be used to control a universe of timbres (through software and analogue synthesis), the guitar - as an interface - is best suited to carry social ideas through its ubiquity and accessibility. My approach in interrogating these notions consisted of taking the sacrosanct aspects of the guitar (materials and desired timbre) and subvert them to see if the form has the same conceptual power when its encoded differently. In this void, poeticisms and ambiguities formed, which Kettley asserts are key elements by which a user is left to truely express their character (Kettley, 2012: 69-70).

These ideas contribute to understanding how a musical artefact, created from a distinct perspective, can imbue musical outcomes. Inclusivity and experimentation are conveyed through a visual and tactile medium and translated through their relationship to sound. This is the style of communication which fosters meaningful transmittal (Saunders, 2002: 5).

In tandem to sculpting ideas through prototypical work, a formative component of the research was based in immersion in the topic. Playing, practicing and improvising on the prototypes enabled a native dynamic of action and analysis. This also mediated a post-optimal methodology, whereby analysis is rooted in emotional and expressive realities as opposed to usability and accuracy. The two methodological pillars of making and playing, although seemingly unreconcilable in their mechanics, were in fact mediated through the ideas of free-improvisation - however on different time scales. This sought to open up the potentiality of closed loops by introducing tacit and divergent stimulus to various exercises. A central focus on free-improvisation also coaxed interlanguages into existence. Dealing with problems and scenarios through intuition as they arise leads to new pairings of words and concepts, forming these new interlanguages, in this case between sound and form.

Aluminium was a desirable material choice to adequately inhabit the forms of this interlanguage. It also stands in contrast to the principles of wood and bronze and material counterparts. This again feeds back to earlier notions of conviviality - aluminium being cheap and ubiquitous, easy to add and subtract and particularly stable whist soft enough to exhibit signs of human interaction in the from of scuffs and scratches. Paired with an animal skin resonator and exhibiting elements of sawari both bring a further sense of living relationships which reinforce the ideas native to the musicking perspective - representing not just musical ideas, but also ideas about how sound can relate to us.

This perspective culminated in an innovative fretboard design that certainly shares links to instruments from the past, but treats the devision of a string as a customisable and intelligible process. The idea was further enhanced by the mechanical rail design, allowing the user to change an adjust these fretboards - further aligning it the theoretical nature of microtonal theory as laid out by prior practitioners. Alignment of constituent elements formed a consistent interface by which musicians can access microtonal musicking. This treatment transforms the linearity of the guitar string into a core interface dynamic - embodying the continuousness of pitch. The marriage of all these elements formed the final instrument which presents ideas of microtonal musicianship in a familiar physical paradigm. By following a divergent improvisational approach to creating this tool, I was able to cater for a kind of musical endeavour that is functionally difficult to interact with (microtonality), while bringing it closer to familiar form of music making (the guitar). These two spheres are elevated in their alignment while affording access to a world of pitch relationships and textures. This object is reflective of my own design practice, and it is hoped that it will spur similar musicking from people who might interact with it.

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APPENDICES

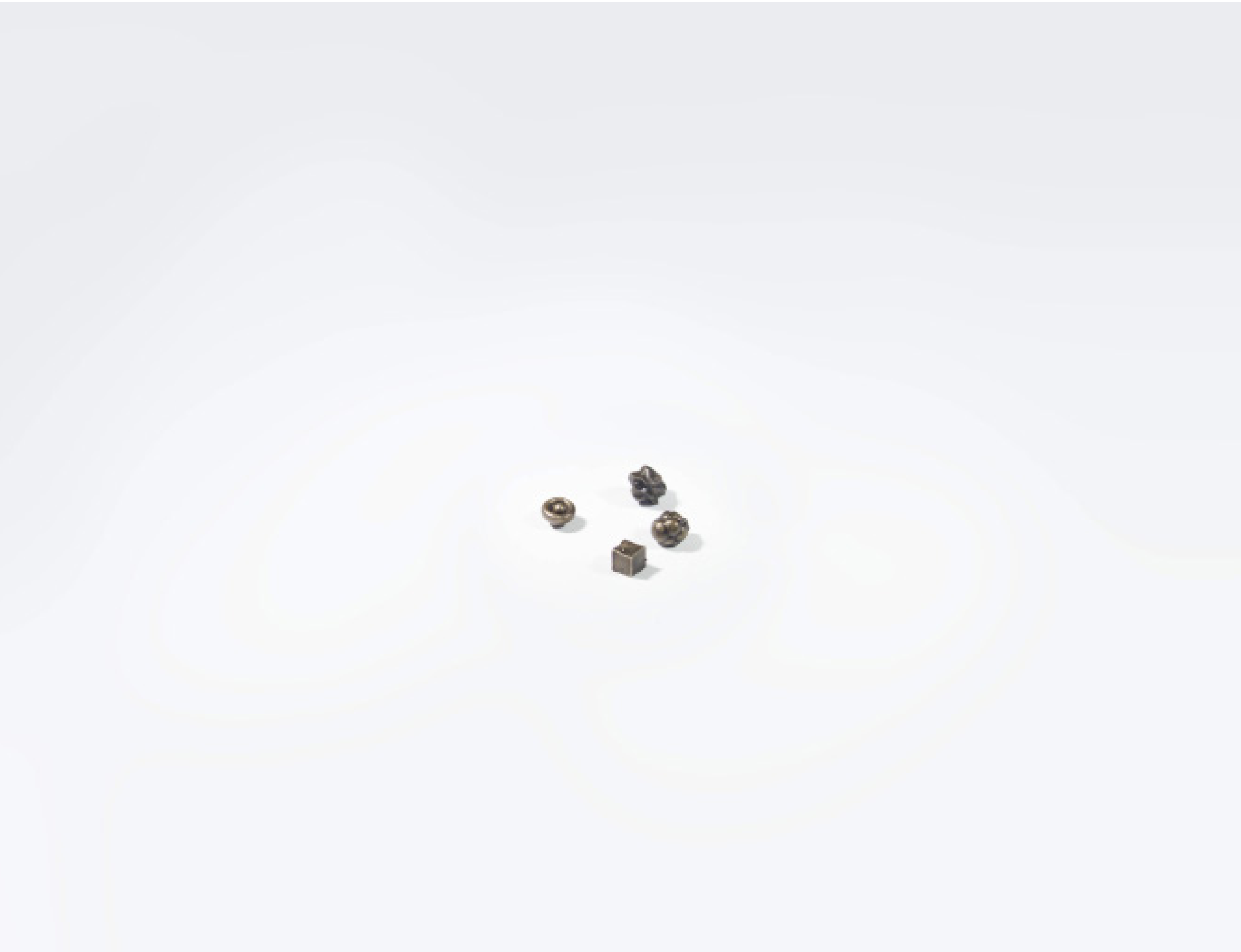
Appendix 1: Making


Figure 1


Figure 2


Figure 3


Figure 4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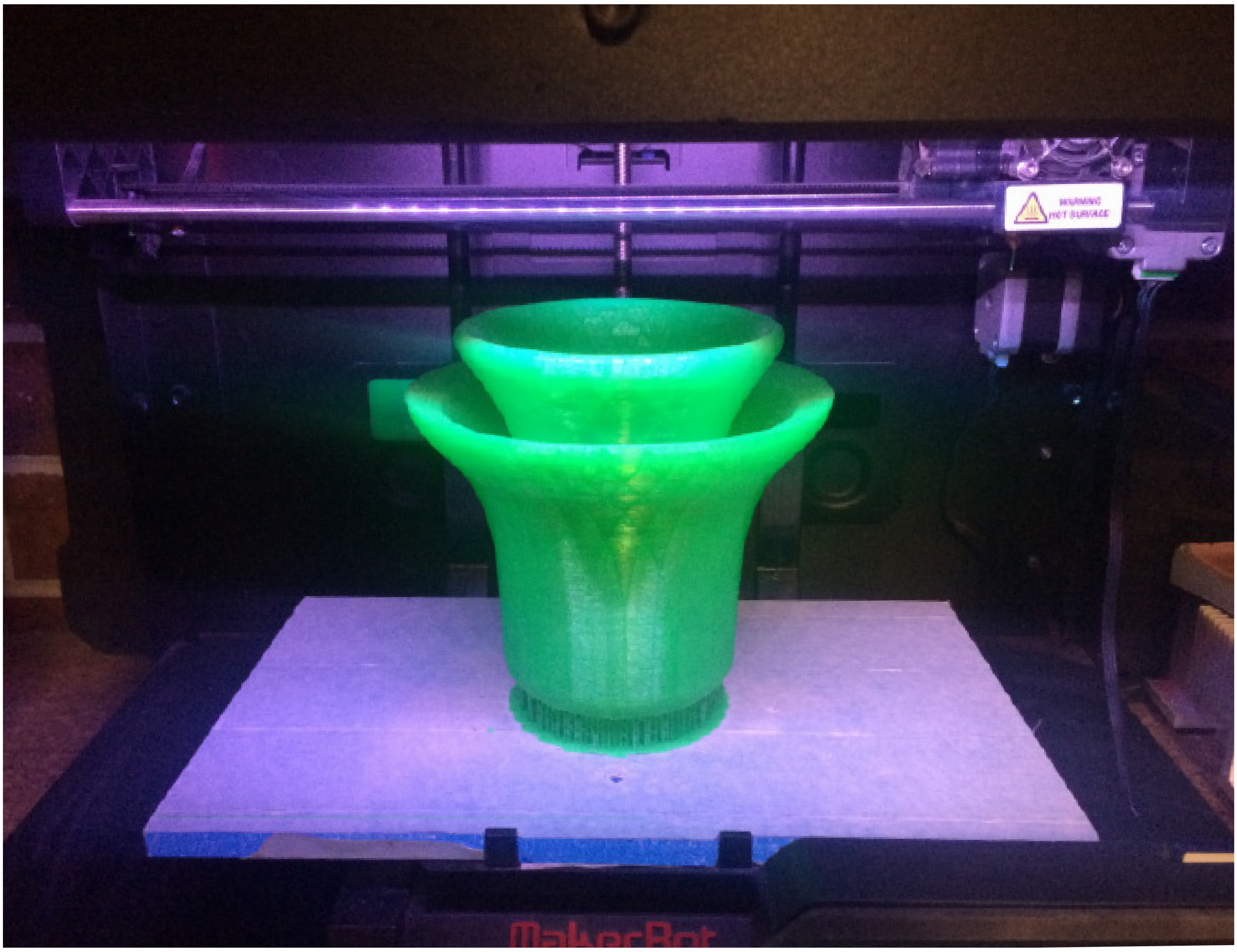

