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CONTENTS

0.1 Abstract

This thesis provides the documentation and discussion of a practice-led research project into paper electronics. It explores how installation and printmaking can be enhanced through contemporary technology – with a focus on digital tools and printed electronics. Through the exploiting the tacit knowledge of the printmaker, the work seeks to discover new ways in which art and science can successfully interact. The research has been conducted through the production of artworks, informed by a theoretical, technical and historical comprehension.

Considering the emerging field of printed electronics this paper delves into contemporary uses, not only in industrial and scientific applications, but by practitioners and artists. Following this, the conceptual framework draws inspiration from ancient astronomy and interdisciplinary explorations of space. The research contemplates the Sound of the Spheres - an ancient belief which has inspired artists and astronomers for thousands of years; a concept that all planets and heavenly bodies emit an (in)audible harmony as they move through the sky. This idea drives the visual and audio aspects of the work, setting a scene for the theory and painting a night sky for the technology to illuminate.

The work aims to inform future artists within the field of print and physical computing. The final outcome of the thesis is a body of prints, books and an installation. All combine the traditional forms of printmaking with the contemporary possibilities of paper-based computing and post-digital print. This paper documents the process, various challenges, obstacles and new opportunities that came to light.

0.2 Acknowledgements

The introductory acknowledgement must be paid to my supervisor, Prof. Aleksandra Janik, who has not only shown dedication and kindness to all of her students but whose role extended beyond supervisor to a sincere mentor and an honest friend. I am genuinely thankful for her time, and it has been the most incredible honour to work with her.

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As in many life ventures, this work would not have existed without the unrelenting patience of my partner, who pushes me to be the best person I can and has supported me throughout. Charles Schulze – I owe you one. Finally, to my parents for the many stressed phone calls and tears; Dante and Suri, who patiently survived without their daily walk, and every other contributor mentioned in this paper - especially Mana Kaasik for the beautiful photos.

The inspiration for this research began during a residency at The Laboratory in Spokane, Washington. During this time, I began to combine my interest in electronic art with my practice of printmaking and bookbinding. It was here when I met Liza Stark.[1] Her works in textile-based computing and electronics and physical computing set the wheels of inspiration turning. She taught me to understand computing by using my existing practice to incorporate my craft into approaches to digital technologies. Here I created the first venture into printed electronics, which is described and documented in chapter 4.1. and the influence of which is evident throughout the work.

1 Liza Stark, 'The Soft Circuiteer', The Soft Cicuiteer, 2020 <http://thesoftcircuiteer.net/> [accessed 15 April 2020].

0.3 Introduction

The initial infatuation with new technologies has passed and, as throughout printmaking history, we have entered a relationship with them in expanded artistic adventure. [2]

The works presented seek to analyse the tangible elements of print; how these can be successfully integrated with digital technology to create hybrid and immersive art experiences. The investigation presented in this thesis experiments with conductive ink, embedded circuits, and the integration of audio into paper art, while extending the possibilities of print through post-digital forms of printmaking. Unlike E-textiles, the world of paper electronics is a relatively small yet growing field of research. Today, we find a growing number of artists who are exploring these potentials. This research will further the potential of hybrid analogue and digital media through a series of prints, books, and print-based installations. The project combines tools from the past alongside new printmaking and technology trends with innovative uses of embedded circuits and hybrid media.

This process will question how print can serve as a space for storytelling and empathetic aesthetic experiences. Unlike existing enquiry into paper-based electronics, often for scientific, marketing and design purposes, this Ph.D. will explore this as a space for storytelling within a fine-art and experimental context. The research and inspiration will draw links with the tradition of art and astronomy of ancient Greece when science was held in the same domain of thought as that of music and visual arts. Science has drifted so far from its original aims that to attempt to question its relationship to music might appear to be an exercise in irrelevancy.[3] Is there still meaning to be found in this way of thinking? In contemporary research, interdisciplinary approaches are becoming a hot topic.[4] This Ph.D. will consider how historic forms of astronomy can be explored, drawing links between printmaking, art and science.

This thesis will demonstrate the influence of the stories and harmonies of the skies into the context of my own practice. Influenced by E-textiles and wearable technology, the research will focus on the unexplored field of printed electronics in prints and books. A free and unrestricted investigation will allow for genuinely innovative approaches, with the potential to uncover new technical processes relevant to artists, designers, or industry. Printmaking has a long history of experimentation and an exchange of ideas between the artistic and industrial; this Ph.D. project is an extension of this time-honoured custom. The model is a practice-based research/Ph.D. by project. Following are the definitions of research through art and design practice.[5] In this instance, the written thesis describes the background, concepts, processes, and conclusions of the work generated. Through this method, this research hopes to determine the following questions.

Research Questions

How can printmakers seamlessly incorporate conductive ink and electronics into their artistic works?

How can ancient theories of planetary harmonies be expressed through printed theory?

How has looking to the heavens brought an understanding of who we are?

This thesis is divided into four sections; the first is inspecting the technology of printed electronics and the relevance of paper and printmaking to the project. The second will consider the field of ancient astronomy and the theory of the sound of the spheres, which inspires a significant proportion of the works created. Chapter 3 will investigate how other artists explore similar themes and processes. The final chapter provides documentation and a presentation of the works. The works presented are collections of books, largescale prints, and installations created over this research period. In order to create an accessible guide for artists who want to utilise the knowledge of the Ph.D., the processes, materials and tools documented have been presented as an online blog, as an appendix to this thesis, which can be found at the site below:

www.charlottebiszewski9.wixsite.com/embeddedprint[6]

2 Paul Catanese and Angela Geary, Post-Digital Printmaking: CNC, Traditional and Hybrid Techniques (London, 2012), 8.

3 Jamie James, The Music of the Spheres: Music, Science, and the Natural Order of the Universe, Reprinted (London, 2006), 10

4 Keisuke Okamura, 'Interdisciplinarity Revisited: Evidence for Research Impact and Dynamism', Palgrave Communications, 5/1 (2019), 141.

5 How practice can be integrated into an arts PhD is often a topic for debate, I find one of the clearest and most straight forward set of definitions in Christopher Frayling and Royal College of Art, Research in Art and Design (London, 1993).

6 This is the 'appendix' as referred to throughout this document.

1. THE PRINTED MATTER: Embedding Theory into Paper

Why investigate printed electronics?

What is the relevance of print and paper to this form of technology?

These questions came up countless times within this Ph.D. project. The motives and outlines of this research will be covered over the first chapters, which will look at paper, printmaking and books, all once key-players in the history of communication, now created in the artist's studio. The fascination and creative potential of these disciplines come from their history, the history of global communication. Printers, printmakers, bookbinders and papermakers[7] are interesting beings; they are often found in this strange realm between fine-art, craft, design and industrial heritage. They are never entirely accepted by the fine-art world. In fact, many printmakers and bookbinders would shy away from the term 'artist'. This rejection could be because of questions of authenticity in the printed object,[8] print's reproducible nature, or the craft and skill that creates an edition. Printmakers can be both infatuated with technology and repulsed by it.[9] The question of the relevance of technology in the printmaking process is an often and over-discussed subject. This paper will not attempt to deny this relevance.

So what now? Now that the print, which has come from industry, is no longer a technology at the forefront of highspeed communication and the speed of the world has accelerated. Now, these traditional techniques do not bear the same meaning as before. Just as the link between music and astronomy disappeared into the murky pages of history,[10] the role of traditional print techniques and the realm of communication is quickly becoming a concept found only in museums and history books. However, in today's world, the relevance of print is not dead, as previously and drastically predicted.[11] Instead, it is changing, mutating and becoming something new. True that print is close to extinction in its previous role; paperwork, paperback fiction, and paper products have drastically decreased in production, and ever newer digital

7 I define print as an area of design, something which is closer linked to the industrial processes and printmaking a purely artistic pursuit. However, I like to picture all of these disciplines and practitioners with a healthy dose of fluidity, moving in and out of these domains.

8 Kathryne Reeves, 'The Re-Vision of Printmaking', in Perspectives on Contemporary Printmaking, Critical Writing Since 1986, ed. by R. Pelzer-Montada (Manchester, 2018), 72–81.

9 Graeme Cornwell, The TECHNO-FETISH in Printmaking (1992), Australian Prints + Printmaking, 1992 <http://www.printsandprintmaking.gov.au/references/4852/#_edn18> [accessed 2 March 2021].

10 The discussion of which is to follow.

11 Jeff Gomez, Print Is Dead: Books in Our Digital Age (London ; New York, 2008).

ways of working are becoming the new normal. However, the technological relevance of print has returned full circle, with printed electronics at the forefront of much scientific research. There is a further investigation into how traditional printing, papermaking, and even origami techniques can be incorporated into new technologies such as paper batteries[12] - cheaper and more environmentally friendly forms of energy storage.

Where better to combine all these disciplines than in this strange field of not quite art, not quite craft, not quite industry and not entirely design? The interest in the processes and techno-fetishism[13] is evident in the works presented in this thesis. This Ph.D. does not see indignity in the appreciation of materials, processes and techniques. Furthermore, the research presented does not need to produce a new material, make scientific or industrial breakthroughs. Exploring these processes through open experimentation and the tangible and material appreciation of printmaking will allow for the unexpected and novel approaches to this emerging discipline. The scope of this research is to discover how traditional tools, craft and understanding can bring some new understanding to the world of printed electronics and, at the same time, question whether old 'out-of-date' print technologies represent something beyond nostalgia? [14]

Starting from the here and now, the following chapters will begin with an overview of printed electronics at the time of writing, this is an ever-changing field, and the scientific shelf-life of this section will be short. Still, it will serve as an introduction to the field; the focus of the Ph.D. is for the everyday artist and to be accessible to those with little or no prior knowledge. The following section will observe some of the research issues presented, including the ethical issues and practical difficulties encountered in this study. The third section considers the experimentation and links with post-digital printmaking, demonstrating experimental and technology-driven prints. The fourth section will look at the knowledge acquired from the E-textiles community, which can be considered as an older and more developed 'sister' discipline to this investigation. Finally, we will travel back in history to consider how the heritage and craft of print and printmaking impact the works presented. The final section of this chapter will seamlessly lead us onto the second chapter, investigating Astronomy's ancient predecessors and linking with another scientific discipline that has mutated drastically to its contemporary counterpart.

1.1 Printed Electronics

The research into printed electronics lies at the heart of this project, and the goal is to discover how these methods can be exploited for artistic purposes. As the name implies, printed electronics are a form of electronics created by printing technology. To be more specific, it is an electronic science and technology based on conventional printing techniques to manufacture electronics devices and systems. To most people, 'printed electronics' is an unfamiliar phrase.[15] There are many forms in which the electronic circuits, particularly the traces- normally copper wires or foils in the plastic body of a PCB (printed circuit board), are applied through print processes. Print techniques are used to apply conductive ink – which can be composed of silver, carbon, gold or copper, or other forms the most commonly applied to a substrate by silkscreen, inkjet, gravure, flexography or lithography. Paper and printed electronics are currently being researched for several purposes, including their use in medical devices and printed antennas. There are also examples of PE in graphic design to create clever marketing campaigns with shiny interactive paper or print combined with augmented reality and audio.[16] There are few studies in which artists have explored this field for the sake of artistic experimentation and creation; however, this number is on the rise.

Much of the current research into this area focuses on the potential for technological advances and printed electronics' industrial possibilities. This technology is currently linked heavily with wearables; for example, the flexible electronic can be used to create a discreet sensor applied directly to the skin to measure heart rate. Other potential uses are RFID tags, antennas, OLED,[17] paper batteries and electronic paper.[18] As highlighted by researchers at Aalto University in Finland, some of the benefits of printed electronics were to create cheaper produced electronic devices that could be used for more disposable devices.[19] The issues surrounding the environmental impact and a comparison between the impact of plastic PCBs and paper substrates are fully discussed in chapter 1.3.1. Paper batteries are a key example of just how old technology is contributing to the new.[20] The exciting and counter-intuitive feature of this technological advancement is that print, a feature that we continue to cite as being 'dead' or obsolete in contemporary society, now plays an essential new role in communication technology, health care and much more.

Various methods can be employed for creating printed electronics, many of which bear similarities to that used by artistic and industrial printers: silkscreen, flexography, gravure, offset lithography, and inkjet. They can be relatively cheaper forms of manufacturing for the electronics companies, even if their environmental benefits cannot be fully proven at this early stage.[21] These printed electronics can produce new forms of battery, conductors,

12 Rather Kirigami (Origami's relative) Zeming Song and others, 'Kirigami-Based Stretchable Lithium-Ion Batteries', Scientific Reports, 5/1 (2015), 10988.

13 Techno-fetishm, an unhealthy interest in new technologies, often cited as a negative feature in contemporary society D. Harvey, 'The Fetish of Technology: Causes and Consequences', Macalester International, 13 (2003), 7. and printmaking. Cornwell, The TECHNO-FETISH in Printmaking (1992).

14 C. Kierulf, 'Printmaking and Multiple Temporalities', Journal of Visual Art Practice, 14/3 (2015), 179–91.

15 Zheng Cui, Printed Electronics: Materials, Technologies and Applications, 2016 <https://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=1226534> [accessed 15 April 2020].

16 Emily Corrigan-Kavanagh, 'Next Generation Paper', Next Generation Paper, 2019 <http://thewritingplatform.com/2019/03/next-generation-paper/> [accessed 15 April 2020].

17 Radio-Frequency Identification and Organic Light Emitting Diode (basically printed compound which emit light when an electrical current is applied to them)..

18 Such as found in e-readers or smart notepads.

19 Vesa Kantola and others, 'Printed Electronics, Now and Future', in Bit Bang – Rays to the Future (2009), 63–102.

20 Liangbing Hu and others, 'Thin, Flexible Secondary Li-Ion Paper Batteries', ACS Nano, 4/10 (2010), 5843–48.

21 Esa Kunnari and others, 'Environmental Evaluation of New Technology: Printed Electronics Case Study', Journal of Cleaner Production, 17/9 (2009), 791–99.

resistors, transistors and other electronic components, asking us to re-examine the materials and approaches chosen in the traditional plastic-enclosed forms of computers.

Today, countless ink companies offer many types of electronic inks, composed of different semi-precious metals such as copper and silver, to more cost and environmentally friendly substrates, such as carbon or graphite – and even graphene.[22] Working with relatively new technology, something which is not yet widely practised amongst artists and designers, meant that a certain number of issues arose in the process. These have been further discussed in the following chapter. Some of the artists who are already taking advantage of this can be found in chapter 4, which provides a broad scope of inspiration - focusing on artists who have sought to combine these new potentials into their practices.

1.2 Post-Digital Printmaking

This research also places itself within the realm of post-digital printmaking, as defined by Paul Catanese - the integration of contemporary technology, such as CNC, lasercutting and 3D printing, with the plate-making methods of traditional print.[23] It will build on his view that as the novelty of the digital wears off, it allows for expanded artistic experiments. Post-digital printmaking has been a significant buzzword for over close to a decade. It seems that it could be considered now as the post-post-digital era of art and printmaking. Many artists and researchers investigate how traditional print forms can be combined and refigured with contemporary technologies finding ways of using digital technology to modify the printing matrix and as a tangible and process-orientated technique

The works presented in chapter 4 explore the inherent materiality which comes from printmaking and digital processes. To seek and understand how new tools can bring their own inherent visual features to the work while embracing the fleshy, rich appearance of the print. 'Printmaking is a developing culture; we need to embrace the new and the old together'.[24] The works described, especially in chapter 4.2 have attempted to take this one step further, exploring both the potentials of digital technology in matrix production and how they can alter the physical paper and create new forms of making a multiple.

Today there are many examples of laser cutters and CNC machines being used in creating the print matrix.[25] Some are genuinely embracing the old with the new, who acknowledge the limitations and inherent qualities of these tools and can exploit them successfully.[26] In chapter 4, the works provided show examples of works created during this Ph.D. that fully utilise the tools of a laser cutter or digital plotter. The works attempt to embrace this ethos, explore each tool with respect and transparency, exhibit the aesthetics of the digital alongside the haptic qualities of the physical print. To explore the following ideas, common to

22 I have included in the appendix a description and overview of several of these materials, including homemade as well as shop bought items

23 Paul Catanese and Angela Geary, Post-Digital Printmaking: CNC, Traditional and Hybrid Techniques (London, 2012), 8.

24 Stephen Hoskins, 'Printmaking with Extreme Technology; Beyond Digital', 2009 <https://www.uwe.ac.uk/sca/research/cfpr/staff/stephen_hoskins/presentations_papers/sgc_text.pdf> [accessed 10 April 2021].