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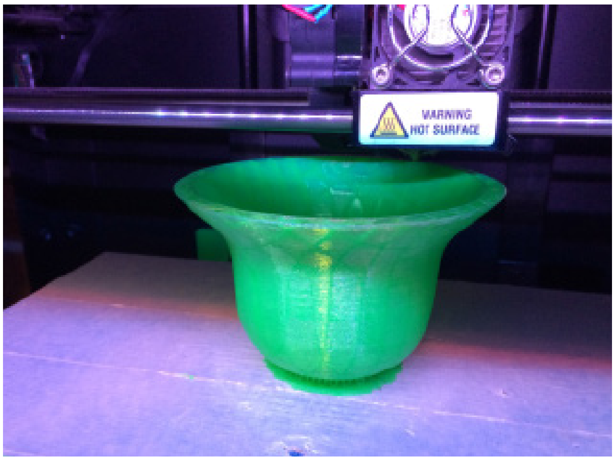

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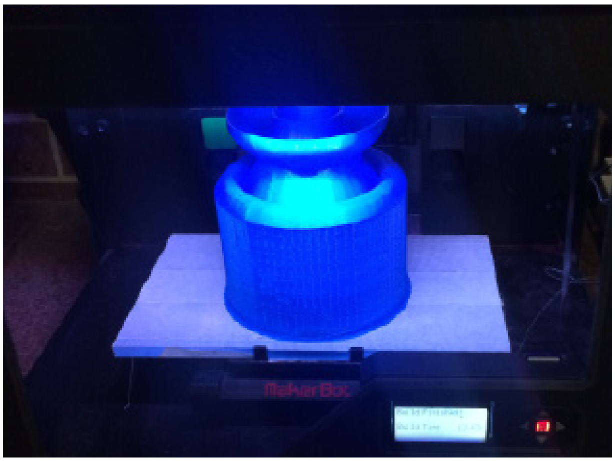

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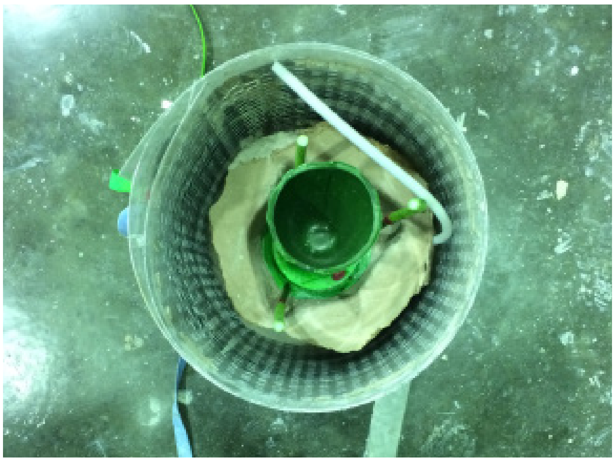

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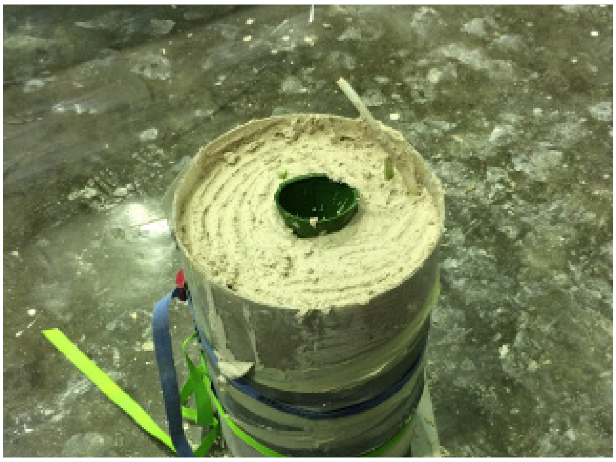

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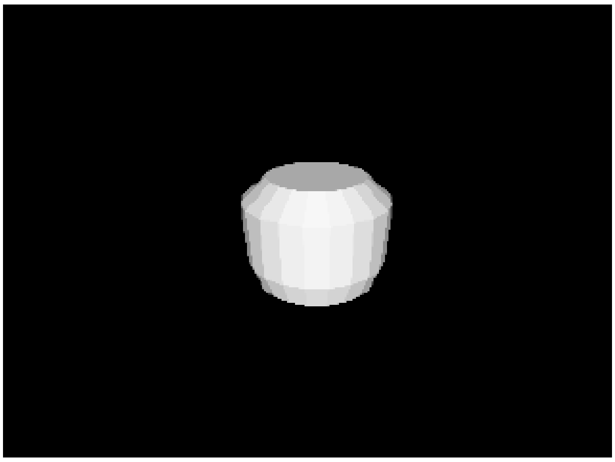

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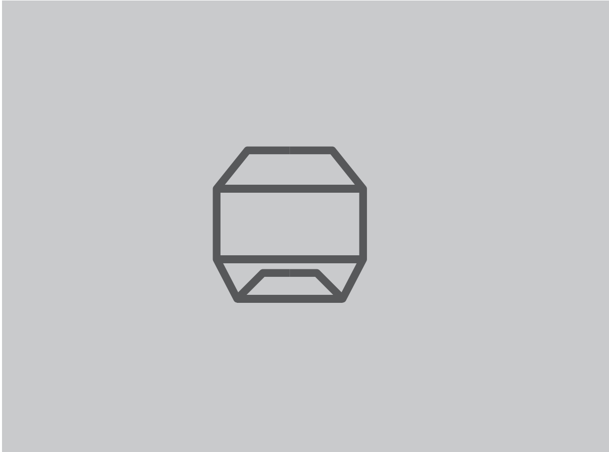

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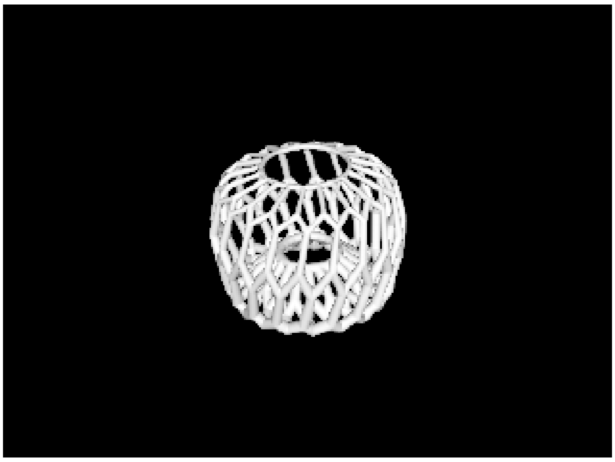

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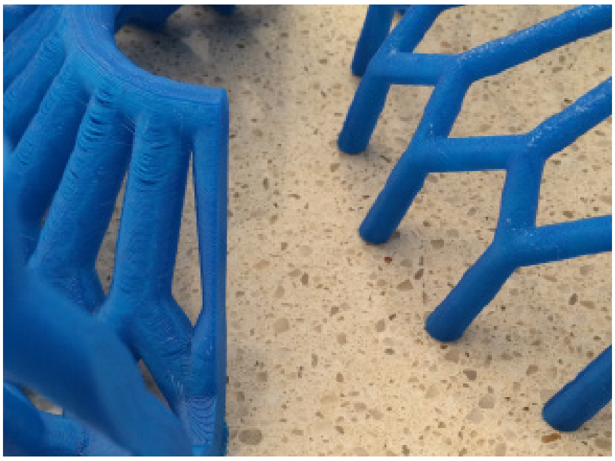

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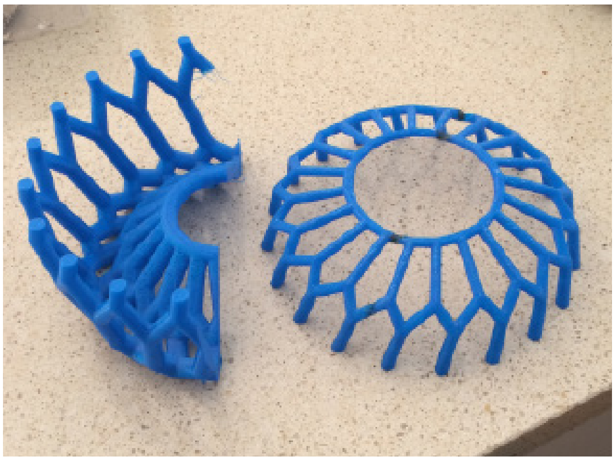

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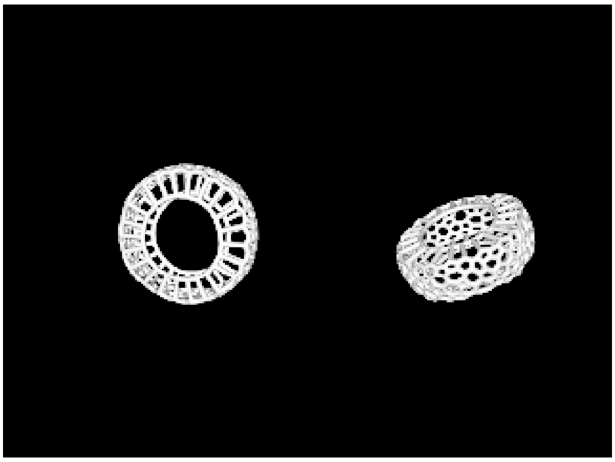