25 A simple search on Google, Pinterest, tumblr or any leading image-based social media platforms will provide a whole range of examples.

26 For a particularly successful example see The work of Letterpress studio, The Print Project, in the UK: 'Work', The Print Project, 2021 <https://theprintproject.co.uk/work/> [accessed 20 April 2021].

Fig. 1 - Forming. Linocut. The Print Project. 2019

printmaking - haptics, technology, the multiple and the craft of the process, - how they can contribute to the possibilities of paper-based, physical computing. Following the belief that the printmaker holds an intangible knowledge with which they will be able develop new forms of experimentation.

1.3 Technical Issues and Approaches

One of the most significant issues which arose in this research was a distinct lack of documentation for artists, aside from Bare Conductive and CircuitScribe, two of the larger producers of e-inks, available to hobbyists and amateurs; they have produced several guides in using their products, with many well-documented projects and collaborations.[27] However, as documented in the appendix, neither of these products was suitable for the needs of the work. Obviously, over the last three years, there has been a rise in popularity and new research appearing all the time. However, as discussed in the following section, e-ink and

27 Bare Conductive Resources, Bare Conductive (2021) <https://www.bareconductive.com/blogs/resources> [accessed 18 March 2021]; Fun Projects and Lessons, Circuit Scribe Official Store: Teach Electronics by Drawing! (2021) <https://circuitscribe.com/pages/fun-projects> [accessed 18 March 2021].

paper electronics are not nearly as well documented as e-textiles. There is apparent space for the development of this field outside of the scientific and industrial scale.

The second issue was being unable to access certain inks or technologies – being unaffordable for the artist and hobbyist. These issues are fully covered in the annex which will also serve as a guide for the artist and practitioner. Finding the necessary resources and the ever-changing opportunities of new technology and the constant issues surrounding this can be demonstrated in one key example. Here, I provide a single anecdote as an example of the continuous frustrations experienced throughout the entirety of the research. This was the case of hunting for an affordable, low-resistance printing ink.

At the beginning of this project, I was interested in the idea of using copper-based electronic ink. This was mainly for aesthetic purposes. After contacting several suppliers, all of whom were only interested in selling in large quantities to other industry partners, I contacted Copprint.[28] They advised me that the sintering process of copper was still too complicated. I later found out that it would require special equipment for this – known as a pulse-forge and was a surprisingly high-tech and expensive process.[29] I checked many options, such as silver inks, around $400 for 100ml, before import tax, to homemade style inks.[30] In the end, I was able to source a silver-based ink from China. As of today, at the ending point of this thesis, the Copprint website now has copper ink available, with a wide range of application and sintering methods. This is a small anecdote that demonstrates the issue of working with emerging and changing technology.

Similar issues arose with power and battery sources. Paper batteries are another emerging technology, even further from reach and homemade batteries are unstable, and the chemicals involved can impact human health.[31] There are ever more prospects that look like exciting ideas but are very far away from being accessible and available and in everyday use. These are items such as paper-thin Organics LEDS, which are only available in the hands of multi-million-dollar research facilities or companies- such as Rohinni, a company in Idaho developing microscopic 3D printed LED-paper and a 1mm thick LED thread.[32]

The other end of the scale is the paper electronics maker projects which consist of copper taper, with LED's crudely soldered on, - often for school educational projects. These examples, designed by electronic engineers, see the field of artistic paper electronics as a child's experiment– without the artists or paper-based crafter's sensibility. However, the frequent conundrum is that many artists do not have the knowledge and resources to access this process. Many find coding and circuit design beyond their reach. However, there are more courses online than ever before.

One of the other approaches to overcoming this barrier is to collaborate. The act of collaboration has always been integral to the printmaker's work.[33] It can be challenging to find an engineer or coder who has the will to work with someone of less knowledge or for an affordable price. However, there are options, finding partners in maker-labs or, more commonly, online freelancer sites. These can provide beneficial partnerships and allow for actual interdisciplinary projects as attempted in this thesis.

1.3.1 Environmental, Ethical and Safety Considerations

The environmental impact of electronics is vast. The amount produced, consumed, and disposed of is monumental and the pollution caused by the growing number of electronic products, such as smartphones, watches, earbuds, laptops, tablets, smart IoTs products, is escalating. A typical PCB contains epoxy resin, fibreglass, copper, nickel, iron, aluminium and a certain amount of precious metals such as gold and silver; and solder, which contains lead and tin. The devices release toxic gases into the atmosphere or seep into groundwater. This environmental impact is widely documented,[34] and the rate of e-waste produced is enormous. The sourcing of metals, especially precious gold and silver, comes with destructive and hazardous mining processes, with devastating effects on local habitats.[35]

The safety issues surrounding inks and chemicals used can be seen as hazardous to human health. As printmakers often we are exposed to chemicals that have adverse health reactions, whether the spirits used to clean up ink, acids in the etching process or some of the photo-print chemicals in the darkroom. Previous blasé approaches to handling any toxic materials now seem dinosaur in the printmaking studio, and correct PPE is an absolute must.

However, at this point it has to be noted that the chemical and environmental impact of pulp production and paper waste once occupied this hazardous space. With the chemical bleaching of pulp impacts on local water sources or the tons of wastepaper produced. Today there are strict measures on pulp mills. However, the impact is still evident – it is more a case of reducing them, and as with all industries the environmental impact seems inevitable.

As printed electronics give more potential for disposable devices, this raises serious ethical concerns on where this potential technology will lead us. Looking at historical trends and current trajectories it seems these technologies will only create more material waste on the earth unless careful considerations and new ways of thinking materialise. Perhaps it is impossible in the current capitalist global systems in place today. There is a potential for organic material electronics, those which use carbon or carbon nanotube printing in their processes,

28 The Future of Printed Electronics Is Copper, Copprint <https://copprint.com/> [accessed 1 February 2021].

29 The process which allows the particles to 'connect' better and allow for electricity to pass through the traces,

30 All thoroughly documented in the appendix

31 Please see appendix for a first-hand experience of this.

32 Rohinni, Rohinni (2021) <https://www.rohinni.com/> [accessed 5 February 2021].

33 For full, indepth, critical and historical arguments, as well as methods of collaboration in printmaking and case studies: Paul Laidler, 'Collaborative Digital and Wide Format Printing: Methods and Considerations for the Artist and Master Printer', 50–81; Paul Laidler, 'Collaborative Print Studio', G&e Print and Art Edition Magazine, 55, 2017, 25–41.

34 Muhammad Zaffar Hashmi and Ajit Varma, Electronic Waste Pollution : Environmental Occurrence and Treatment Technologies (Cham, SWITZERLAND, 2019) <http://ebookcentral.proquest.com/lib/nyulibrary-ebooks/detail.action?docID=5975747> [accessed 2 March 2021]; Karin Lundgren and others, The Global Impact of E-Waste: Addressing the Challenge, 2012 <http://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_196105.pdf> [accessed 2 April 2021];

35 Winco K. C. Yung, Subramanian Senthilkannan Muthu and Karpagam Subramanian, 'Chapter 13 - Carbon Footprint Analysis of Printed Circuit Board', in Environmental Carbon Footprints, ed. by Subramanian Senthilkannan Muthu (2018), 365–431 <https://www.sciencedirect.com/science/article/pii/B9780128128497000131> [accessed 3 March 2021].

Fig. 1 - Textile Sensors. Mixed Media. Kobakant. 2017

to make more environmentally sound electronic devices. Currently, multiple companies and scientific institutions that are racing to get their products complete. However, the common opinion is that this technology remains in the future.[3637]

1.4 The World of E-textiles

E-textiles or 'wearables' refers to the use of electronics in clothing and worn accessories. These are currently heavily explored by clothing labels, [38]medical technology and hobbyists. Like astronomy, it is an area where open-source and online documentation means that amateurs can contribute significantly to new discoveries. The world of E-textiles has been around a lot longer than that of printed electronics and is far more accessible to the hobbyist or maker. There is a considerable amount of literature, online, open-source documentation of wearables. Together with the rise in e-textiles and paper electronics comes a growing community of makers, a relatively new phenomenon, who share a pleasure in materials, an appreciation for technology and political rejection of the mainstream.[39] This rise of makerspaces and online collaboration and knowledge sharing can be directly compared to amateur astronomers, whose work and research throughout history impacted scientists' research, making and contributing knowledge across a large global community. [40]

Some of the most fascinating and ambitious wearable work comes from the Kobakant group in Berlin.[41] They have documented and presented not only their research but a collection from others. They are meticulous about reviewing the best tools and methods and promoting a focus on open-source, accessible, and shareable forms of knowledge. A great deal can be learned from this group and the e-textiles or wearable community online. This project, in particular, has motivated the style of documentation throughout this Ph.D.; the drive to create a similar space in which printmakers working in paper electronics can share their research.

36 Kunnari and others, 'Environmental Evaluation of New Technology', 791–99.

37 The Flexible Electronics Opportunity (Washington, D.C., 2014), 18812 <http://www.nap.edu/catalog/18812> [accessed 31 March 2021].

38 Frederic Lardinois, 'Google Brings Its Jacquard Wearables Tech to Levi's Trucker Jacket', 2019 <https://techcrunch.com/2019/09/30/google-brings-its-jacquard-wearables-tech-to-levis-trucker-jacket/> [accessed 31 December 2020].

39 Theresa Jean Tanenbaum and others, 'Democratizing Technology: Pleasure, Utility and Expressiveness in DIY and Maker Practice', in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (presented at the CHI '13: CHI Conference on Human Factors in Computing Systems, Paris France, 2013), 2603–12 <https://dl.acm.org/doi/10.1145/2470654.2481360> [accessed 31 December 2020].

40 Johan H. Knapen, 'Scientific Collaborations in Astronomy between Amateurs and Professionals', ArXiv:1101.0684 [Astro-Ph], 2011 <http://arxiv.org/abs/1101.0684> [accessed 15 January 2021].

41 Mika Satomi and Hannah Perner-Wilson, 'Kobakant Documentation', Kobakant <https://www.kobakant.at/DIY/> [accessed 16 June 2020].

1.5 E-paper and E-books

This chapter will outline another approach to interactive paper and print-based artworks: augmented reality and computer/paper interactions.[42] As mentioned in the previous chapter- technological advances in print, paper, and book arts have been slowly taken up by artists and designers. Interactive prints can consist of paper-based illustrations and graphic prints which interact with specific smart, hand-held devices. Reacting to QR-codes or certain 'readable' graphic prints, a different animation can be triggered on a camera device; in this way the digital world is colliding with the physical. David M Frohlich has been on the research team at the University of Surrey, looking at future paper and book formats since 2017. In a presentation in 2020, at the end of this research project, they discussed the findings generated by the team.[43] This webinar presents exciting opportunities for guidebooks, fiction and new possibilities for storytelling. The focus has been on providing marketable solutions for areas within the publishing industry. There is great potential to express storytelling beyond the pages of the book through digital technology. However, a counter-argument is that we spend so many hours exploring the world through our smartphones and laptops; the beauty of a physical print and a book is the escapism. It is a strange concept we experience now, especially from a post-pandemic context, that the physical could be considered as a form of escapism. Will the role of physical artwork and printed matter become more significant after spending over a year experiencing the world through our computer screens?

42 Radu A. Sporea and others, 'Next Generation Paper: An Augmented Book Platform', in Organic and Hybrid Sensors and Bioelectronics XI, ed. by Ruth Shinar and others (presented at the Organic and Hybrid Sensors and Bioelectronics XI, San Diego, United States, 2018), 37 <https://www.spiedigitallibrary.org/conference-proceedings-of-spie/10738/2320107/Next-generation-paper-an-augmented-book-platform/10.1117/12.2320107.full> [accessed 13 January 2021].

43 Webinar - Next Generation Paper: future book technology <https://surrey.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=32a09776-a75d-48dd-9232-ac700153a632> [accessed 4 March 2021].

1.6 Paper and Print; Between Craft and Technology

It is easy to forget that paper is technology; its invention shaped the world today. Paper has impacted global communication, art, hygiene, environment, water, and numerous other factors of our daily lives. Paper is made of cellulose, a fibre found in plants. This is a solid and flexible material, and when long enough fibres are woven together, the result can be a robust and wettable material. Paper in this form began in 105AD, credited to Cai Lun, a Eunuch of the Hann dynasty; he was rumoured to have been inspired by wasps making their nests.[44] In this form, papermaking was far more lightweight, transportable and storable than the bamboo slips, clay tablets, animal skins, or other forms of writing surfaces that existed before. It revolutionised communication even though its spread was not as rapid as other inventions such as the printing press; it did not arrive in Europe until the 11th century and took another two hundred years to become truly widespread. Paper has

44 James Raven, ed., The Oxford Illustrated History of the Book, First edition (Oxford, United Kingdom ; New York, NY, 2020), 35.

completely evolved over its two-thousand-year existence, from a novel technology into both a mass-produced industry of cheap disposable commodities and a delicate art form. Artistic paper, the type found in Japan and East-Asia, made by hand into large, delicately crisp, translucent sheets, is elegant and beautiful enough to transcend the role of a mere surface for artwork.

The invention of using a woodcut to print onto this new surface followed soon after,[45] with the earliest woodblocks dated from 220 AD. The original woodcut prints in China served as a means of reproduction to copy and replicate paintings. However, it was in Japan it became an art form.[46] This can be viewed as an early beginning of the division between print and printmaking. One discipline is for a reproductive purpose and the other an artistic purpose, yet they are linked by their roots, and born at the intersection of craft and technology.

The work presented has always tried to embrace and acknowledge the craft of a process and a similar appreciation of the significance of craft in modern forms can be exampled in the following example. In his talk on the Seven Lamps of Design, Dean Brown discusses the projects that come out of these makerspaces, are often kitschy reproductions (such as 3D Yoda heads), which are often for the sake of creating quick tests of materials.[47] In this project, he challenges himself to take John Ruskin's Seven Lamps of Architecture[48] to inspire him to make seven lamps, which followed the principles which guided Ruskin: Sacrifice, Truth, Power, Beauty, Life, Memory, and Obedience. This was his challenge to employ this 'maker' style with a new approach, avoiding the cheap, quick and unimaginative trends which he saw coming from other maker studios. This project has greatly influenced the direction of the thesis and outlined throughout this section and the following chapters, the body of created work aims to respect technology and craft– whether the historical traditions of papermaking or the new potentials of electronic components.

The following section will consider the boundary of astronomy and astrology in the same manner of print and printmaking - two separate disciplines born out of the same foundation.

45 There are examples of prints onto textiles in Ancient Egypt, which date around 300BC. As referenced in Tsuen-hsuin Tsien, Paper and Printing, Zhongguo Zhi Ke Xue Yu Wen Ming ; v. 5, Pt. 1 (Cambridge [England] %3B New York, 1985), 310–11.and King, 'Gilding Textiles and Printing Blocks in Tenth-Century Egypt', Journal of the American Oriental Society, 140/2 (2020), 455.

46 Rebecca Salter, Japanese Woodblock Printing, 2013, 9.

47 Dean Brown, '7 Lamps of Making', 2015 <https://www.youtube.com/watch?v=Wv9wQUP5gvE> [accessed 23 February 2021].

48 John Ruskin, The Seven Lamps of Architecture, 2016.

Now that the technology has been introduced, the conceptual framework will be discussed. The following chapter merely sets the scene and presents the scientific and philosophical theories that have inspired the artworks.

Firstly, this chapter will paint a broader picture, looking at the link between ancient astronomy and art. It will then focus on the Sound of the Spheres, an ancient theory that linked music and art and has continually been reimagined by scientists and artists. The following section will also touch upon radio astronomy and the sonification of stars in contemporary research. This section is not intended as a scientific or philosophical exercise. Instead, it sets the scene of the visual research, provides the centre for which the work revolves, and introduces some of the historical concepts explored.

2. THE CONTEXT
Music From Ancient Skies to Modern Science

2.1 Understanding Our World by Looking Up

Looking out towards the night sky has always been a way for humans to understand who we are and our place in the universe. A heavenly hunt to understand ourselves. In history, astrology and astronomy went hand in hand. Today, the stars still have the same mystery for us on earth; astrology's pseudosciences seek to provide comfort, UFO conspiracists demonstrate society as distrusting of government and those in power, so much so that many have chosen to believe the pre-Pythagorean flat earth theory. Man has continuously sought a glimmer of their own psyche in the guidance of the stars, seeking council with the night's sky, to make sense of what is around them by looking up to the universe and find codes, stories, and patterns in the night's sky.