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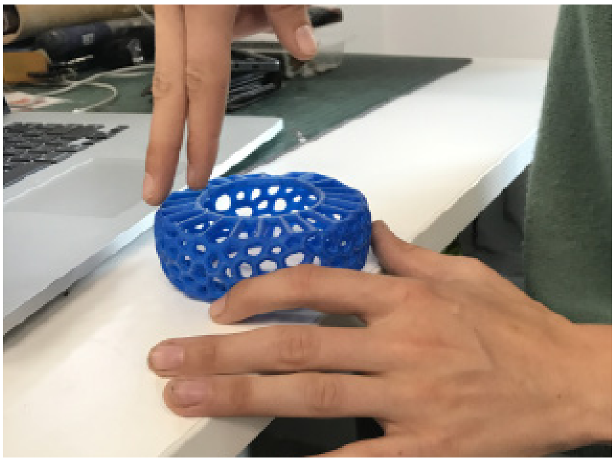

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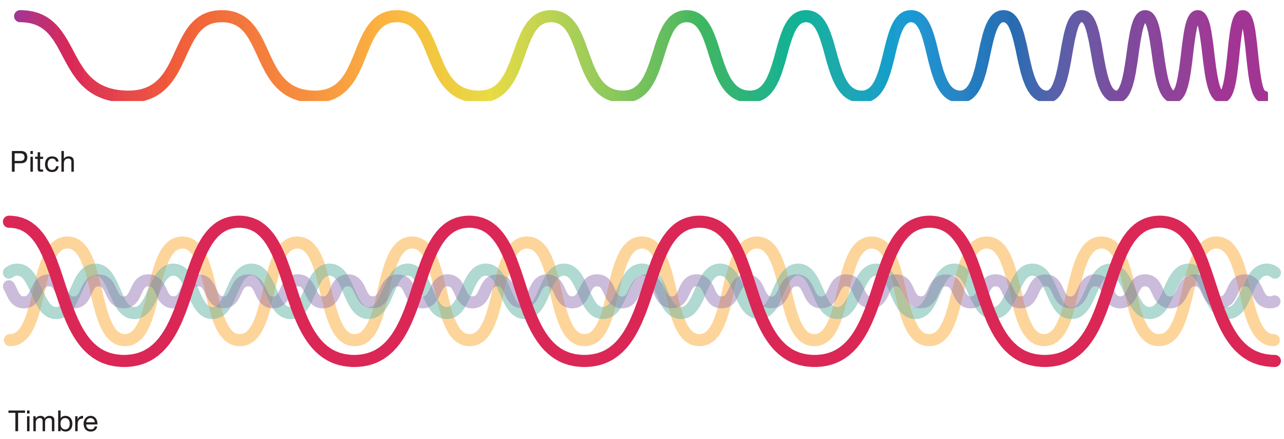

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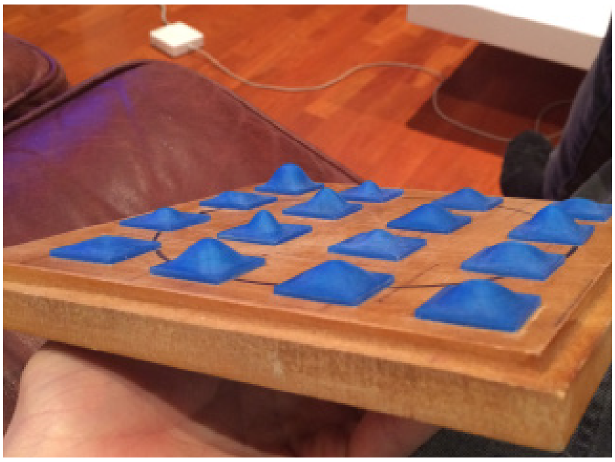

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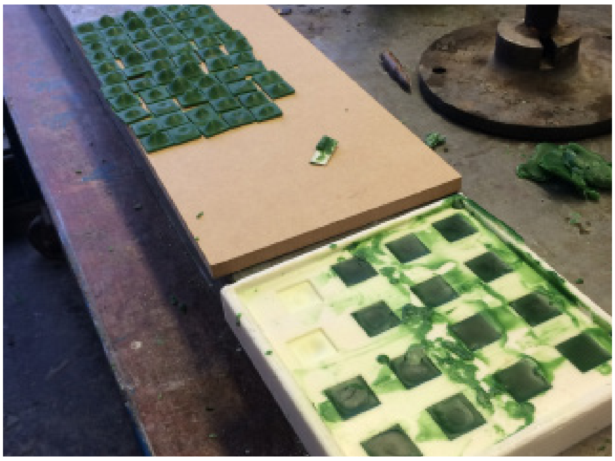

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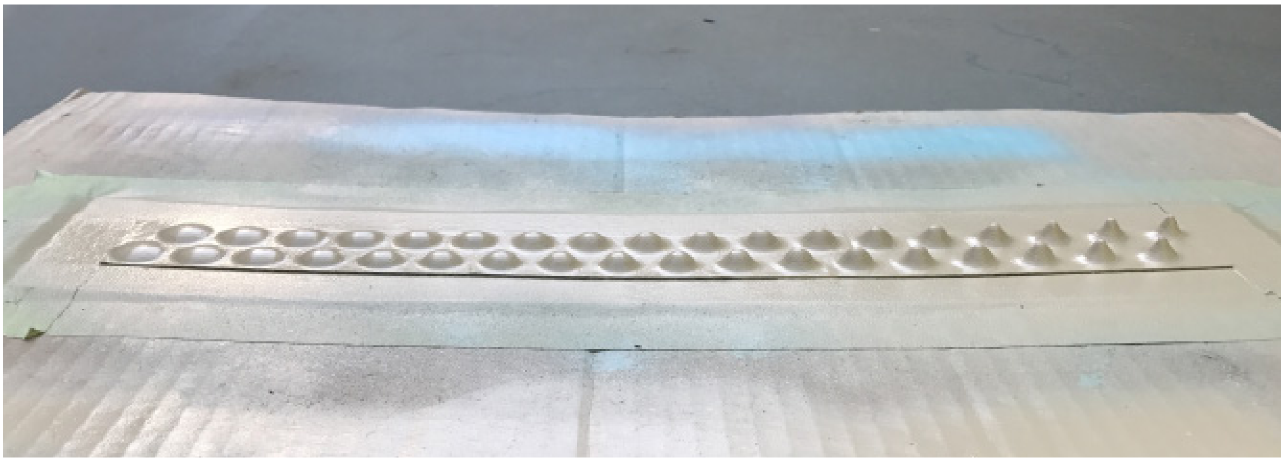

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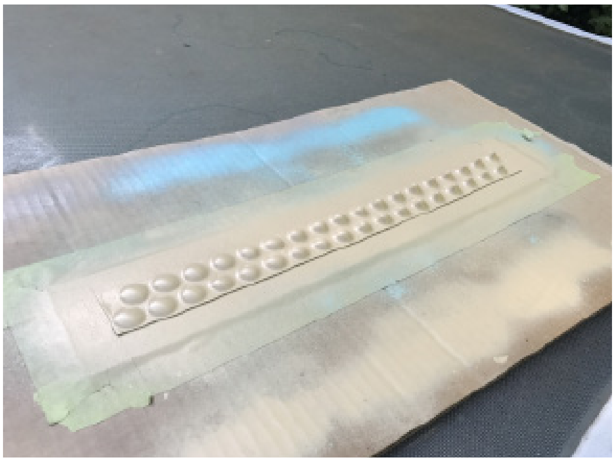

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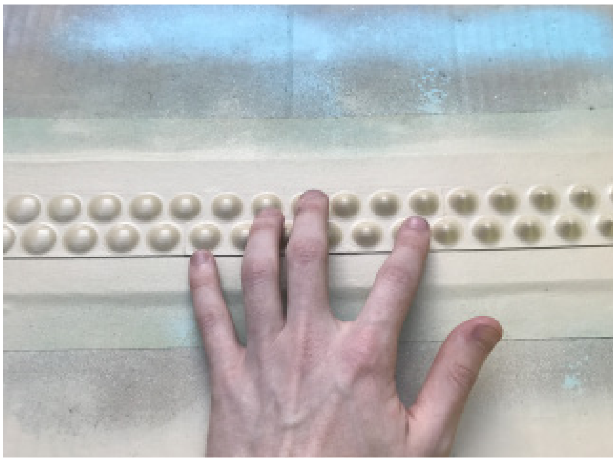

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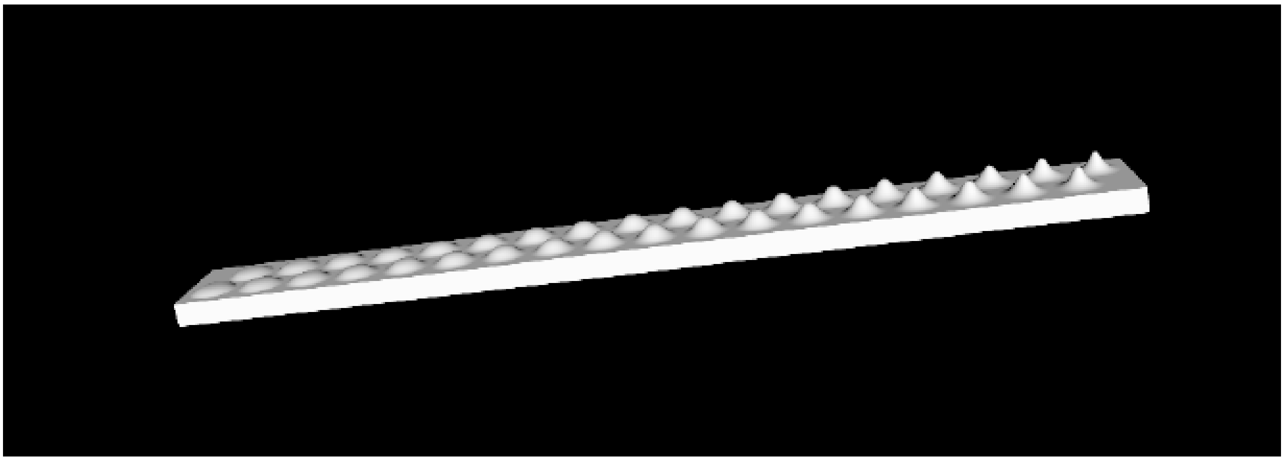