At the birth of Astronomy, one of the oldest natural sciences, it was strongly connected to religious, mythological, and astrological disciplines, bearing no similarities to its new discipline's data-driven practices. Outside of the scientific world, our society today is still heavily influenced by these early traditions – for example, our calendar still dictates many of the West's contemporary traditions and celebrations. Astronomy also heavily shaped the world today; historical sea-faring traders, empires, slavery and exploration all relied on astronomical navigation, the marks of which are still seen today. James Cook was originally sent on a mission to observe Venus transit the sun, before discovering Australia. Along the way, he met many nations who could sail great distances, guided by stars. Astronomy not only directed our way but also guided the ritual aspects of human lives. Many early civilisations demonstrated signs of studying the night sky –the naming of the zodiac in ancient Babylonia; The Antikythera Mechanism, in Ancient Greece; an analogue computer from 150–100 BC used to make planetary predictions, ancient rock carvings found in India, depicting a supernova and star map or the highly detailed maps of the Dunhuang Star Atlas[49] and the Suzhou Star Chart (pictured). The movement of the heavens dictated the planting and reaping of crops, the many rituals and traditions that guide human life, death and much more.

Today our knowledge of the heavens has come on leaps and bounds since that one small step. We have found life outside of our own planet, explored dark holes and pulsar stars through radio technology and can create simulations proving the existences of dark matter and unknown pieces of the universe. Looking outwards has also

49 J. Bonnet-Bidaud, Francoise Praderie and Susan Whitfield, 'The Dunhuang Chinese Sky: A Comprehensive Study of the Oldest Known Star Atlas', 2009.

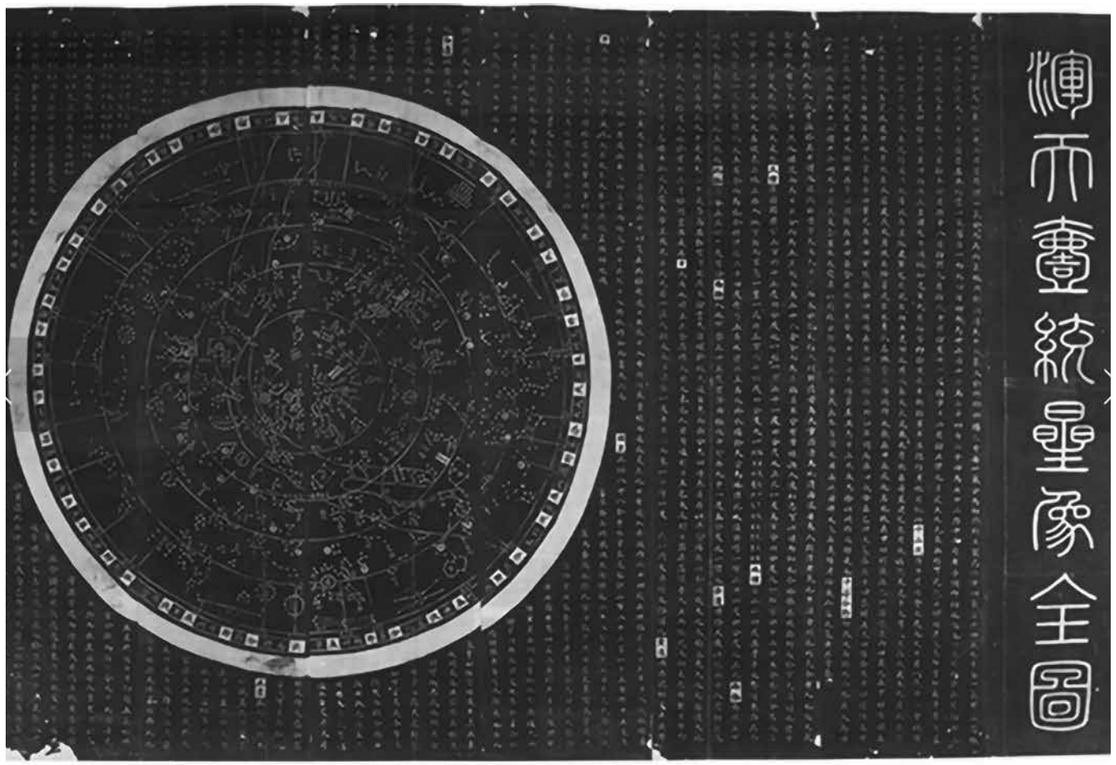


Fig. 3 - Suzhou Star Chart Rubbing. Stone carving by Huang Shang (c. 1190). rubbing by unknown (1826)

led to a greater understanding of ourselves; the invention of the telescope and the microscope happened within a decade of each other. Astronomers Ptolemy and Kepler, were as fascinated with looking up as with the act of looking itself and the mechanics behind the optical vision.

Nowadays, we can still see this fascination with the night sky and using GPS and satellites, and we are once again being guided by what is above us using our heavens to understand what is going on better in our world. With the 2020 outbreak of the coronavirus, the New York Times reported a distinct increase in Astrology articles traffics and people online seeking out the answer to their lives through the stars.[50] Whether driven by boredom or hermeticism, this re-infatuation with the heavens demonstrates our own psyche. With religion playing less of a role in Europe and the U.K. and with a global distrust of government, we find ourselves being drawn to the concept that our futures are still not entirely in our own control. If this Ph.D. paper may prove to be a little of a self-indulgent exercise, it is still relevant in many ways. These ancient theories reoccur and resurface in contemporary society, especially during turbulent and uncertain times. Just as we find recurrent themes in literature or films, ancient storytelling traditions and motives which resurface countless times, repeated and revamped, this research takes these historical motives and reimagines them in a contemporary setting.

50 Heyley Phelan, 'Will Coronavirus Kill Astrology?', The New York Times (9 May 2020) <https://www.nytimes.com/2020/05/09/style/coronavirus-astrology-predictions.html?searchResultPosition=6> [accessed 20 April 2021].

1.2 The Pythagoreans, Musical Scale and The Number Four

'Bless us, divine number, thou who generates gods and men! O holy, holy tetraktys, though that containest the root and the source of the eternally flowing creation! For the divine number begins with the profound, pure unity until it comes to the holy four; then it begets the mother of all, the all-compromising, the all-bounding, the first-born, the never-swerving, the never-tiring holy ten, the keyholder of all. [51]

There exists one theoretical phenomenon which pops up throughout history and demonstrates how entangled art and science can be, and that in Musica Universalis, or the Music of the Spheres (sound of the spheres, it has many names, but for the purpose of continuity it will be referred to as the sound of the spheres from now on). This is the concept, in simplified terms, that the heavenly bodies, our cosmos and all the particles in existence transmit a symphony of music. Well, not exactly music, but an inaudible harmony. This link between mathematics, celestial orbit and musical tone began with Pythagoras.

Born on the Island of Samos, 500BC, and probably travelling around Babylonia, Egypt and ancient Italy, Pythagoras was one of the founders of modern mathematics. He was also credited to be the first person to determine the direct correlation between a length of string and the note played when it vibrates. The tone and pitch were determined by the ratio of the length of the string. The Pythagoreans were also obsessed with numbers, both for their mathematical and symbolic purposes. It is impossible to form an understanding of the Sound of the Spheres without first grasping the symbolism of numbers, which ran through this theory and many more or the Pythagorean knowledge. To Pythagoras and his followers, everything was a number, and the universe was dictated by rational numbers. Not only this, but all numbers had an intricate symbolism assigned to them. There were many elements to the Pythagorean number theory; one example, the Tetractys, is a triangular figure consisting of ten points arranged in four rows:

51 A prayer of the Pythagoreans, Tobias Dantzig and Joseph Mazur, Number: The Language of Science, The Masterpiece Science ed (New York, 2005), 42.

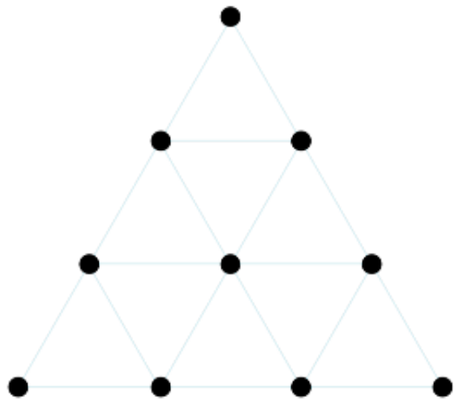


Fig. 4 - Tetractys. Diagram

(1) **Monad**- The origin of everything
(2) **Dyad** (Power)
(3) **Triad** (Harmony) had a beginning, middle, and end and was the smallest number that could be used to make a triangle - a symbol of Apollo
(4) **Tetrad** (Kosmos), the number of order, the four seasons, the states of the moon and the elements.

This "Fourthness" (tetraktýs) was, as it seems, of central importance for the Pythagoreans. As demonstrated, number theory was crucial to Astronomy and the sound of the Spheres. As was previously mentioned, to the Pythagoreans, numbers dictated our universe.

" the so-called Pythagoreans, who were the first to take up mathematics, not only advanced this study, but also having been brought up in it they thought its principles were the principles of all things ..they saw that the modifications and the ratios of the musical scales were expressible in numbers; ... they supposed the elements of numbers to be the elements of all things, and the whole heaven to be a musical scale and a number.... "[52]

As this quote demonstrates, the Pythagoreans were the first to develop the theory that musical scale and mathematics were connected. There is the story that Pythagoras discovered this concept of scale when he was a blacksmith. On hearing how the hammers had different tones, he deduced that these tones were related to the size of the hammer. The Pythagorean scale is any scale that can be constructed from only pure, perfect fifths (3:2) and octaves (2:1). So keen was he to keep this scale, this concept of ten in this system, that it affected the understanding of the universe and the Pythagorean cosmology developed in an extraordinary direction.

He observed that dividing a string by consecutive integers yields (up to a point) harmonious and pleasing musical intervals. This was the first known discovery of a musical scale; the Pythagorean was constructed from only pure fifths (3:2) and octaves (2:1). In Greek music, it was used to tune tetrachords, so once again, it was built on this concept of the number ten. The scale, ratio and decisions of this number theory have played a crucial part in the inspiration of the work created for the Ph.D. project. This is demonstrated in the works of 4.4.1 and 4.4.2. The

52 Aristotle and W. D Ross, Metaphysics (Sioux Falls, SD, 2009).

importance of number and scales which run through the pieces. The choice of the four maps, from the Tetrad. Where possible and the options arise, even numbers are made preference, with complete devotion to the number four and its multiples. The use of 64 LEDs on each side of the print = 128 in total per print. For example, in other experimentations, with the MAX7219, a chip to control 64 LEDs, which is detailed in the appendix. Trying to keep the work to fall within this number-lore, ignited by the Pythagorean. The concept of Pythagorean scale has been embedded into the audio work of the piece, which was a collaboration with Patrick McGinley,[53] and is elaborated in the following chapters.

2.2.1 Philolaus of Croton

'The doctrine of the harmony of the spheres may have had more influence on the western intellectual tradition than any other aspect of Pythagoreanism'. [54]

To Pythagoras and his followers, the solar system consisted of ten structures, revolving in circles about a central fire, each sphere giving off a sound the way a projectile makes a sound as it swished through the air; the closer spheres gave lower tones while the farther moved faster and gave higher-pitched sounds. All combined into a beautiful harmony

53 Collaborator on the musical element of the project, Patrick Mcginley is a US born, Estonian-based sound artist. Patrick McGinley, Murmerings <https://murmerings.com/> [accessed 03 March 2021].

54 Carl A. Huffman and Philolaus, Philolaus of Croton: Pythagorean and Presocratic: A Commentary on the Fragments and Testimonia with Interpretive Essays (Cambridge [England] ; New York, NY, USA, 1993).

or the music of the spheres. According to Aristotle, this astronomical system was developed by The Pythagoreans and Philolaus of Croton. It made the earth a planet and set it revolving alongside the five other planets.[55] The outer sphere were the fixed stars, and between the earth and the other rings were the sun and moon, which rotated around a great central fire. This fire was the watchtower of Zeus.[56]

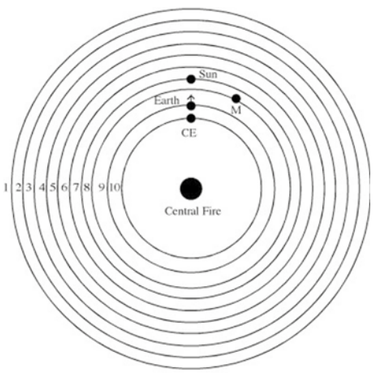


Fig. 5 - Spheres Diagram.

However, as described previously, this system of nine bodies would not make sense to the Pythagoreans. Their demand to put the number ten (the "Tetractys") into the world led Philolaus to invent second earth or counter earth. This counter-earth also continuously blocked the earth from this central fire – which explained that it was invisible from view. With this extra earth, the number ten, the sum of the first four numbers, the universe acquired a harmony made up of the musical ratios of the Pythagorean

55 Only five planets were visible to the ancients before the telescope was invented.

56 Huffman and Philolaus, Philolaus of Croton, 237–38.

music theory: 1/2, 2/3, and 3/4, and the universe made sense once again. [57]

Most of the information which we have obtained about this system comes from the writings of Aristotle,[58] however, in these works and the works of his student Alexander's Metaphysics, there is very little on the harmony and the harmonical properties which dictate the ratios of the planets. As noted by many scholars, there is no direct mention of the doctrine in the fragments, but there is strong implicit evidence that the harmony of the spheres had an essential role in Philolaus' system. Due to the lack of texts, missing documentation, and writings from this period, we do not have a clear vision of the doctrines of Pythagoras and Philolaus. This system, which was not quite, but almost a Heliocentric model, played an influence on Copernicus.[59] Its insistence on numbers, on finding a perfect order, symmetry, and destiny - telling of the human psyche. The need to find an order of a higher power and explanation even if it means ignoring scientific evidence, a common theme in the sound of the spheres.

2.3 Ptolemy, The Zodiacal Scale and Constellations

Claudius Ptolemy's Ptolemy (Claudius Ptolemaeus) lived around AD 100 to 179; there is almost nothing known about his life, except that he mainly worked in Alexandria. He is considered as a significant astronomer and an outstanding scientist, credited with the following texts: Optics (a treatise on optical and visual theory), The Harmonics (an insight into music theory and the harmonies of the universe), The Almagest (a treatise on the motions of the stars and the planets), Geographia, (a collection of coordinates and maps of all the known Roman empire). These four texts can be seen as an attempt to explore all aspects of the physical world entirely, and Ptolemy, like the Pythagoreans, continued this hunt for the harmonies found in the universe.

The two texts, The Harmonics[60] and The Almagest[61] are of particular interest to this thesis. In the Almagest Ptolemy catalogued over 1000 stars. In this text, he named forty-eight constellations. Most of these were taken from previous Greek and ancient Babylonian systems; however, he provided crucial documentation of these. Full of scientific errors, miscalculations of distances and inconsistencies, The Almagest puzzles many contemporary astronomers on its fidelity[62] and location.[63] Still, this work is more suitable as an account of ancient Greek thought than accuracy. Scientists have also seldom considered The Harmonics, and instead, it has been considered for its contribution to music theory and impact on renaissance music theory.

57 According to Aristotle's theory for the addition of the centre-earth. Huffman and Philolaus, Philolaus of Croton, 141.

58 In Aristotle's treatise on the heavens, 'De Caelo'.

59 Owen Gingerich, 'Did Copernicus Owe a Debt to Aristarchus?',
Journal for the History of Astronomy, 16/1 (1985), 37–42.

60 Jon Solomon, Ptolemy Harmonics: Translation and Commentary. (Leiden, 1999) <https://public.ebookcentral.proquest.com/choice/publicfullrecord.aspx?p=5740154> [accessed 9 May 2021].

61 Ptolemy and others, The Almagest: Introduction to the Mathematics of the Heavens, 2014.

62 Many belief that the work was taken from previous Hyparchus's observations.

63 James Evans, 'On the Origin of the Ptolemaic Star Catalogue: Part 1', Journal for the History of Astronomy, 18/3 (1987), 155–72.