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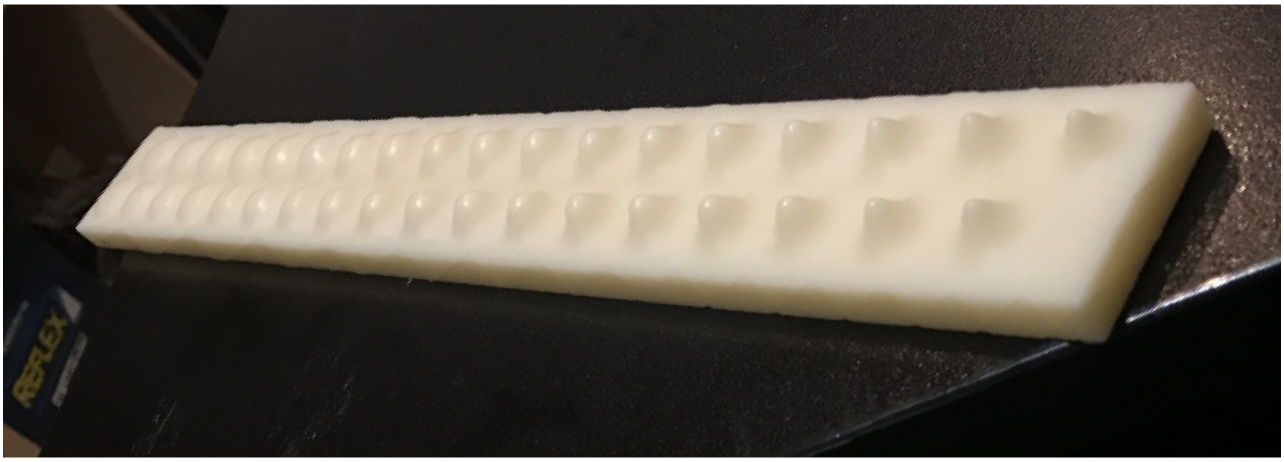

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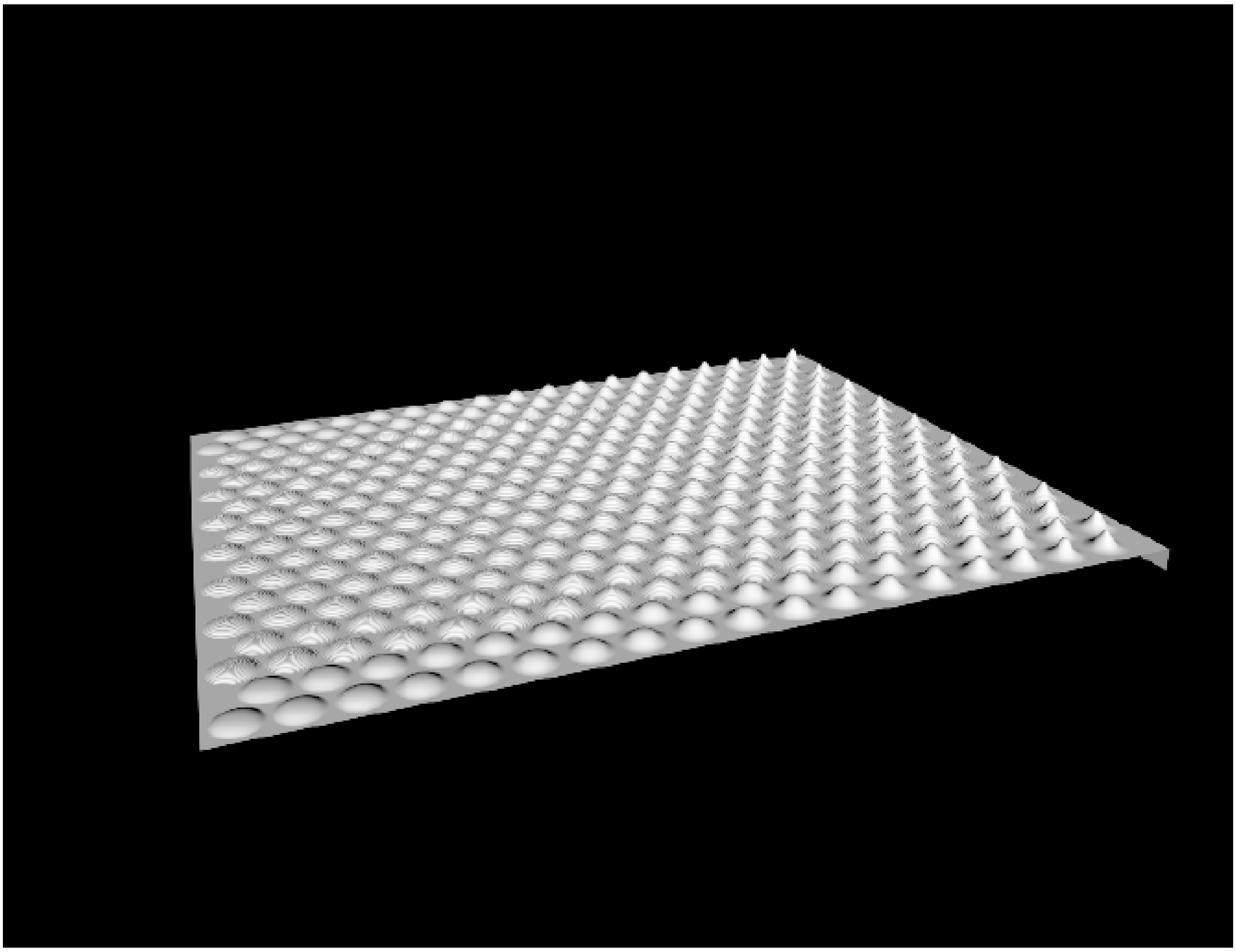

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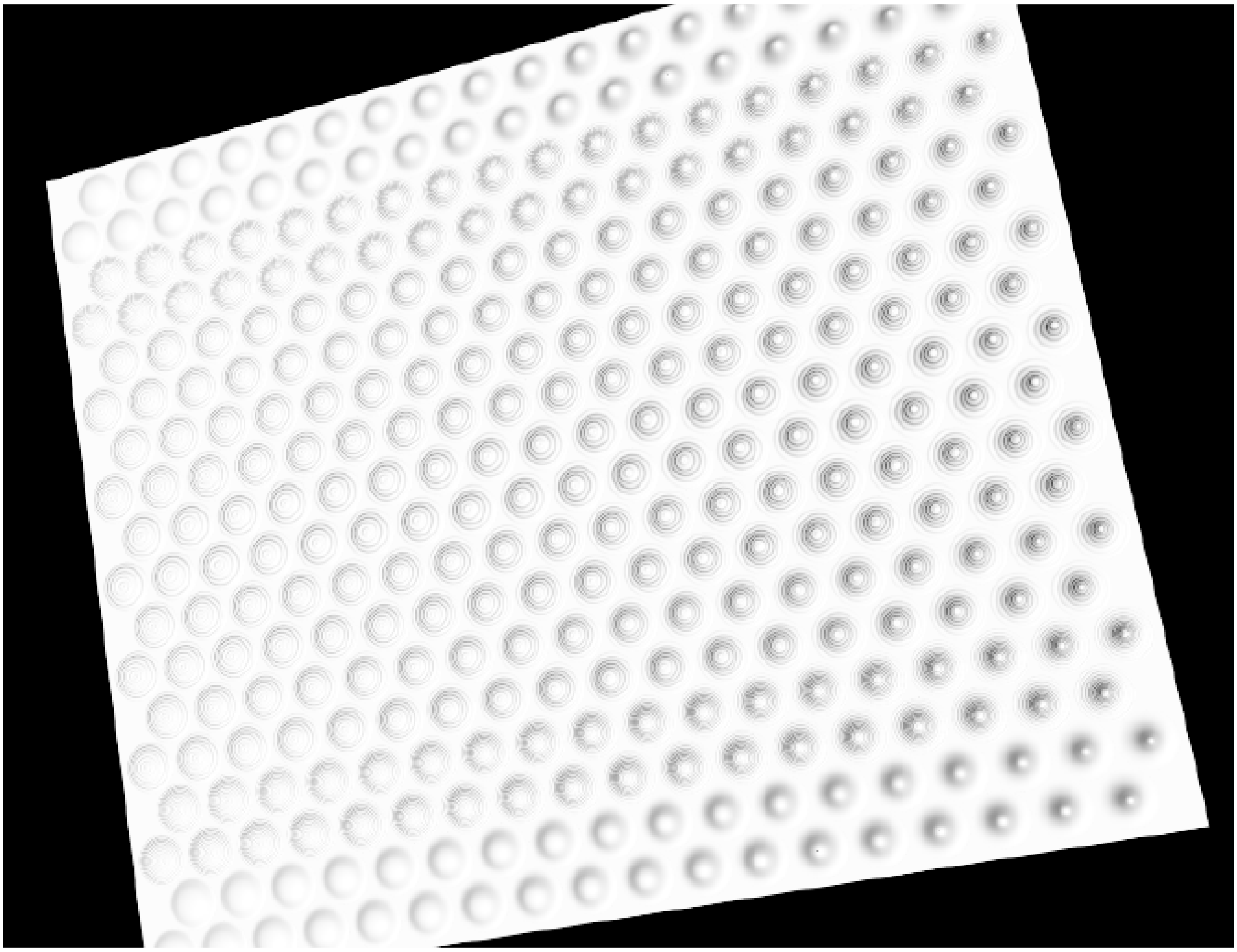