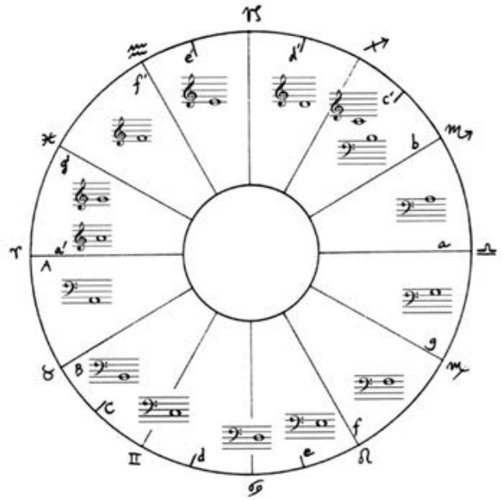


Fig. 6
- Ptolemy Tone Zodiac. Johann Friedrich Wolfgang Hasler. 2011

In Harmonics, Ptolemy related musical harmonies to the properties of mathematical proportions, building on many of these theories developed by Pythagoreans centuries before. He thought that those harmonies were found in all aspects of the physical universe, in both the planets and the human soul. Ptolemy argued the two highest senses, sight and hearing, were the only two senses which can determine beauty and power, and both are fundamental to the sciences, mathematics and arts. [64]

There was no distinction between astrology and astronomy in this ancient world. So there is little scientific theory that still stands within Ptolemy's Harmonics. However, it lays an exciting ground for musical and artistic experimentation. The focus of this thesis is not the audio work, so the works developed from this, for this project, were created by collaborator Patrick Mcginley and are further described in 4.4.2. Much of this audio draws from the thesis and framework developed by Johann Friedrich Wolfgang Hasler.[65] In this body of research, JFWH investigates many ancient concepts of music and astronomy, including that of Pythagoras and Ptolemy and even Cabalistic ideas. Mcginley combined the scales and harmonics from the structure of these texts with the tones and drones, VLF radio and recordings from his practice.

The Geocentric Model, defined in Ptolemy's writings, remained the guiding principle for astronomy for over a thousand years. His texts were transcribed and translated and finally put into print at the end of the 15th century. Thanks to the printed copies of Ptolemy, Copernicus and later Kepler and Tycho Brahe were able to develop their observations.[66]

2.4 Kepler; Between Ancient and Modern Astronomy

Over 1500 years after Ptolemy, when the printing press was truly impacting the Scientific Enlightenment, Kepler wrote his Harmonice Mundis.[67] Kepler was both a severe astronomer and astrologer. He was working on the complicated mathematics of planetary motion alongside

64 Andrew Barker, Scientific Method in Ptolemy's Harmonics (Cambridge ; New York, 2000), 264–69.

65 Johann Friedrich Wolfgang Hasler, 'Towards Hermeticist Grammars of Music : A Proposal for Systems of Composition Based on the Principles of the Hermetic Tradition, with Musical Demonstrations' (Newcastle University, 2011).

66 Elizabeth L. Eisenstein, The Printing Press as an Agent of Change (New York, UNITED STATES, 1980), 575–635 <http://ebookcentral.proquest.com/lib/nyulibrary-ebooks/detail.action?docID=1543494> [accessed 9 May 2021].

67 Johannes Kepler, Harmonice Mundis (Linz, Austria, 1619).

creating readings and predictions for extra income.[68] We find one of the final moments when astrology, alchemy, and what we consider true sciences still intermingled at this point in human history. Kepler was a fascinating scientist. Many of his critical theories on planetary motion have stood the test of time; his adaptation of the Copernican model , which replaced the circular motions of the planets for the more accurate elliptical motion, is still recognised today. However, he existed at a crossroads between antiquity and scientific models. It was Kepler's astronomical work, which contributed to astronomy becoming more scientific, and ironically, put an end to the theory of harmony, which he dedicated himself to proving.

If the scientific rationale of Ptolemy's Harmonics is disregarded today, it was irredeemable in Kepler's time. However, still, Kepler became convinced that Ptolemy held a similar argument to his own, as outlined in the Harmonice Mundis – the Harmonies of the world. Here, we see one of the final 'scientific' attempts to prove the theory of the Sound of the Spheres. He wished "to erect the magnificent edifice of the harmonic system of the musical scale . . . as God, the Creator Himself, has expressed it in harmonising the heavenly motions ".[69] He too, believed, as the Pythogorean's had, that there was a symphony in the heavens, whereas instead of being led by number-lore, it was instead that hands of God who was creating this symphony. He was trying to find the link between astronomy and a higher creator, looking at space as a model to prove the existence of God.

After the publication of his Mysterium Cosmigraphicum[70] he was invited to meet with Tycho Brahe in 1600, a year before Tycho's death. This meeting prompted Kepler to become Tycho's assistant in Prague. Tycho had spent his life's work collecting a meticulous star catalogue of over 1000 items (to match that of Ptolemy's). After his death, this catalogue landed in the hands of Kepler, and with this, he was able to chart the movement of Mars and deduce the elliptical form of its orbit.[71] Many of the works created during this doctorate are a tribute to these pre-telescopic star maps of Tycho Brahe and Ptolemy and The Uranometria.[72] The Uranometria was an atlas produced by Johann Bayer, published in Augsburg in 1603 by Christoph Mangle. It contained all the 48 Ptolemaic constellations and was based on the maps of Tycho Brahe. Drawn on copper plates, this is an artistic representation of the scientific documentation of astronomy.

If the print phenomena surround communication, astronomy is vastly connected to print art and printed words. From human beginning, the carving of the first constellations happened in stone tablets in ancient Babylonia and was deeply tied into the transformation of language and writing.[73] The scientific community was quick to recognise the impact that the introduction of the printing press and its revolution was having on the advancement of knowledge. The printing press gave way for the shedding of many ancient scientific and astronomical theories. The history of paper, print, and the sciences are deeply intertwined, and the exploration of one through the other appears most natural.

68 It is debated whether Kepler genuinely believed in the scientific accuracy of these readings.

69 Johannes Kepler and others, The Harmony of the World, Memoirs of the American Philosophical Society, v. 209 (Philadelphia, Pa., 1997), 2–5.

70 J. Kepler and E.J. Aiton, Mysterium Cosmographicum: The Secret of the Universe, Janus Series (1981) <https://books.google.ee/books?id=SHSktAEACAAJ> [accessed 2 February 2021].

71 Mario Livio, The Golden Ratio: The Story of Phi, the World's Most Astonishing Number, 1st ed (New York, 2002), 150.

72 Johann Bayer, Uranometria: A Reproduction of the Copy in the British Library, [Nachdr. d. Ausg.] Augsburg, 1603 (Alburgh, 1987).

73 J. H. Rogers, 'Origins of the Ancient Constellations: I. The Mesopotamian Traditions', Journal of the British Astronomical Association, 108 (1998), 9–28.

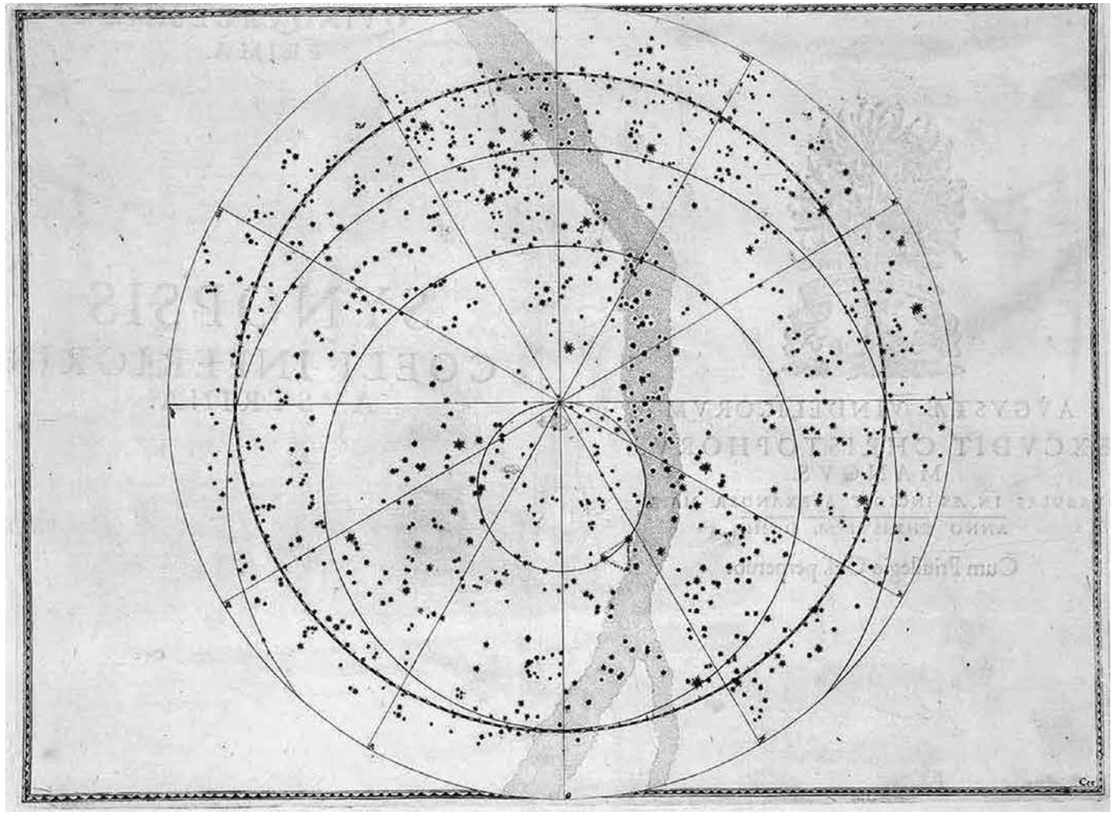


Fig. 7 - Bayer's Uranometria. 1603

As we move into the age of the digital, the works in the thesis reimagine the historical, alongside the contemporary and intermingles communication with storytelling to create innovative, artistic experiences.

2.5 Contemporary Approaches to Astronomy

Here the world jumps forward to a contemporary exploration of the stars and the skies in the hope of reaching out to new planets, ones that look more like earth and bear the possibility of life. It is a time after Carl Saigan popularised the NASA photograph – the Pale Blue Dot,[74] when we are beginning to comprehend our place in this universe is becoming ever more insignificant and minute. It is a time when traditional telescopes can no longer tell us what we need to know, and astronomers seek multidisciplinary approaches to understand the skies. This is the second influence for the work created and takes these ancient theories expressed in the earlier chapters and puts them into a modern context. The same ideas draw parallel in the medium of the Ph.D. practice. The use of ancient techniques – that of papermaking and printmaking, which stems back to the 1st century B.C., and embedding it with electronics and modern tools. Again, as with the previous chapters, this is not seeking to prove a scientific theory or present an in-depth investigation into the field of contemporary astronomy but rather present the context and inspiration for which this work sits.

Astronomy is a field where, akin to printmaking, collaboration is critical. The unique nature of this science has meant that amateur astronomers with home-set telescopes have had a crucial part to play in the data collection and discoveries of the skies. There have been countless global bulletins and newsletters of astronomers, amateur and professional who have shared their recordings and discoveries openly across borders. In the same way, many amateurs can now access data and observations from large telescopes – made public on various internet sites. This form of open-source and shared creation has begun to link new global communities, makers, e-textilers, astronomers, and more and more, printmakers. Even throughout times of massive global tensions and conflicts, such as the Cold War, astronomers have continued to collaborate across borders.

Until the mid-19th century (and in many of the works discussed previously), the focus for amateurs and astronomers was observational astronomy, the mapping of stars, planets, asteroids, solar flares, and other heavenly movements.[75] After this period, Astrophysics began to be an essential discipline. This change in approach to our knowledge was driven in part by developments in the 1800s in photography and chemistry, allowing for new observations of light to be collected and documented.[76] Up until this point, the work of the astronomer and the amateur was of a similar vein, however, with developments in the field of astrophysics, a need for bigger, more premium telescopes which could take in more light and more observations was required, and the gulf between the two worlds began to grow. In the same manner, as Astronomy began to leave behind its storytelling and astrological past, so too did it abandon those who took up the pursuit as a mere hobby.

74 Voyager, Pale Blue Dot, September 1996 <https://www.jpl.nasa.gov/images/solar-system-portrait-earth-as-pale-blue-dot> [accessed 2 February 2021].

75 D. Boyd, 'Pro-Am Collaboration in Astronomy - Past, Present and Future', Journal of the British Astronomical Association, 121 (2011), 73–90.

76 J. B. Hearnshaw, The Analysis of Starlight: One Hundred and Fifty Years of Astronomical Spectroscopy, 1st pbk. ed. (with corrections) (Cambridge ; New York, 1990), 23–29.

2.6 Radio Astronomy and Contemporary Explorations of Space through Sound

Since Karl Jansky's 1933 publication Radio Waves from Outside the Solar System,[77] the world of radio astronomy has allowed man to gather another form of data, rather than relying on visual means to understand the universe. This reading of radio signals has meant astronomers can access the further reaches of the Milky Way, unobstructed by gas clouds and other visual blocks. Much of this data has been sonified to create intriguing audio pieces. Many contemporary physicists and astronomers have compared it to a real-life sound of the spheres.[78] So this is where contemporary astronomy takes an interesting turn, that space is a noisy place. Perhaps this is not the same as a symphony or a harmony as described by ancient astronomers. However, today, various 'noises' have been discovered in the universe's outer reaches and on our own planet. For example, the 1967 discovery of the first pulsar by radio, in Cambridge by Jocelyn Bell Burnell and Antony Hewish. The PSR B1919+21 is a pulsar with a period of 1.3373 seconds; a pulsar is a highly magnetised rotating star, creating a series of blips; they have been compared to atomic clocks and used as a way of creating 'maps' of the universe. Nasa and the European Space Agency and various space-facing microphones offer numerous recordings and digital databases of sounds.[79] Audible whistling has been detected, ever since the invention of the telephone, electromagnetic emissions produced in the atmosphere, but their cause is still partly unclear. All of this weaves together a rich audio piece created in the works of 4.4.2. The idea of the movement of planets and stars creating noise or radio waves that can be turned into noise presents a rich opportunity for artistic exploration.

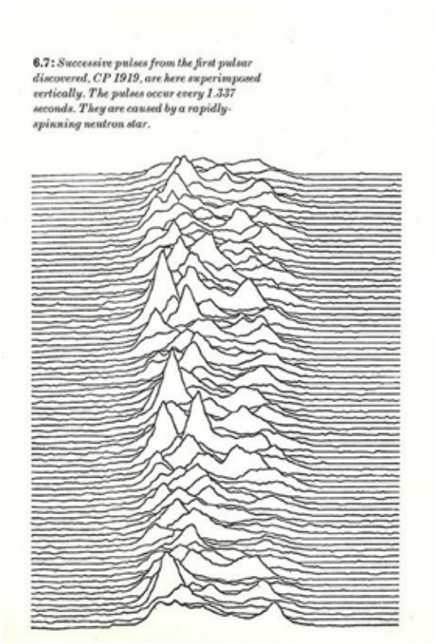


Fig. 8 - Pulsars Diagram. 1970

77 Karl G. Jansky, 'Radio Waves from Outside the Solar System', Nature, 132/3323 (1933), 66–66.

78 Donald Kurtz, The Songs of the Stars, Vimeo <https://vimeo.com/75538344> [accessed 20 February 2021].

79 Sounds from Space, Sounds from Space <https://www.esa.int/Science_Exploration/Space_Science/Sounds_from_space>. [accessed 20 April 2021]

3. RELEVANT ARTISTS

3.1 Artists Working With Interactive Installations

The following art projects demonstrate significant links between the visual and audio, the tangible with invisible and cognitive energies. These pieces demonstrate the understanding and interest of embedding the tangible and analogue processes with the digital and contemporary. The artists were selected for this section because of how they express the cold mathematical properties of computer coding within the physical warmth of the material object. They occupy a space between the historical, the craft and the technological, embracing the nostalgia of technology through the potential of new tools. Both artists exampled in this section hold communication at the centre of their focus, expressing thought and human interaction between language and music. This concept of communication, technology and music represent the key ideas of the Ph.D.

3.1.1 Peter Vance - Alphabet

Peter Vance is a multidisciplinary artist from the United Kingdom.[80] He draws inspiration from the various ways data can be transmitted, most notably inspired in this piece by the earliest computer program from 1801. This program was created for the Jacquard Loom device and formed a binary code, presented on punch cards to tell the loom what to weave. This early form of coding, which took the form of punch cards, was not solely found in textiles but commonly used in the letterpress process. During a residency at the Estonian Paper and Print Museum, he combined coding, audio, weaving and print to explore the link between language, communication and technology innovatively.