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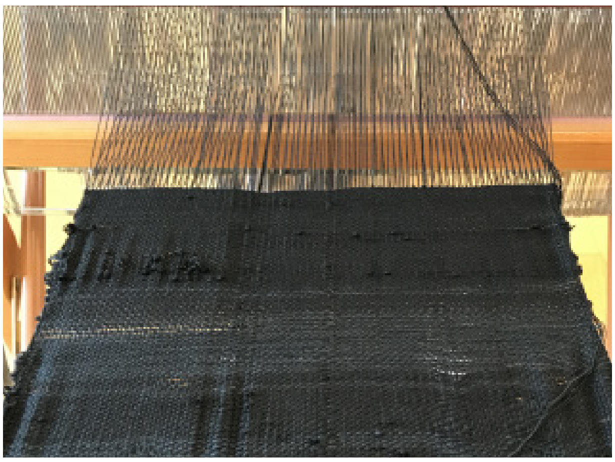
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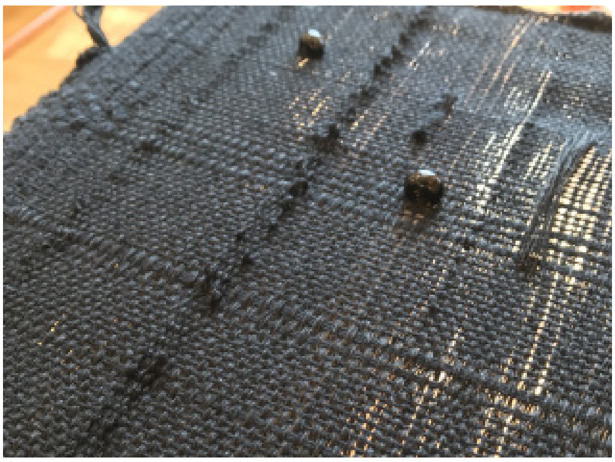
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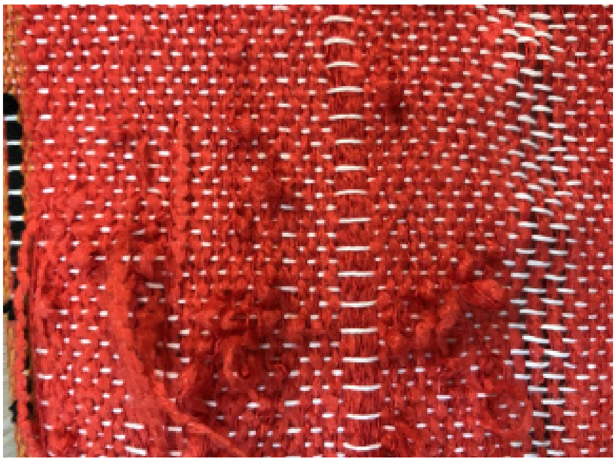
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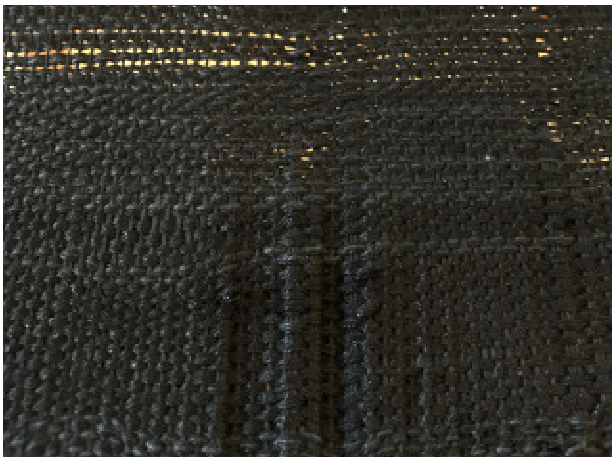
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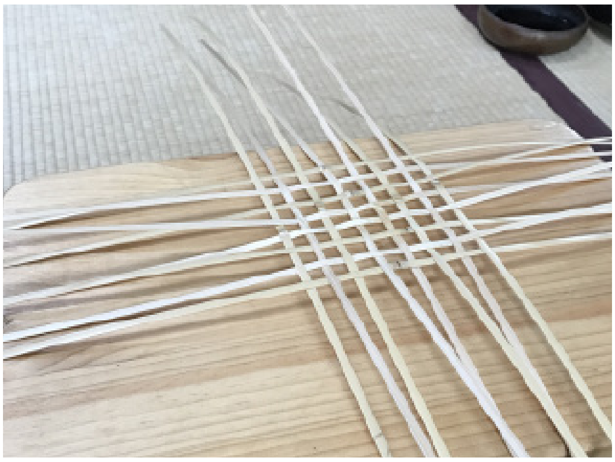
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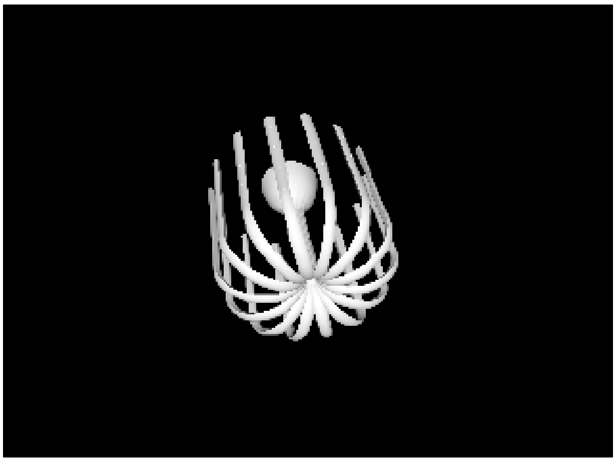
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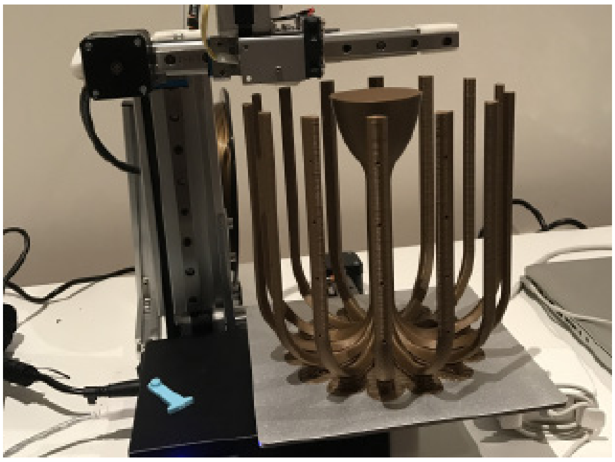
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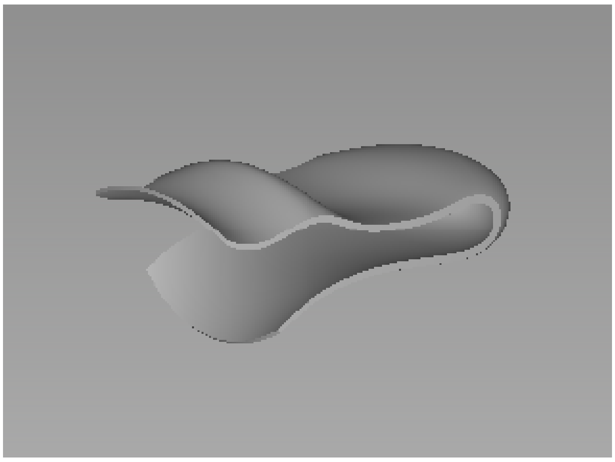

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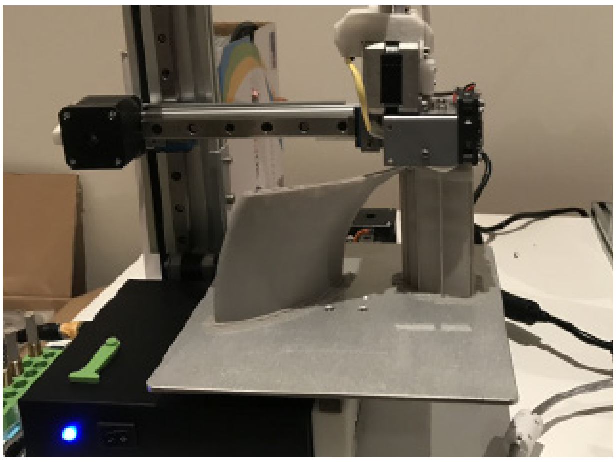

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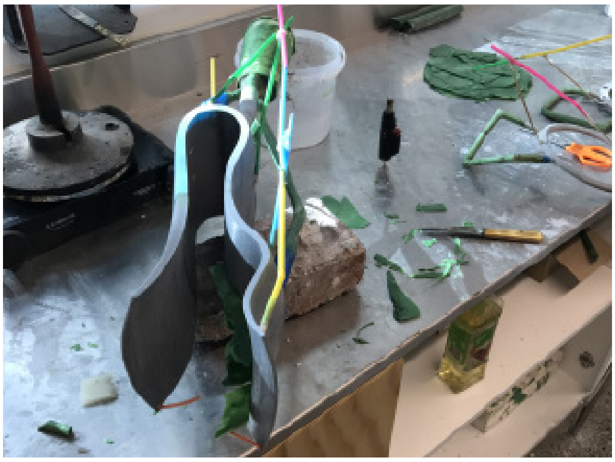

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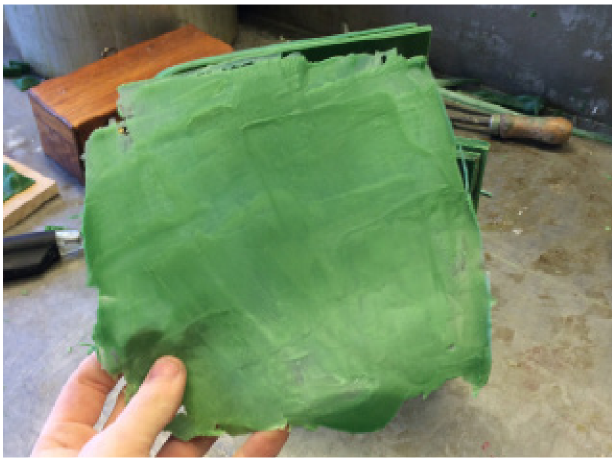

Figure 78

Figure 79


Figure 80


Figure 81


Figure 82


Figure 83

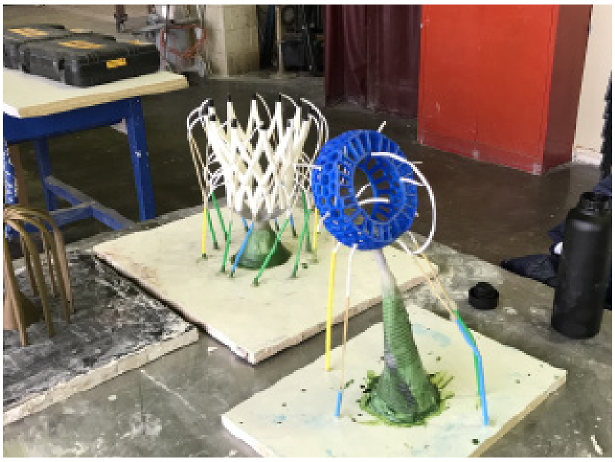
Figure 84


Figure 85


Figure 86


Figure 87


Figure 88


Figure 89


Figure 90


Figure 91


Figure 92

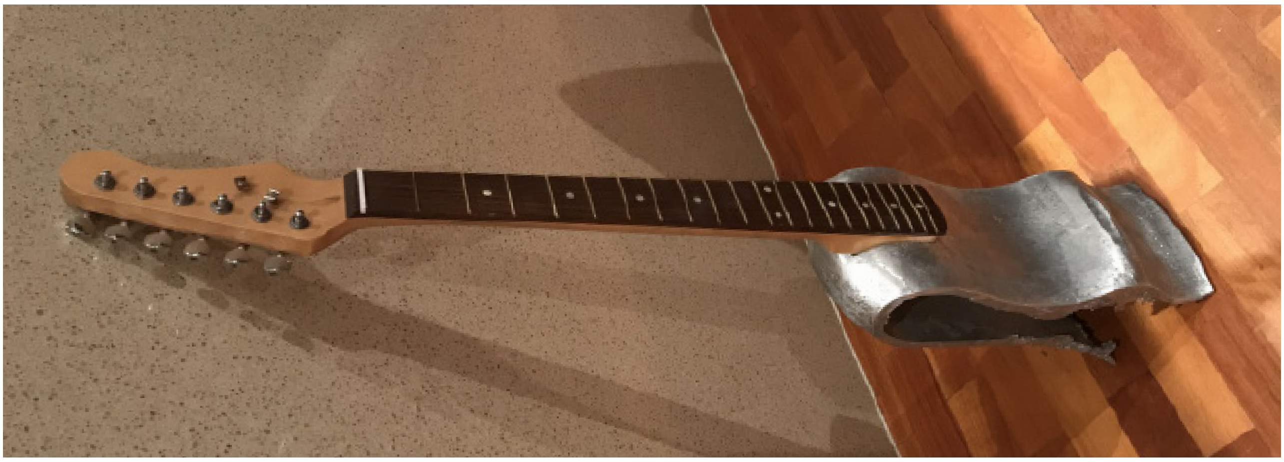
Figure 93

Figure 94

Figure 95

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Figure 107

Figure 108

Figure 109

Figure 110

Figure 111

Figure 112

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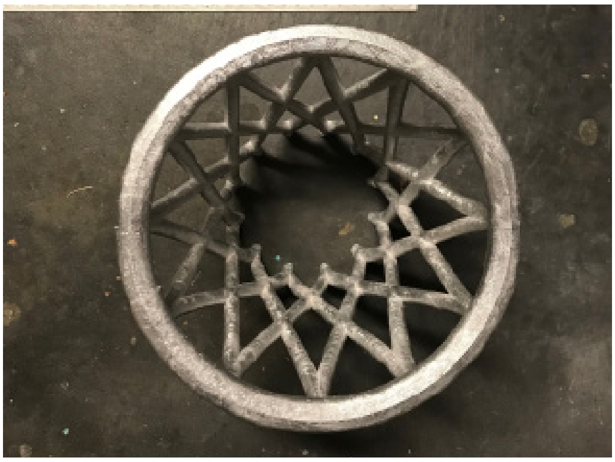
Figure 114

Figure 115

Figure 116



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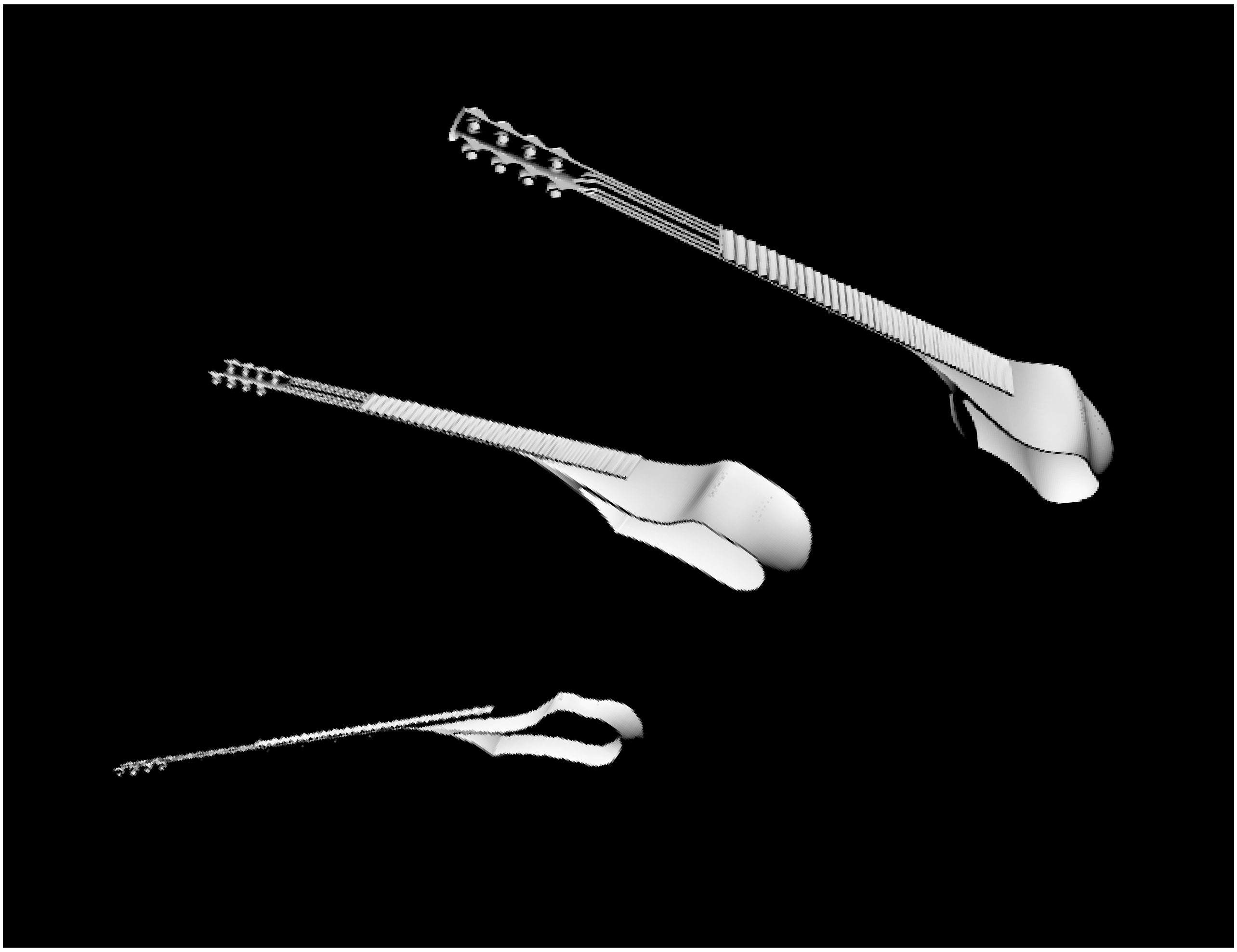