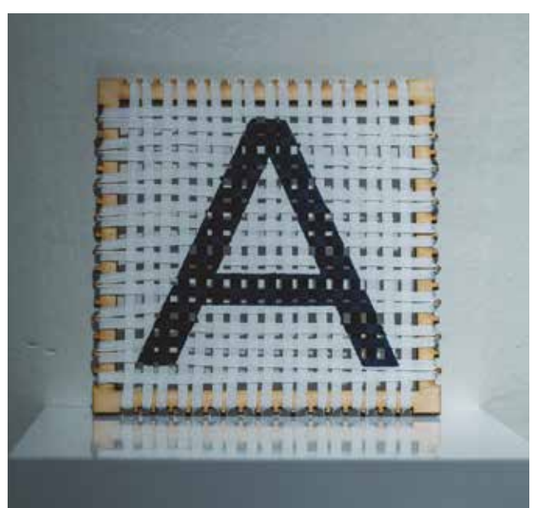


Fig.9 - Alphabet. Installation. Peter Vance. 2018

80 Peter Vance, Alphabet, January 2017 <http://petervance.co.uk/alphabet> [accessed 1 October 2020].

Frames were tightly woven with white tape, which were over printed with each letter of the alphabet. The tape was then unwound and then rewound across a frame to dictate a piece of music. This work was a truly inspired use of old and new technology, expanding the work across mediums and media; he wove an imaginative and interdisciplinary artwork that discussed data and communication.

This interdisciplinary piece covers audio, coding, computers and print. It took a two-dimensional practice and brought it across four dimensions. As the music cycles through the lines of code, there is something reminiscent of John Cage's Etudes Australes, a series of piano pieces built on the skies' star charts. I would argue that this is a unique example of how print and electronics can complement each other. The concept is intertwined, and the work benefits from this multidisciplinary approach. The fact it was created in a printing museum, a place of cultural heritage and the keepers of communication history, impacts the work's conceptual framing. The work is most inspiring to my own practice because it explores historical forms of communication and the concept of dissecting the alphabet, which is a code of symbols and communication representation. The methods in which this is then translated and abstracted to form the musical code and scale draw parallels to the works presented in chapter 4.

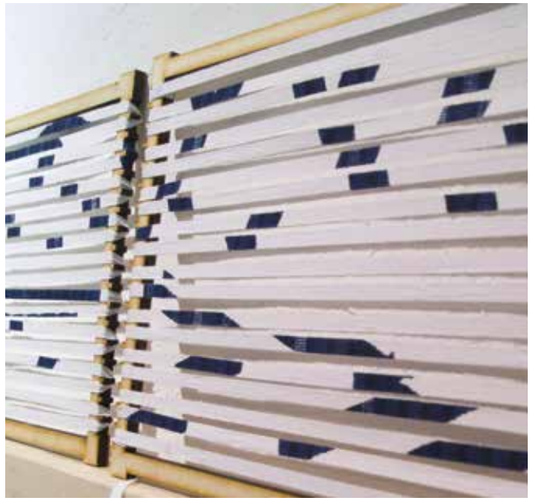


Fig. 10 - Peter Vance. Alphabet Exhibition. 2018

Fig. 11 - Peter Vance. Alphabet Exhibition. 2018

Fig. 12 - NeuroKnitting Beethoven. Performance. Varvara & Mar. 2020

3.1.2 Varvara & Mar

Varvara & Mar is an artist duo formed by Varvara Guljajeva and Mar Canet in 2009. The duality of artistic forms of digital making inspires them. Their works investigate the social changes and impact of technology, and they often employ artificial intelligence, kinetics, participation, and digital fabrication. They are included as an example, as they acknowledged the physical object's tools, craft, and materiality through digital tools. They have been an inspiration on the research presented here, not because it is linked in style, but rather in ethos. This thesis follows a different line of inquiry but is bound by the same thread. This can be seen in pieces such as 'The Rhythm of the City' and their 'NeuroKnitting' project. The concept of using digital technology with traditional forms of making and playing with the characteristics of each medium to exploit them to their full potential.

NeuroKnitting[81] is a long-term project which was recreated to celebrate the anniversary of composer Ludwig van Beethoven by reimagining his music through the creative application of brain waves and knitting. The piece consisted of a Beethoven piece played by a pianist in both Hong Kong and Seoul. In Seoul, the readings were measured from a Buddhist monk's brain; his neural brain waves were recorded as playing the music that dictated the pattern and speeds created by a knitting machine; the higher is the attention, the denser is the pattern; the faster knits the machine. All these processes were real-time and took place simultaneously. This knitted representation of data, generated from thought patterns, try to make sense of the incomprehensible. The thought patterns of human beings, the subconscious and psyche seem to be immeasurable and something out of the grasp of science or human comprehension. This takes this phenomenon, transfers it into data and then into something tangible. It is an exciting concept to appropriate a knitting machine, a strange piece of technology, to embrace its potentiality and creating visible works of art. There is the same goal within my work – to engage with the audience on another level of interaction.

3.2 Artists Working with Space and Sound

These are examples of artists who have explored space through sound experiments. They have built their tools, machines, or what could be considered instruments to capture other worldly noises. When looking upwards, both projects tell stories of our own planet and are captured from their near surroundings. It emphasises that space is almost a giant mirror and what we are looking and listening for up there is resonant of our existence on earth.

3.2.1 Stephen P McGreevy

Loosely related to the world of radio astronomy is Stephen P Mcgreevy, an American sound recordist. He was born in 1963 in California. He most notably built many of his instruments and tools for collecting ELF (Extremely Low Frequency) recordings of natural processes of nature, such as the Aurora Borealis and lightning storms. [82] He tries to understand our world through radio recordings further. He provides access to sounds, recordings, and documented journeys, and even schematics of his home-built radio devices on his online site.

The vast collection of audio recordings span decades, and the website is a collection of audios from numerous continents and countries. The audio samples all contain a mix of the author's notes, time confirmations and sound checks. With the distinctive glimpses of radio audio playing The Beachboys, Mozart is cut with strange sounds of the planet, strange hissing and high pitch whistling. They are the resonance of the earth and radio frequencies from planetary and solar disturbances. Storms, the aurora and even events on the sun that impact the radio waves heard on earth. Building his tools to collect these unique sounds, his work is a multidisciplinary exploration of our planet's audio and radio waves, exploring the invisible sounds which buzz

Fig. 13 - Machine 9. Project Adrift. Audio instrument and installation. Nick Ryan. 2017

and surround us. This work has directly impacted the sound pieces created, taking inspiration from his collections and his approaches. The idea of the handmade radios, which draw parallels to amateur astronomy and the shared knowledge of the maker community.

3.2.2 Adrift, Satellites and Space Junk

The Adrift project used an electromechanical instrument to transform the silent movement of 27,000 pieces of space junk into sound. In this collaboration between Cath Le Couteur and Nick Ryan,[83] the aim was to connect with as many viewers as possible on the subject of space debris. They wanted to present to a broad audience and connect personally with them on this growing yet invisible issue. The project became a multi-platform project with a documentary. However, this will focus on the sound-instrument, 'machine-9', which Nick Ryan created as a way of 'giving voice' to the otherwise silent pieces of debris orbiting earth. In the film , he describes the immense power

81 Varvara & Mar, Neuroknitting <https://var-mar.info/neu-roknitting-beethoven/> [accessed 18 December 2020].

82 Stephen Mcgreevy, 'Auroral Chorus', Auroralchorus.Com, 2021 <http://www.auroralchorus.com/> [accessed 12 February 2021].

83 Adrift: The Secret World of Space Junk, Adrift: The Secret World of Space Junk, Adrift: The Secret World of Space Junk, 2011 <http://www.projectadrift.co.uk/> [accessed 2 March 2021].

that much of the debris has, moving at an incredible speed across the earth's atmosphere, yet being in a vacuum so producing no noise.

As with Varvara & Mar, Ryan talks about turning a cognitive data process into a sensory exploration. This project was also a collaboration across public members, who were invited to send objects that represented their idea of space debris. With these pieces, Nick Ryan created a compilation of audio collated from the sounds and used this in the instrument. Nick collaborated with an engineer – the instrument was based on an old phonograph system – with numerous audios engraved into the cylinder- similar to an old record. The arms would move across the different audio tracks, depending on the debris overhead at that time.

Like many of the projects exampled in this chapter, demonstrate a need to explore a concept, ideas, invisible though the tangible, the real. The phonograph was chosen as it was the most tactile method of recording music and noise. Knitting, letterpress, books and phonographs, all the artworks in this section deal with the physical, tactile and nostalgic implications of historical forms of technology. Within the practice and examples in chapter 4, I attempt to use similar collaboration, whether collaborations with communities and participants or with other engineers. This idea of taking an abstract concept, in this case, space debris, and presenting it through an audio-visual experience, hugely inspires the works below. Whether this is the sound of the paper mill in the Resonance of Waste (chapter 4.3.2) or collecting stories from a community in Reframing Southmead (chapter 4.1.3)

3.3 Artists Working with Electronic Ink

The following three artists present many different approaches to electronic printmaking. They present very different approaches and materials demonstrating the opportunities with electronics inks in printmaking.

3.3.1 Jono Sandilands; Playable Prints

Jono Sandilands is an artist and designer from the Shetland Islands in Scotland. The act informs of play and games his work within his printmaking and technology. During a 2016 residency at the Pervasive Media Studio at the Watershed, Bristol, he developed the playable prints project. Here he investigates how a print object can be brought to life by integrating a screen or incorporating e-ink. His prints always have a fun and bright aesthetic, avoiding the formality and severity of the classic printmaker.

Fig. 14 - Playable Prints. Mixed Media. Jono Sandilands. 2016

Fig. 15 - Jono Sandilands. Connect Four. 2016

In the Playable Prints series,[84] he takes on the classic games of pinball and Connect-Four. He adapts these classic games from the physical – pre-screen games, made up of balls or plastic markers and embeds these into his prints. The pinball prints are created with a screen-printed image onto paper or card and pinball screen embedded seamlessly into the print. The frame has been inserted with two game buttons, which control the pinball game on the screen. The idea is to play a game with this work of art.

Connect-Four uses conductive ink to paint capacitive sensors in the paper itself. Using basic red or yellow LEDs behind the paper, the players can operate the game board. Both prints/games use a cleverly designed yet complex form of exploring these technologies. They are also simple and minimalist, without overly heavy concepts, but with a great design, execution, and planning. These ventures into the field of electronic ink present the potentials and embrace nostalgia, printmaking and touch.

84 Jono Sandilands, Work Art Play, 2021 <http://www.jon-osandilands.com/>. [accessed 2 March 2021].

3.3.2. Contours

This sculptural structure of large hanging fabrics covered with interactive ink, is inspired by the Wiener Werkstätte – a workshop in Vienna, often seen as a precursor to Bauhaus. It investigates the potential of an intelligent tapestry, which senses its audience and surroundings. This was created by Sheets of Tyvekt that were covered by capacitive sensors linked by painted conductive ink; the sensors react to the energy flowing from human bodies without needing to be touched. The designers Fabio Antinori and Alicja Pytlewska built this construction with traditional, non-conductive screen-printing paint which results in an interface that retains a certain haptic quality and enables visitors to interact

Fig. 16 - Contours. Installation. Alicja Pytlewska and Fabio Antinori. 2013

Fig. 17 - Contours. Installation. Alicja Pytlewska and Fabio Antinori. 2013

with an ambient soundscape. The soundscape, which becomes audible when visitors approach the tapestries, is a generative composition based on an algorithm that employs online data streams.[85]

This, like the other projects explore the need to explore data through haptics. It questions the physical object's role in the digital era - reimagining the tapestry in this case. The tapestry reacts to a person's presence within the vicinity and tracks their movements, outputting an ambient soundscape. Within the context of my work, this was included as a demonstration of the artistic potential of electronic ink. The conductive traces create an aesthetic and shape the final visual outcome of the works.

3.2.3 The Electro Library

This project from 2016 still stands as one of the most promising and creative works of electronic book arts and printed electronics, created by Polish artist and graphic designer Waldek Węgrzyn. In this project, the artist turned the book into an interface, interacting with animations on a screen. This project could be argued as one of the first ventures into this form of print and interactive design.

Inspired by Russian Avante-Gardist El Lissitzky's The Elektro-Library, a manifesto on typography which dives into the potential structures of future books imagines in 1923.[86] In this project, Węgrzyn investigates how the book-object and digital structure of the screen can interact.

This project's documentation is incredible, from the

85 Pytlewska, Contours, 2012 <https://lattanziantinori.com/contours/>. [accessed 2 March 2021].

86 This is interestingly adapted in digital form here: Marie Otsuka, EL LISSITZKY: THE BOOK/SITE, 2016 <http://motsuka.com/lissitzky/> [accessed 11 April 2021].

Fig. 18 - Contours. Production process. Alicja Pytlewska and Fabio Antinori. 2013

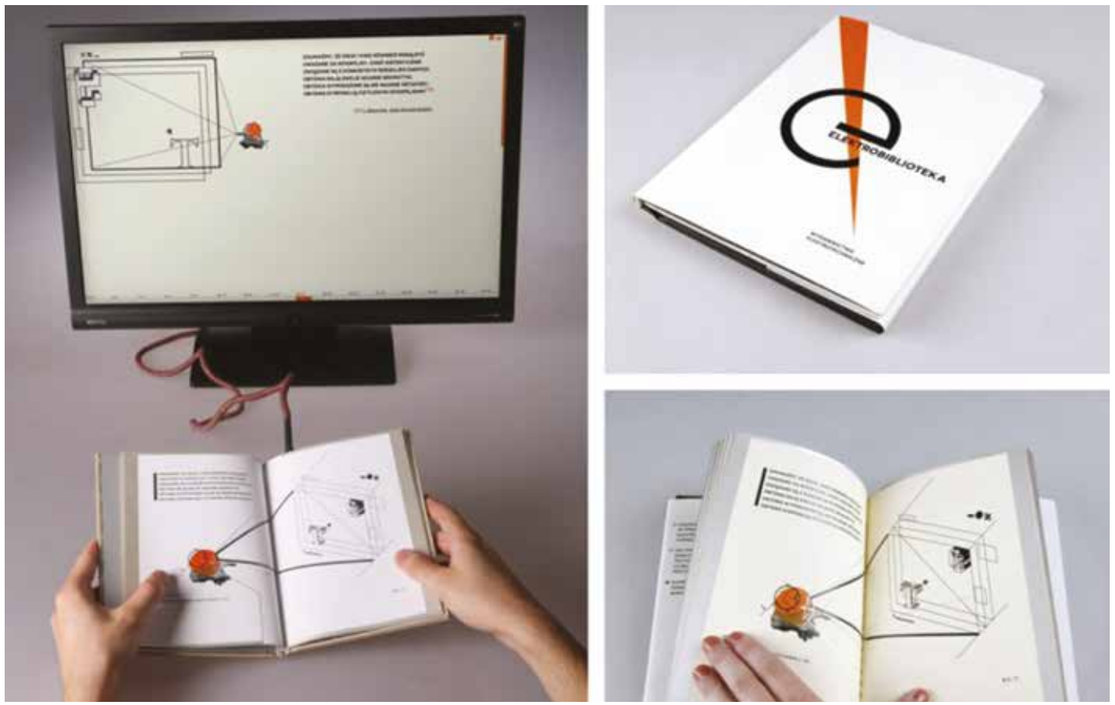


Fig. 19 - Electrolibrary. Electronic Book. Waldek Węgrzyn. 2016

online digital graphics and website to the video of the process which went into the book production.[87] It demonstrates and shares much of the research into conductive ink, as explored in this thesis. It also demonstrates Węgrzyn's knowledge of the craft of book binding and screenprinting. As a designer, he fully employs these techniques seamlessly with electronic ink and Arduino coding technology. The only difference with this project is the outcome. The interaction with the screen would be the one thing I would argue which detracts from the project. The beauty of the tangible and craft of the bookmaking is lost; our attention still lies with the moving images on the screen, something a book can never produce. However, no matter how beautiful the book is, our attention and gaze still fall on the screen. Nevertheless, the design discipline is such a strong and beautiful feature; the electronic dimension weaves itself through all the pages and the graphics on the screen.

87 Elektrobiblioteka / Electrolibrary <https://vimeo.com/47656204> [accessed 11 April 2021].

4. ARTWORKS

4.1 Supporting Pieces

The following artworks and projects have contributed to the research but are not necessarily considered as works within the Ph.D. These example the initial experiments into the process of printed electronics and book and electronic projects.