Figure 118

Figure 119


Figure 120

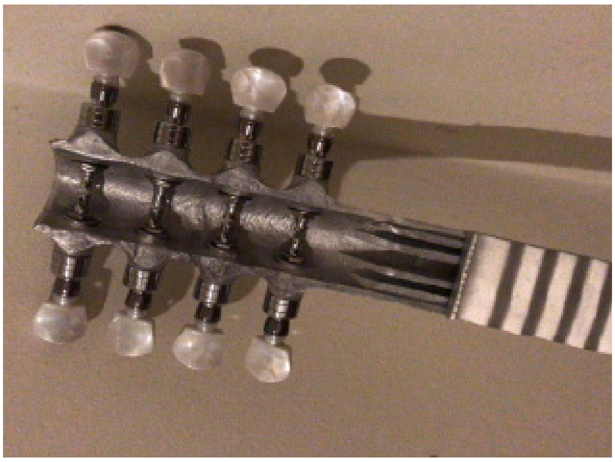


Figure 121


Figure 122


Figure 123


Figure 124

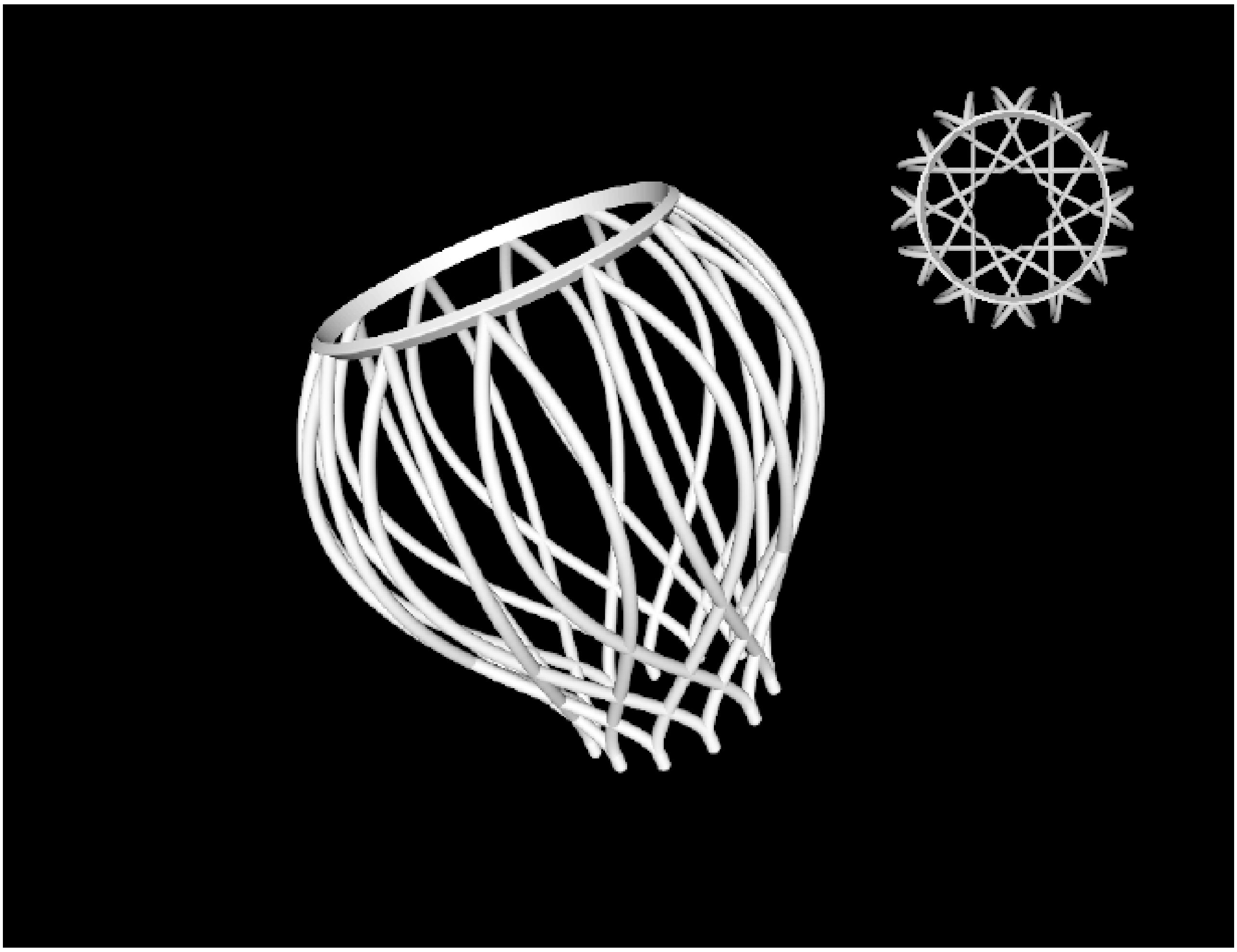


Figure 125


Figure 126


Figure 127


Figure 128

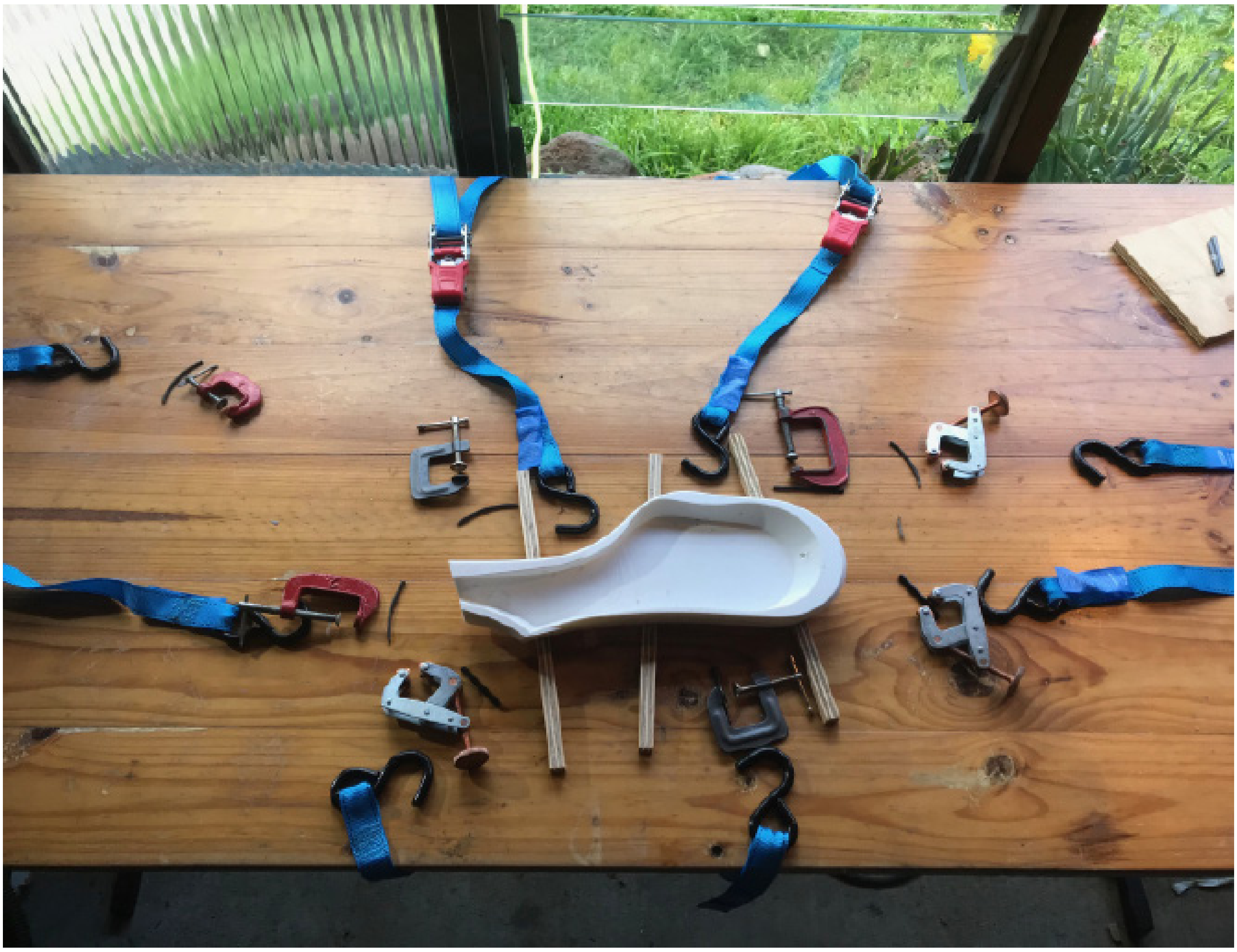
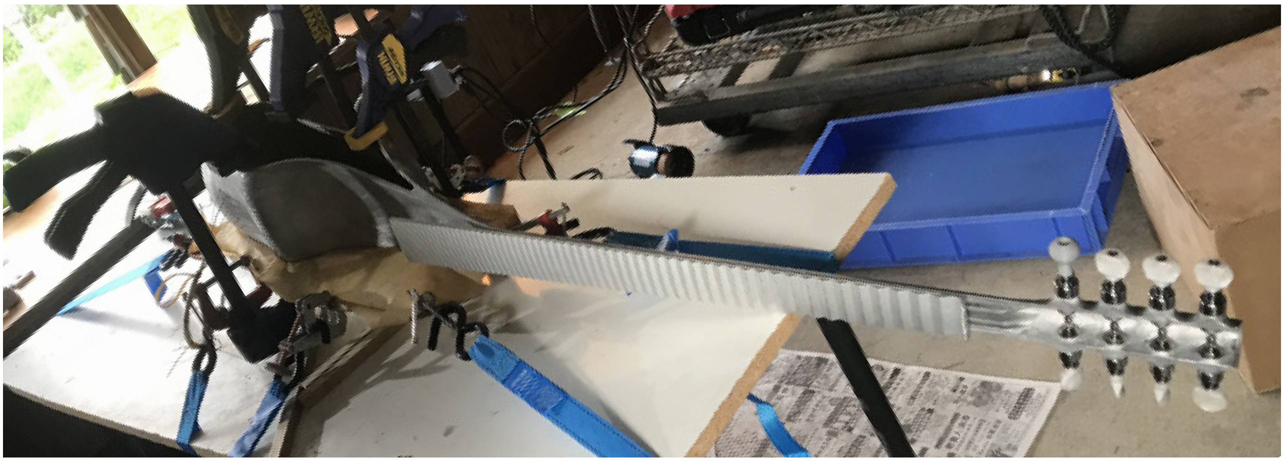