4.1.1 TranSiberia, an Interactive Book. 2017

This artwork was the first venture into paper electronics and provided the space where many of the later ideas developed. It was necessary to include this section as the initial steps taken into this field. It was created during a residency in 2018 at Laboratory in Spokane, Washington - a residency designated for interactive and installation art. [88] The proposal for the residency was to create an interactive artist book, making use of the tools and equipment they had on the residency. The artist book can be considered as inherently a space for experimentation, bound by the form of the book's constrictions, but equally informed by its form. The inspiration for this work came from both the Electrolibrary project cited above and a recent trip to Poland. The book was based on personal family history stories, one of Polish diaspora, enforced migration across Siberia, labor camps and war. The original audio which was included in the project can be found in the appendix.

Aside from taking on a novel approach to storytelling, this was a completely new way to look at electronics. In the past, previous electronic projects had involved creating moving puppets and installations.[89] The first month mainly included research, looking at how electronics could be combined with paper and print. It was a complete unknown and took the form of pure experimentation, looking at how electronics could go inside the paper. The discovery was made of thermochromic inks, [90] and the concept developed of revealing and changing images by embedding electronics between the book's pages - these would then heat up and trigger the inks. The entire process description of tools, microcontrollers, MOSFETS and diodes can be found in the appendix. However, it was found that these inks are slightly transparent and do not mask or cover another image unless applied with an extremely thick layer of paint . The inks did not work well with the traditional oil-based inks of relief or intaglio printmaking.

88 Laboratory <https://www.laboratoryspokane.com/> [accessed 20 April 2021].

89 Which can be found on www.charlottebiszewski.com

90 Thermochromics are a type of ink that changes colour or disappears when introduced to heat. The idea of hiding words, images or more underneath a layer of ink holds many exciting prospects.

Thermochromic testing

This setback shaped the approach and concept of the book, as all material restrictions do. The pages would be hand-coloured by the thermochromic inks. When the heat was applied to each page, the colour would fade, emulating a faded photograph or memory. The final idea was to create photo-realistic scenes on each page. Laser-engraving PET-g etching plates produced them. At that time, I had scant knowledge of electronic ink. The actual heating circuits were a combination of copper tape, with a high-resistance material sewn in between. These were then embedded into paper through the 'double-couch' method.[91] On the residency, during the same period, was Liza Stark, who is credited at the beginning of this Ph.D. Her work is based in the field of wearable technology, so a significant amount of influence and processes came from her and she generously shared her knowledge. In the photographs are tests created with conductive, high-resistant stainless-steel thread,

91 Here you can find an example of this method in papermaking. Katherine DeLamater, 'Couch It! Papermaking Tutorial for Embedding Materials', Paper Slurry <https://www.paperslurry.com/2016/02/24/couch-it-papermaking-tutorial-for-embedding-materials/> [accessed 30 April 2021].

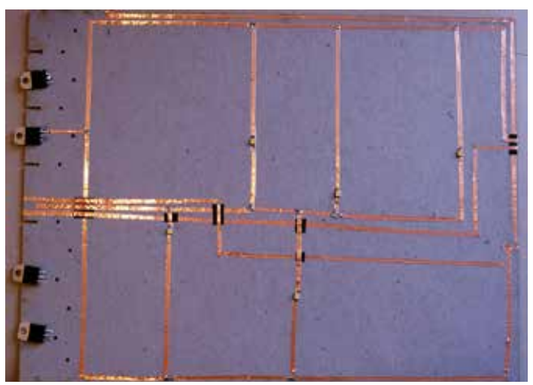
Embedding circuits into paper.

powered by a 3.3v LiPo battery. The batteries then had to be concealed somehow in the cover of the book.

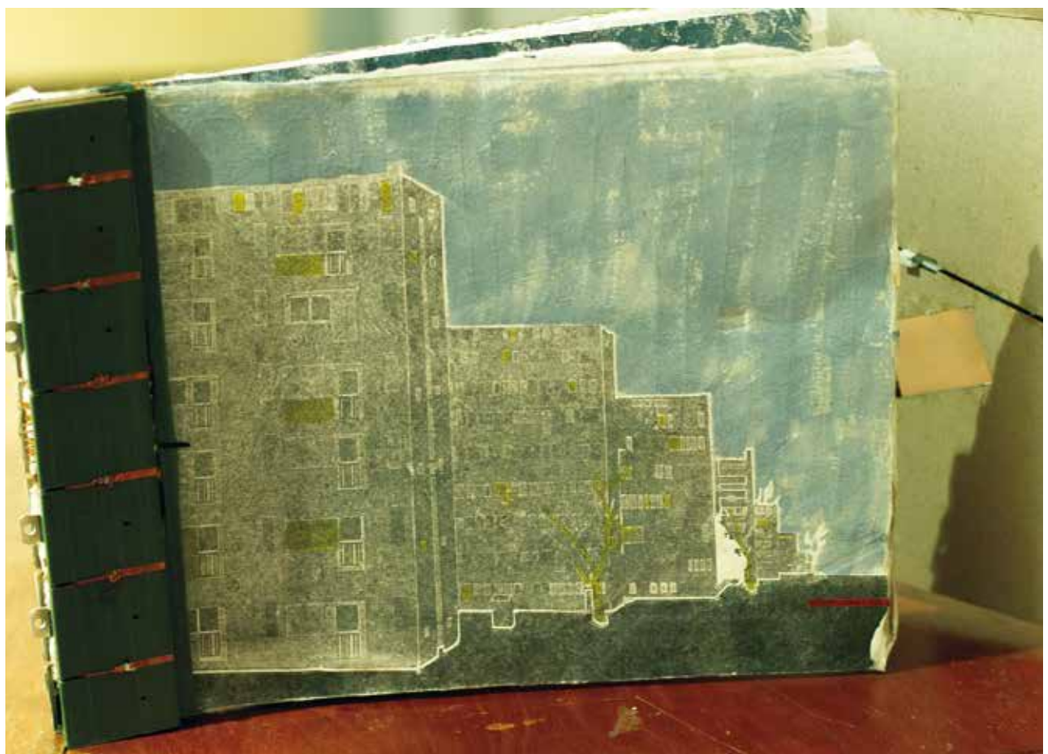
One of the conclusions reached from this line of inquiry was that the electronics themselves became a thing of beauty and integral to the aesthetic. It was more challenging to try to make works appear to be something else and to hide the electronic components. The second conclusion that came about during this process was that it was possible to incorporate my background in print and bookmaking into creating electronic circuits. Soldering and wiring had always been a problem and my projects were always prone to short-circuiting - often accidentally destroying components. Now, electronics became a part of this craft; they were no different to composing a page of letterpress type or measuring every millimeter when binding a book.

Compiling the book, these ideas of including the aesthetics of electronics were integral to the work; the idea was not to hide the components or conductive traces but to use them in the final design. The book consisted of eight pages of narrative, each of which had a corresponding audio track. The book incorporated Japanese stab binding, with a copper electronic thread connecting the heating pages to the relevant MOSFET terminals. A switch was incorporated - which was a conductive book mark – which determined the page that was open. When pressed against each page; the bookmark would send a message to the microcontroller to apply power to the relevant heating circuit and play the corresponding track. There were many issues that arose in this work and countless practical lessons to be learned. However, it was an initial baby step into a vast field, and many of the ideas have been developed later in the Ph.D.

Battery in the cover


MOSFETS and LEDS


The book spine


TransSiberia. 30 x 20cm. Artist book with electronic components. 2018

4.1.2 Speaker Books

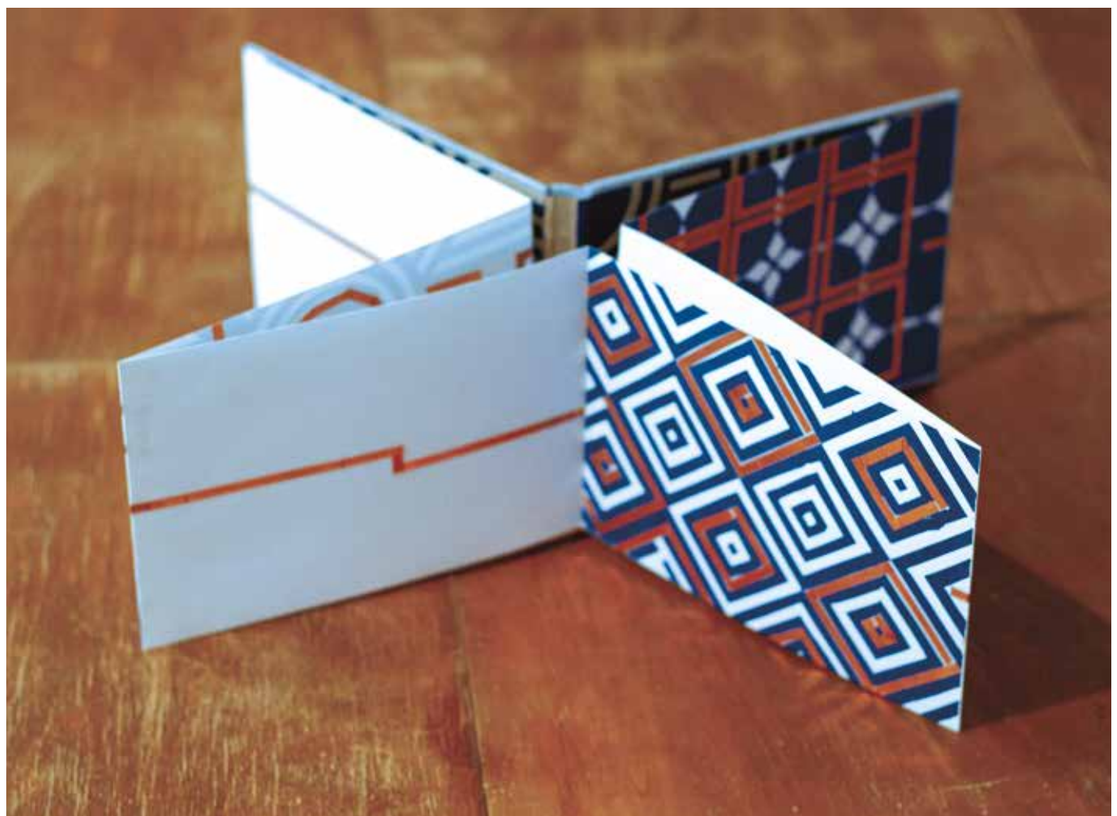
This was the first attempt to create speakers out of paper.[92] This was a short project, again in book form, conducted at the Łodz Book Art Museum,[93] in the summer of 2018. This was a chance further to explore the potential forms of the paper speaker. The work was designed to be as simple as possible, without any programming or microcontrollers required. The books consisted of a mini-amp that could plug directly into a phone or mp3 player, with a magnet embedded into the back of the book.

The front speaker was a simple copper spiral, made out of copper tape. The patterns were inspired from grates, brick and stained-glass windows from around the Book Art Museum. One issue noted was that the resistance across the speakers was too low when using pure copper tape. At this point I was learning what low resistance could do to an amplifier and a couple of components were quickly fried. Since this time, 8ohms has proven to be the standard resistance for speaker. Any more resistance and the speaker proved to be too quiet to be audible and any less there is significant risk of frying the amplifier. It taught me a great deal about how to make very simple yet effective projects, which could incorporate the visual aspects of an artist book, with electronics and audio pieces.

92 An idea which is later explored and developed in the following chapters.

93 More information about the museum and studio can be found here - J. Tryzno, 'The Book Art Musuem History', The Book Art Musuem History, 2017 <http://www.book.art.pl/index.php/en/publishing-house> [accessed 20 April 2021].

Speaker book stages



Speaker book. 30 x 15cm. Linocut,copper tape and amplifier. 2018

4.1.3 We the Curious, Reframing Southmead, 2018 - 2021

This piece was a commission for We the Curious, an interactive science museum in Bristol, UK.[94] It was a project that began before the Ph.D. and was completed during the program's final year. During this time, I worked across Southmead, an area in the outer suburbs of Bristol. Historically, Southmead was built on a garden planning structure. At the beginning of the twentieth century, this was a movement, after WWI, initiated in 1898 by Ebenezer Howard in the United Kingdom.[95] This urban planning movement aimed to relocate people from the slums of the city centres and into areas that bordered on the countryside, giving their inhabitants access to nature and away from the smog and pollution. Garden cities were a new concept, however, today there are cases of these turning into commuter towns, or neglected areas on the outskirts of the city, forgotten by the council and the investment plans of the city. As is the case with Southmead. However, within this estate, inhabitants built a special connection to the area, and this project was developed to celebrate the unique hub of the community. Back in 2018, I began interviewing people about the area and their memories. These were collected for an installation to be part of the permanent exhibition of We the Curious, in the centre of Bristol. This piece was another form of interactive storytelling, this time on a larger scale. The concept took a long time to develop, with a great deal of interaction between myself and the community groups involved in the project. The idea was to make these stories accessible to children and adults alike. The prototypes were developed with Nicholas Willsher [96] – a long-term collaborator.

Speaker test

The initial idea was to have the speakers connect to the audio through copper tracks – as pictured above or found as a working video in the Appendix blog. However, it was thought that the exposed copper traces would be too fragile and breakable. These were later revised, as the speakers and design had to be hard-wearing and unbreakable to be accessible for children.

Speaker close up.
Photo credit: We The Curious, image Julian Welsh. 2021

94 The website can be found here - <https://www.wethecurious.org/> [accessed 20 April 2021].

95 Norman Lucey, 'The Effect of Sir Ebenezer Howard and the Garden City Movement on Twentieth Century Town Planning', 1973 <https://www.rickmansworthherts.com/howard1.htm> [accessed 20 April 2021].

96 Whose works can be found at <https://niklaas.co.uk/> [accessed 20 April 2021].

This restriction influenced the final piece entirely. The team at WTC, developed the idea of having free-floating speaker devices. These work in the same manner as crystal radios.[97] The final piece was constructed by Nick Banks of W19 Design,[98] the artwork designed and printed by myself. The artwork was handprinted with letterpress type from TYPA, A centre for letterpress and papermaking in Estonia.[99] The design is found below, and the video of the piece in action can be found in the appendix online.

Testing with the community

Full installation. Photo credit: We The Curious, image Julian Welsh. 2021

97 A general description of crystal radios and how they work can be found on Wikipedia: Crystal Radio, 2021 <https://en.wikipedia.org/wiki/Crystal_radio> [accessed 6 May 2021].

98 Nick Banks, 'W19 Design' <http://www.w19design.co.uk> [accessed 6 May 2021].

99 More information on TYPA <http://www.typa.ee> [accessed 6 May 2021].

Reframing Southmead.
Letterpress and sound installation
3 X 1.5m. 2021.

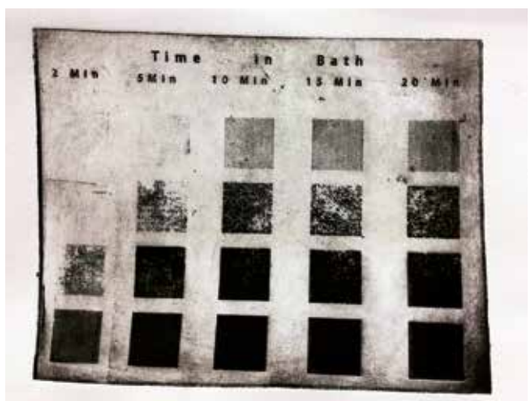
4.2 Printmaking Works

The following prints are experiments into post-digital printmaking processes. They have been created using modern and historic hybrid tools or completely obsolete equipment. The idea behind these works is to push the potentials of post-digital printmaking to its limits, to see just how integrated these contemporary tools can be with traditional techniques of printmaking. The pieces hope to embrace the limitations and features of the mediums presented - to create innovative new works that sit between contemporary and historical printmaking.

4.2.1 Doomsday Clock

This print was part of an international print exchange., 'The State Of...'[100] The print exchange drove the desire to create a piece which furthered the experimental potential of the post-digital print techniques outlined in chapter 1.2. The work was inspired by a controversial binary clock built for Southmead Hospital,[101] an expensive artwork commissioned by a struggling NHS, which bore no reflection on the local area, nor was readable to the general public. With this work, the aim was to create something unreadable and irrational, as a commentary on the absurdity of art and an excuse to play with technology. The piece worked with laser – etching, a technique which has been developed, but not commonly used or documented. There are examples online , however not within the printmaking process.[102] The complete documentation of this process can be found in the appendix.

Most lasercutters cannot directly cut into metal, so to get around this the laser had to lightly engrave a ground and then submerge the plate in acid. The zinc plates were degreased and then coated in a spray paint designed for cars. There was a certain amount of skill and practice required to get an even coating of spray paint. The plates were then cut on the Trotec laser cutter. Below are some of the images of plates that sampled different textures produced.

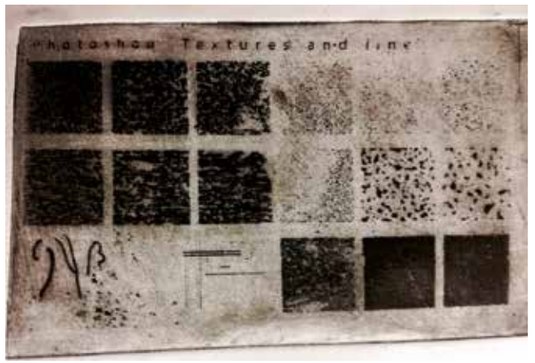


Testing plate

100 An example of the exhibition in Belfast - <https://www.bpw.org.uk/content/state-print-exchange-exhibition> [accessed 20 April 2021].

101 Tobias Rehberger, Atrium Art, Southmead Hospital, 2014 <https://www.nbt.nhs.uk/atrium-art> [accessed 20 April 2021].

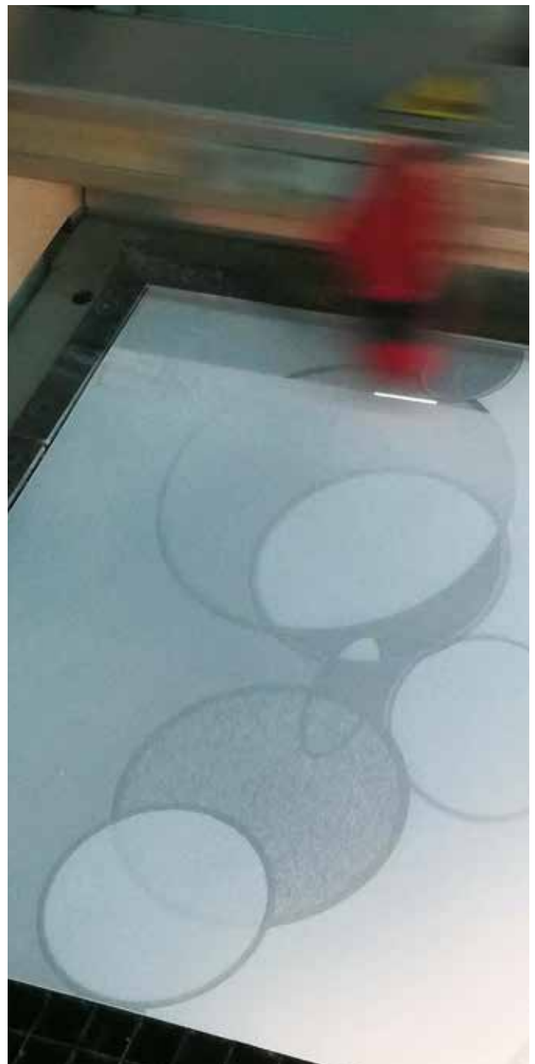
102 Michal Curry, Etching Brass Using a Laser Cutter and Spray Paint, 2016 <https://www.youtube.com/watch?v=KT6XN-3Nc9Kc> [accessed 20 March 2021].



Testing textures

The first images were produced using greyscale rather than a bitmap, so they lack control over dot-size and texture – they were created with the automatic handling of greys by the Trotec program. The second employed the colour half-tone and mezzotint functions of Adobe Illustrator.

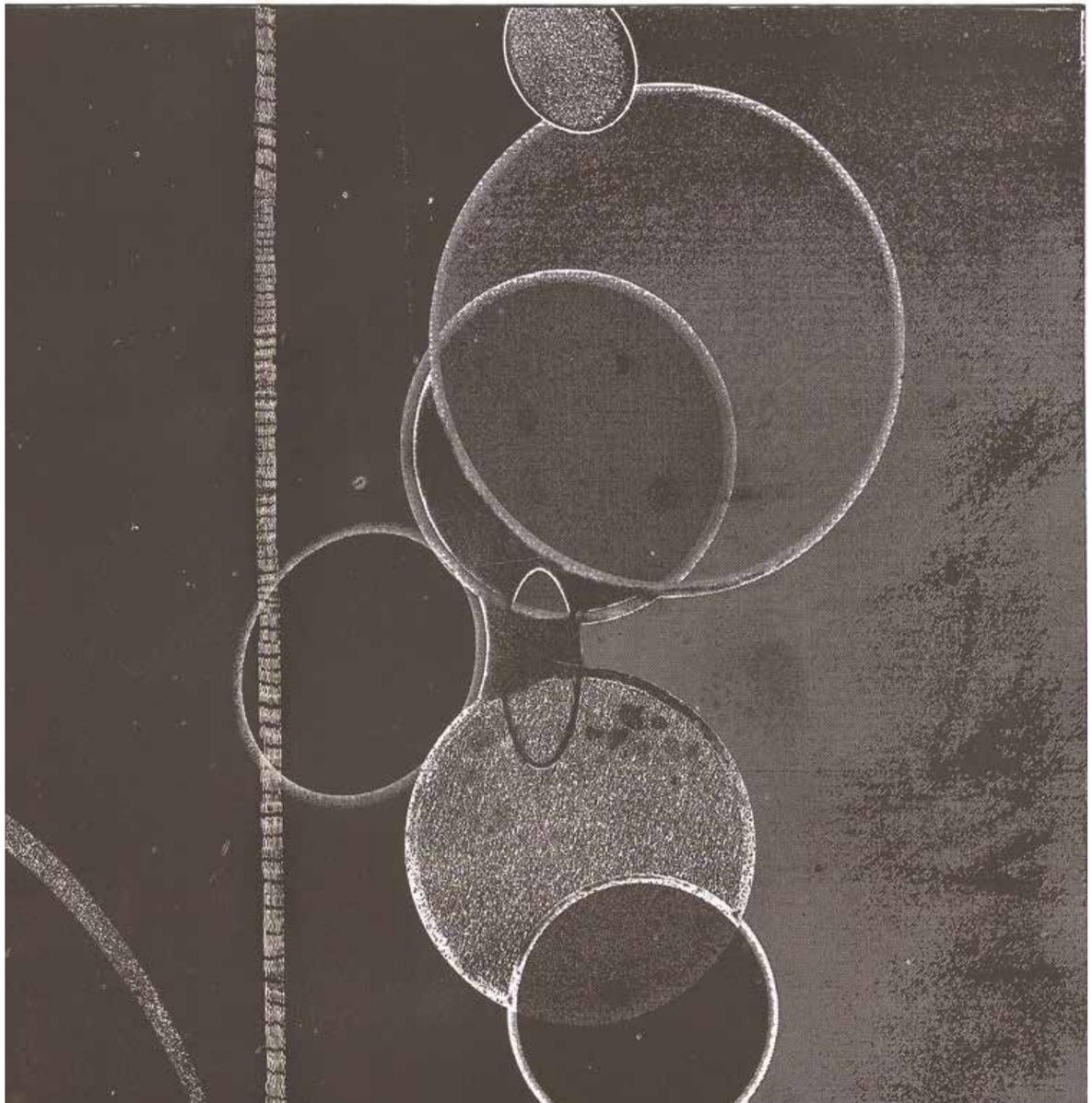
In order to get a clear, etchable image, the laser cutter needed to double etch the image on a low setting. It was best to remove residue in a bath or water and softly wipe as this created uneven images.The etching bath was a standard saline and copper sulphate solution. However, some foul biting occurred after about five minutes which could be fixed with experiments with different paints or a thicker coating or spray paint. There were also issues with how the printing plate was washed to remove any spraypraint residues and even with degreasing thoroughly, there were still problems with achieving an even etch.



Laser etching plate

Laser etching process

Laser etching in bath



Doomsday Clock. 30 X 30cm. Laser etching. 2020

Although designed to be intaglio, the final image was in fact, printed in relief. With the intaglio process, it was tricky to apply ink into the plate's bitmap surface, and often the silk used to apply and wipe away ink would become shredded. The relief process, with careful inking, was far more successful in capturing the fine details. The final effect was a combination of fine bitmap with all the haptic qualities of traditional printmaking.

This piece was then taken into a whole series of zinc etchings, done with the same process. The original images were from star maps from the Tartu University Observatory, from a collection of negatives taken from the Lithographic process of reproducing the Atlas of Star of the Northern Hemisphere in 1855.[103] The large transparencies from the lithographic stones were photographed on a 20th-century pre-press camera of the TYPA - the print museum in Estonia. From this process, many negatives were created, which were digitally scanned and converted in photoshop.

However much I enjoyed and appreciated the final image and the process, I still prefer working with my hands. Etching the plates on the lasercutter was a long and fume-filled technique. The final result was very aesthetically interesting, however, the works did not have the same feeling of life as the hand-drawn star maps, which provided much inspiration. In the final works, the decision was taking to create the large woodcuts by hand and avoid digital image creation where possible.

103 F. W. A. Argelander and others, Atlas des nördlichen gestirnten Himmels für den Anfang des Jahres 1855. Atlas der Himmelszone zwischen 1° und 23° südlicher Declination für den Anfang des Jahres 1855 : als Fortsetzung des Bonner Atlas der nördlichen gestirnten Himmels -- --, 1951, /z-wcorg/.

- Laser etching star map 1. 25 X 75cm. Laser etching. 2020

N°40. 50X 70cm. Laser etching into paper. 2020

4.2.2 Star Maps 40, Lasercuts in Space

This experimentation with lasercutting and the printed matrix extended through this series of prints; turning the paper itself into the print matrix. Using the same star designs from the maps found in the University of Tartu's archive. The idea behind these 'prints' was to take the paper's surface beyond its role as a surface and make it an integral feature of the artwork. The pieces were laser engraved directly into the paper, then washed and bleached back to their original white. The effect is to create a tactile and subtle, semi-invisible print. A series of three prints. Photographing these was particularly difficult, so in this instance closeups of the textures have been provided.

Close up of N°4. Laser etching on paper. 2020

Close up of N°33. Laser etching on paper. 2020

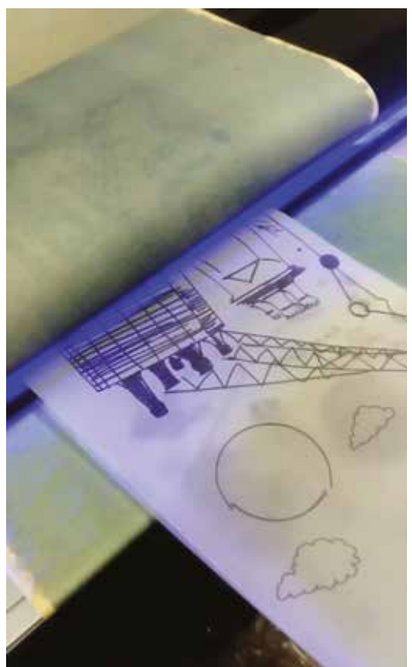
Washing the print

4.2.3 Cyanotyping Star Maps

I was invited to fix a friends diazoprinter – an old device used to make architectural drawings.[104] Originally it would create exact copies of drawings using special diazo paper and an ammonia solution. I was reluctant to change out the old ammonia bucket which was still attached. However, the main construction of the machine was an automatic roller through which a long roll of paper could be fed and would be exposed to two UV lamps. An original drawing would be fed through at the same time, creating a copy through this light exposure. Having used UV lamps in cyanotype before, this presented the idea of making long drawings – maps of the sky, which would be exposed to cyanotype coated paper.[105] Only one drawing was created in this way, the result was average, however it heavily influenced and inspired the visual components of the final pieces.

104 For a further description of the history and process. 'White Print - Wikipedia' <https://en.wikipedia.org/wiki/Whiteprint> [accessed 20 April 2021].

105 Cyanotype is a historic photographic technique known for the cyan-blue colour and used as original blueprints.



Diazoprint machine in action

Architect of the stars. 50 x200cm. Cyanotype. 2020

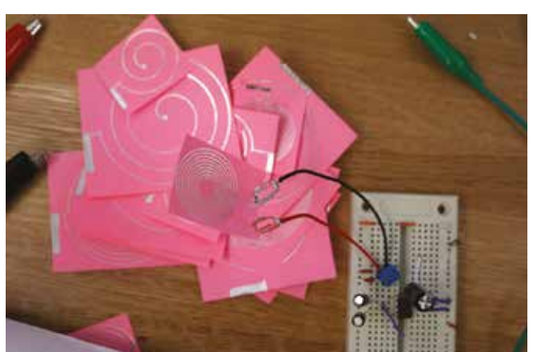
THE SOUND OF THE SPHERES:
Developing Paper Electronics

4.3.1 Residency at NYC's Tandon School of Engineering – Developing Paper Speakers.

This month-long residency allowed for a further understanding of how paper speakers work and the testing of numerous materials and processes.

The experiments were designed to develop an understanding to creating the loudest speaker as possible. This was done by creating vector drawings of spirals which were then drawn with a digital plotter onto various papers. Using a simple Circuitscribe[106] and table-top plotter, different speakers were drawn, using different size spirals and papers.

This is only mentioned to highlight the development and full documentation surrounding this research can be found in the Appendix.



Speaker test

106 CircuitScribe projects and descriptions can be found here: Fun Projects and Lessons, Circuit Scribe Official Store: Teach Electronics by Drawing! (2021) <https://circuitscribe.com/pages/fun-projects> [accessed 18 March 2021].

4.3.2 The Resonance of Waste / Bloom – with Sarah Epping

This piece was developed for Survival Festival, an annual arts festival in Wroclaw, which reimagines an abandoned building within the city, occupying it with artworks. The technology for this piece follows a similar vein as presented in the final Ph.D.; however, the concept was different. This piece began on a trip to Muhu Island, in Estonia, collecting seaweed off the Baltic coast with Sarah Epping.[107] The Baltic Sea is prone to algae blooms and overgrowth of seaweed. These blooms have caused by high levels of nitrates, a by-product of farming and other industrial processes – especially the production of paper pulp which is a staple of Finland. [108][109]

Seaweed paper pulp

The seaweed gathered was pulped in a Hollander

107 Sarah Epping is a British/American artist, printmaker and long-term collaborator.

108 EPA, 'Nutrient Pollution' <https://www.epa.gov/nutrient-pollution/issue> [accessed 25 April 2021].

109 Kristina Saarinen and others, Monitoring and Control Practices of Emissions in Pulp and Paper Industry in Finland (Helsinki, 1998).

Making seaweed paper

beater, and the pulp was poured into the largest vessel available (a children's paddling pool). Inspired by Japanese papermaking traditions and tools, a large sheet was pulled on a homemade SuKeta.[110] Inside the paper was placed a huge 80 x 80 cm copper coil. This was created of thin magnetic wire, wound around nails and fixed in place with glue. By double-couching,[111] the copper coil was trapped inside the sheets of paper. The actual audio track for the speaker came recordings made at Räpina Paper Factory;[112] they combined my own audio recordings and that of Patrick McGinley.[113] The work was presented at Survival Festival 2020 in Wrocław.[114]

110 Traditional Japanese papermaking frame. For more information of the techniques and tools which were developed for this project please see the appendix. [accessed 20 April 2021].