Figure 129


Figure 130


Figure 131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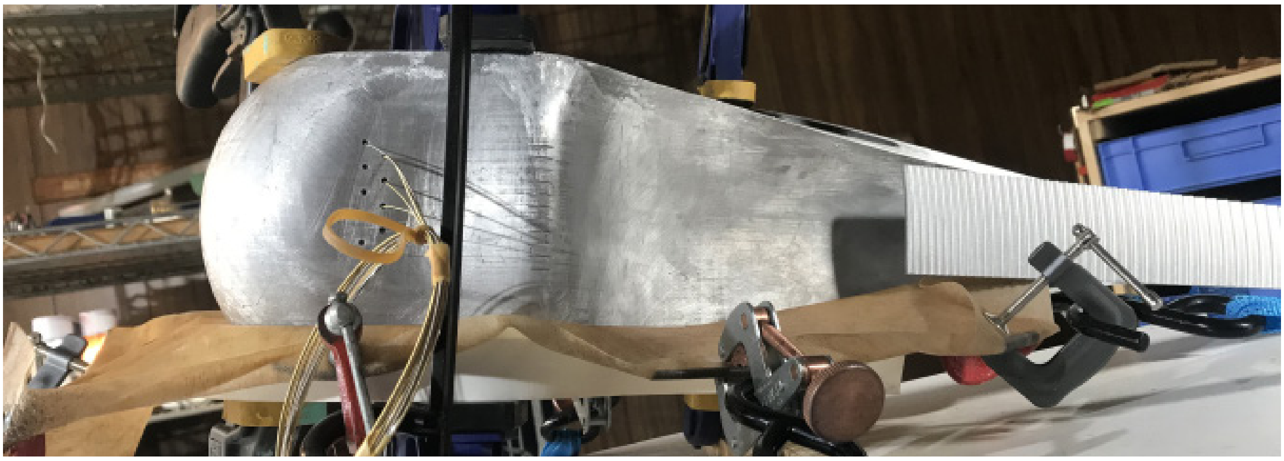
Figure 133


Figure 134


Figure 135

Figure 136

Figure 137

Figure 138

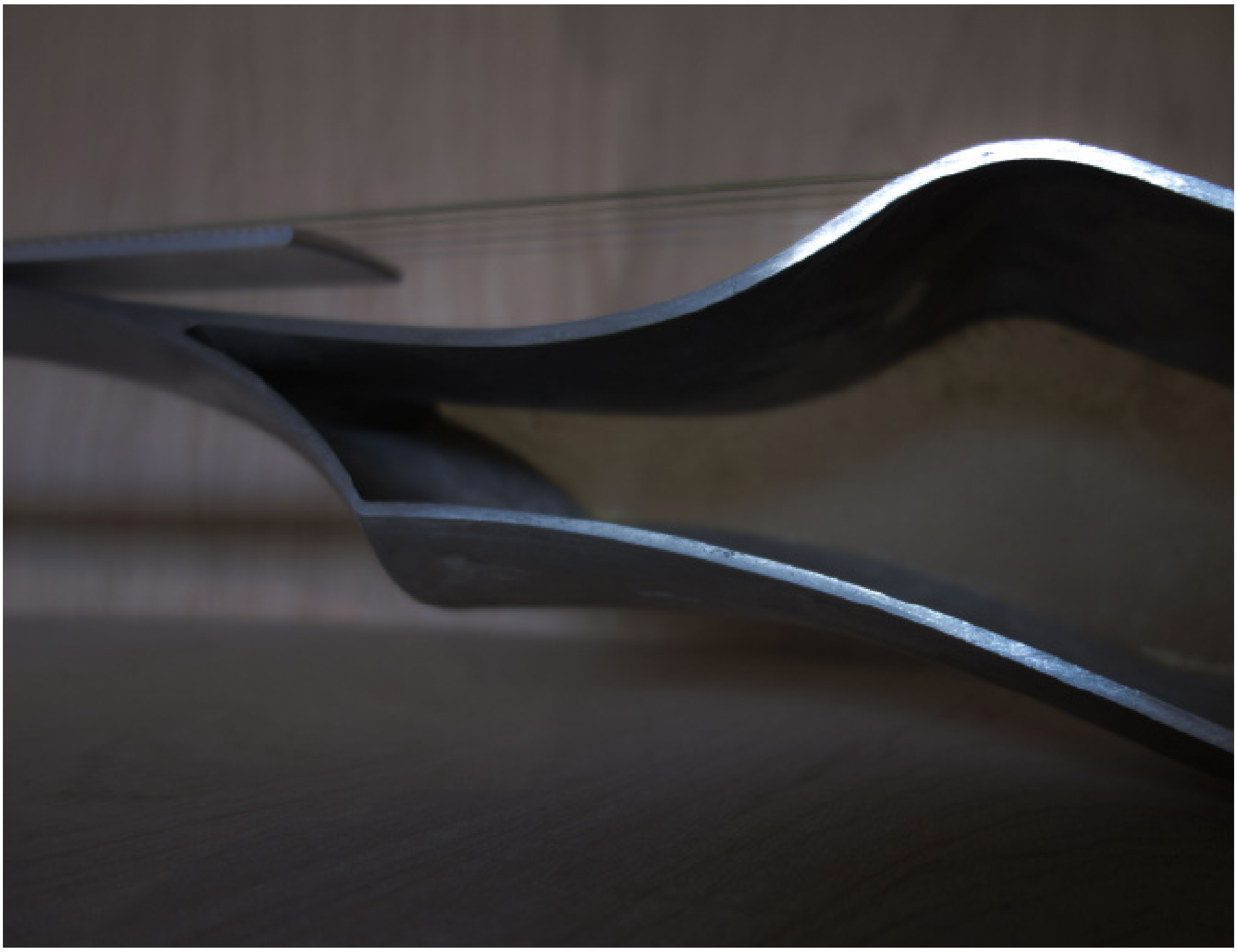

Figure 139


Figure 140


Figure 141

Figure 142

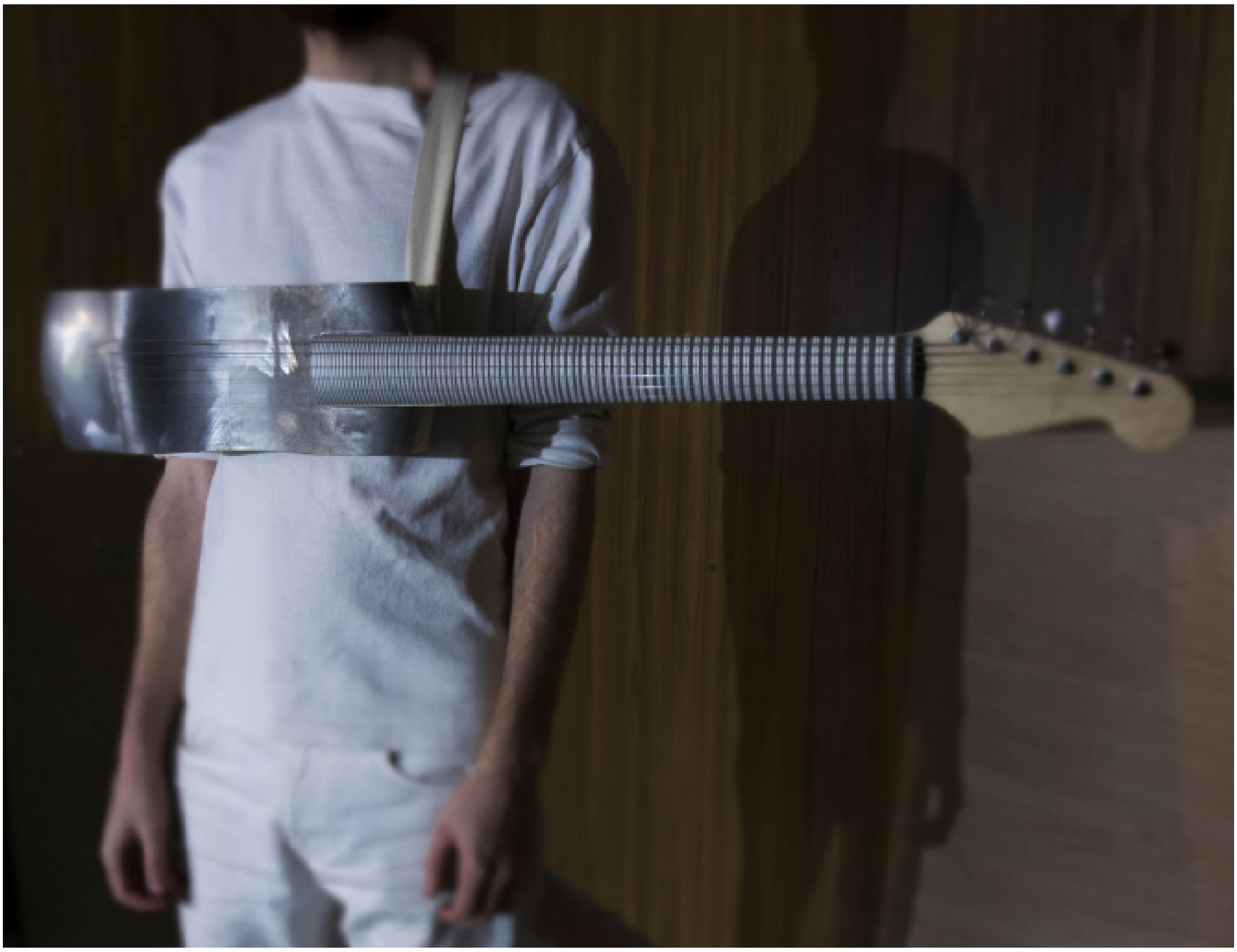

Figure 143

Appendix 3: Sketches

Figure 144

Figure 145