111 See chapter 4.1.1

112 <https://www.rappin.ee/eng/history> [accessed 20 April 2021]

113 See chapter 2.2.1

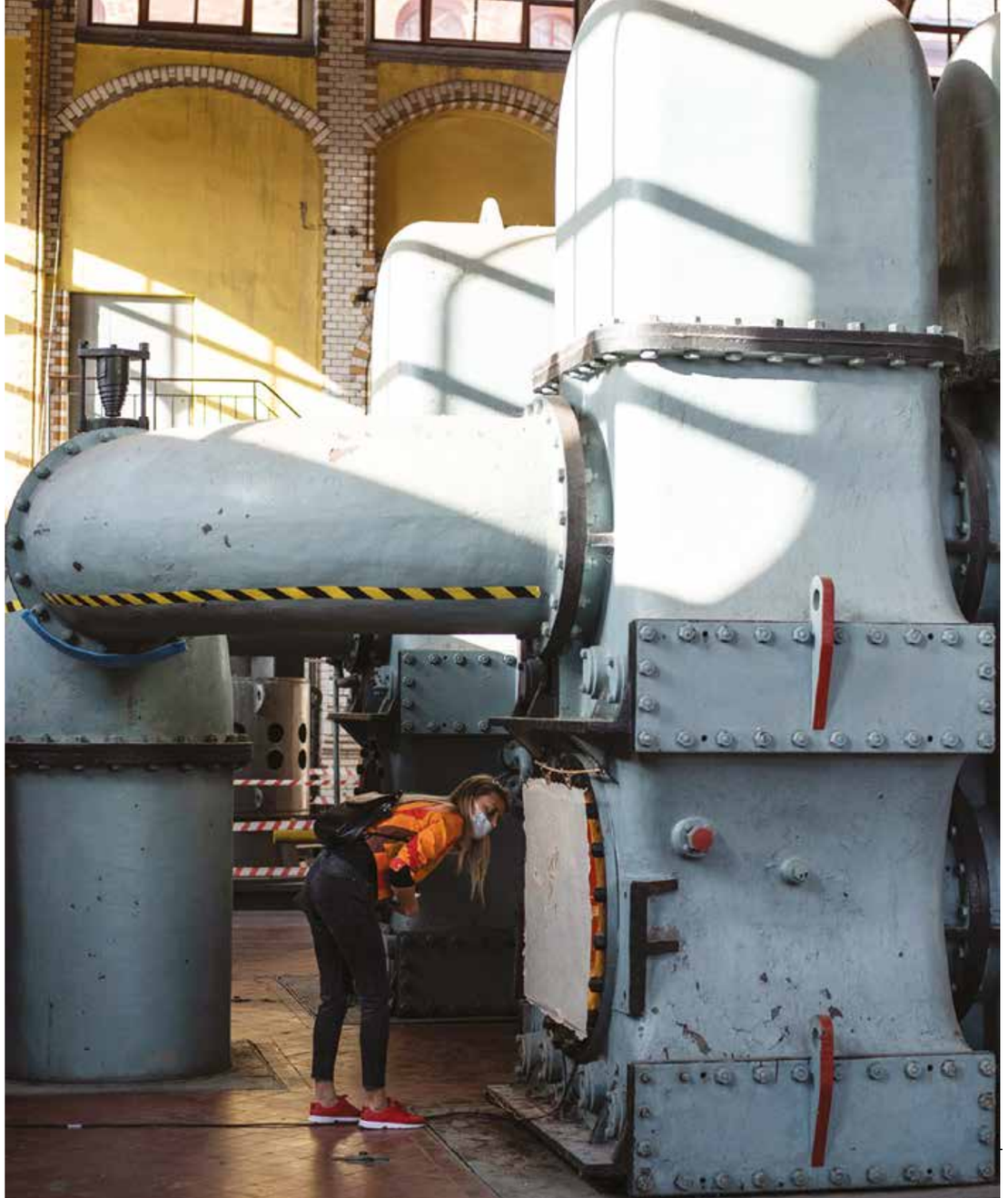
114 Charlotte Biszewski and Sarah Epping, The Resonance of Waste <http://archiwum.survival.art.pl/en/the-resonance-of-waste-2020/> [accessed 20 April 2021].

During the set-up, the small micro-amplifiers which I had provided did not prove to be loud enough. The technical team at the festival found a larger 100W amp, which worked well. It was a surprise that the speaker was able to take so much power without blowing up or overheating the amp.

Seaweed speaker

Placed in the disused sewage pumping station, the loudspeaker diaphragm uses paper made from the Baltic Sea seaweed, which blooms exceptionally profusely due to the flow of nitrate-rich sewage from agriculture and paper products into the sea. Dense thickets of seaweed create "dead zones," devoid of naturally occurring plants and fish. Distorted by the unusual properties of the seaweed membranes, the recordings are audible representations of water pollution and the hidden costs of the production methods used in the interlinked chemical, agricultural and paper industries. 'And this is how the world ends, Not with a bang but with a whimper.' (T.S. Eliot, The Hollow Men)

Resonance of Waste. 80x80cm. Paper Speaker. 2020. photo: Matgorzata Kujda



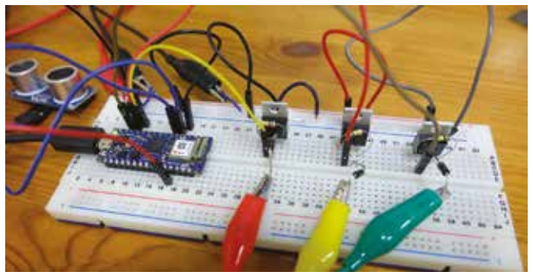
Resonance of Waste. 80x80cm. Paper Speaker. 2020. photo: Matgorzata Kujda

4.3.3 Of Galaxies and Cosmologies

These images are a work in progress, however it felt important to keep them in the final works. With such an experimental project, there were always going to be areas which do not go to plan and it felt important to acknowledge them at the end.

The images were created in part during the NYU residency; the designs were first printed in the Print Lab of the Tandon School of Engineering and are an extension of the research into thermochromic inks, exampled in chapter 4.1.1. These pieces were inspired by a colleague and astronomer at the Tartu university who creates visualisation and simulations of the universe to predict the gas and dust. Many contemporary radio astronomers use radio waves to see through gas and space dust. The background is photograph from the Hubble telescope, printed in a spectrum of colours. This has been printed on a risograph in CMYK separation - to create fantastical colour combinations.

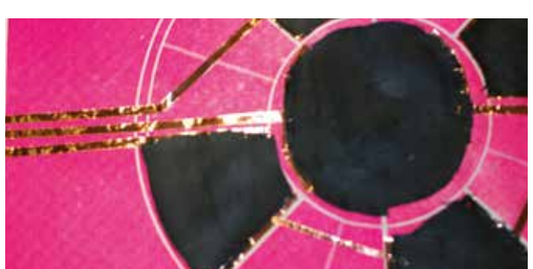
Risograph prints



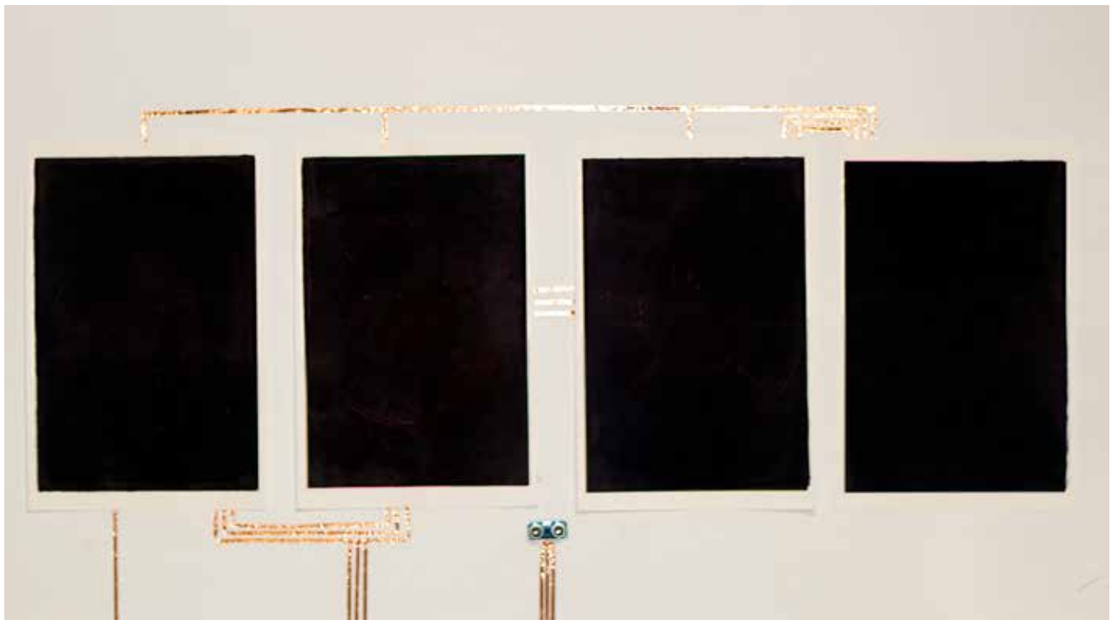
Sonar detection and MOSFETS

The prints were then covered with a thermochromic paint, applied by silkscreen. If applied with a thick enough layer it is possible to cover the images almost entirely - but the paper must be resilient enough to take this amount of ink. At +27 °C the ink changes from black to transparent (if mixed with transparent extender).

On the underside of each print is a heating circuit. This was made from copper tape and carbon silk screen ink- and here is where the difficulties began. In the earlier project of chapter 4.1.1, the circuit which had required heating was a lot smaller than those found in these prints. Therefore it took a lot less power to heat up the circuits to a high enough temperature to affect the thermochromic inks.



Carbon ink and heating circuit



Galaxies and Cosmologies, each print 42 x 31 cm, Screenprint, risograph and electronics, 2021

The goal was to have every page become transparent, simultaneously revealing the images behind. These were to be triggered by a motion detector as pictured above. However, a huge amount of power was required to heat each circuit. there were even three separate circuits within each print - as each section of carbon paint could only heat a smaller area. There is also a fine balance to find between not having any electricity pass through the circuit and having so much that your diodes pop.

The biggest amount of colour change is shown in the pictures below. Each print had to heated individually and it was still only smaller areas which heated up and not a large even section as hoped. However, the research in this area has shown others having similar issues, or have stuck to heating smaller circuits- such as threads or wires.[115]

It felt important to include this work. The project was not a complete failure - it worked, just not to the extent imagined. However, it felt relevant to include this before the final works, in order to bring a counter-argument to the final discussion.

115 A whole section in the appendix is dedicater to thermochromics and the existing research.

Galaxies with the heating circuit turned on

4.4 HARMONICS

Hamonics installation. 3 x 5 m, Woodcut and electronics 2021. Photo credit: Mana Kaasik

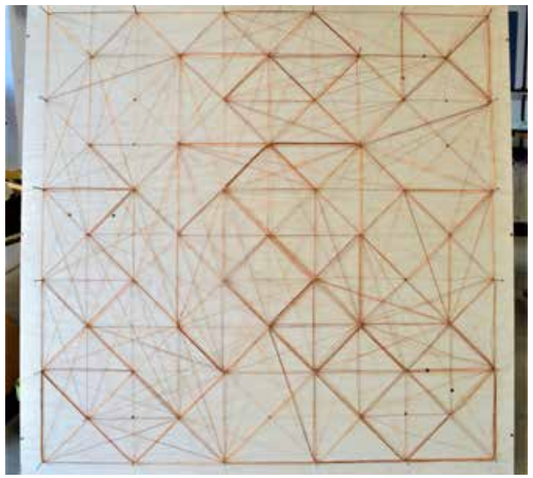
4.4 Harmonics

The works shown here are the final works of the PhD - they are a culmination of the research presented in previous chapters. They appeal to the two highest senses, of sight and sound. The process for each work is described individually and accompanied by the final images. Further descriptions into the tools methods and processes can be found in the appendix.

4.4.2 The Sound of Spheres

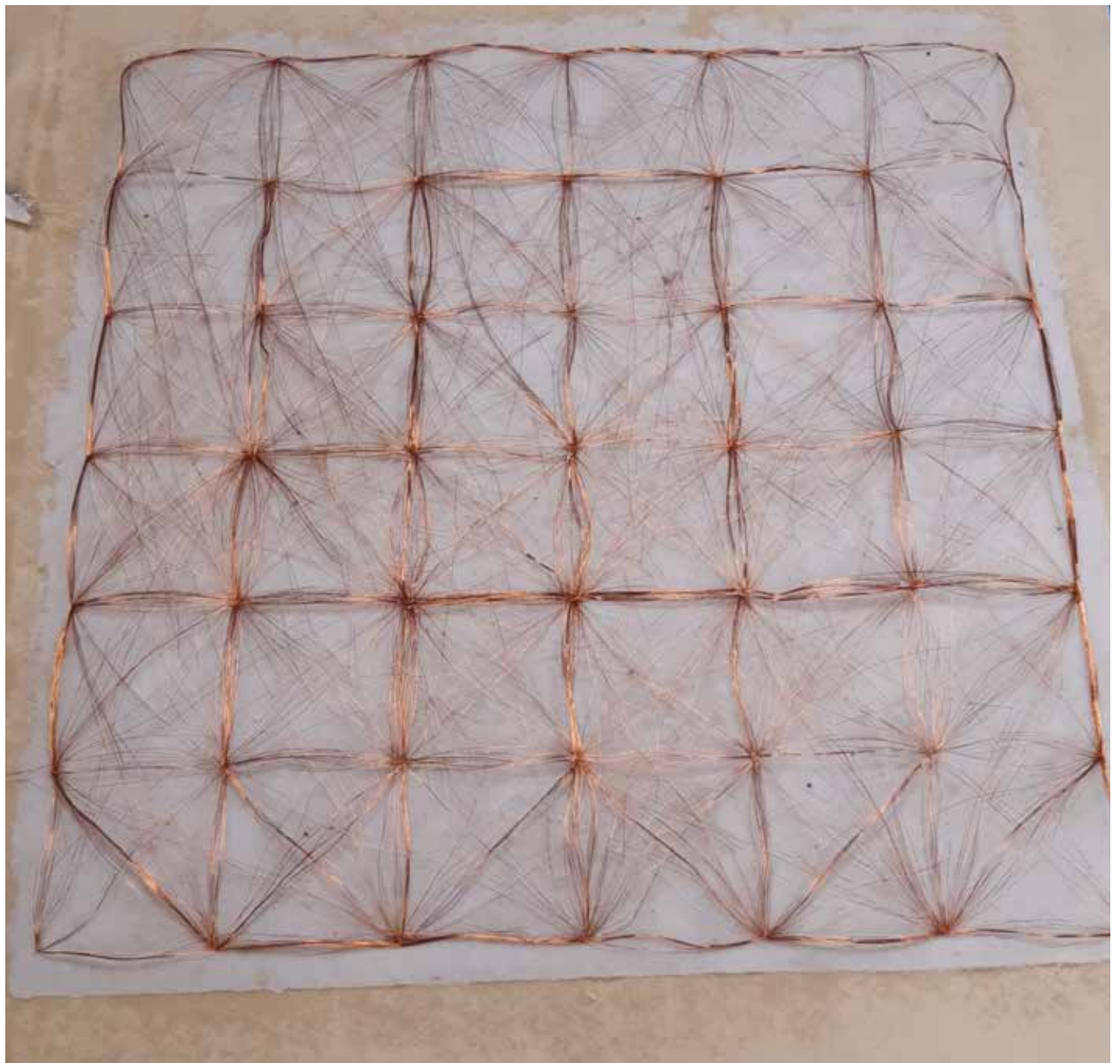
These pieces were built on much the same principle as the piece in The Resonance of Waste, as described in chapter 4.3.2. However, within these works, the pulp was kept to a cotton white and the copper coils were more accentuated with the thinner paper pulp. Each speaker was created by a criss-cross of copper wires, tightly wound around nails which were hammered into a board. The nails were then removed, and the copper glued so it stayed in place. A large papermaking frame was specially built for this purpose and the speaker coil was embedded in between two sheets of paper.

Copper around nails



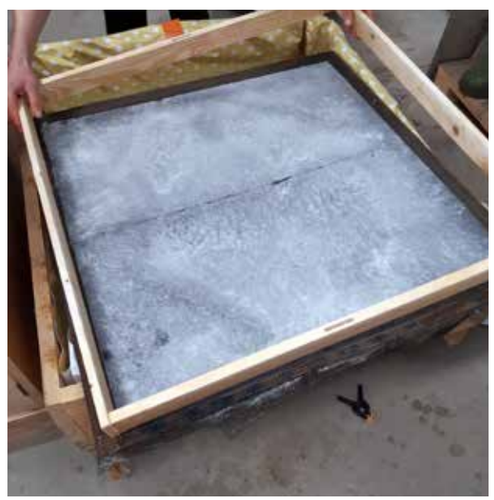
Copper around nails

Instead of one speaker, in this case a series of speakers are presented. This was in order to create the most opportunity for sound and harmony possible. The audio track was developed in collaboration with Patrick McGinley. The audio for these pieces was made up of VLF radio samples from Patrick's collection and, in part, a tribute to Stephen P. McGreevy, who has been described previously. The other part is tones and drones and field recordings collected by Patrick - following the grammatical structure of harmony and musical composition, which Hasler has outlined in chapter 2 of this thesis. The final audio can be found in the appendix and the video documentation of the speakers in action. Each speaker works in tandem with the star pieces; the audio is triggered by the sonar sensor when the audience approaches the work.

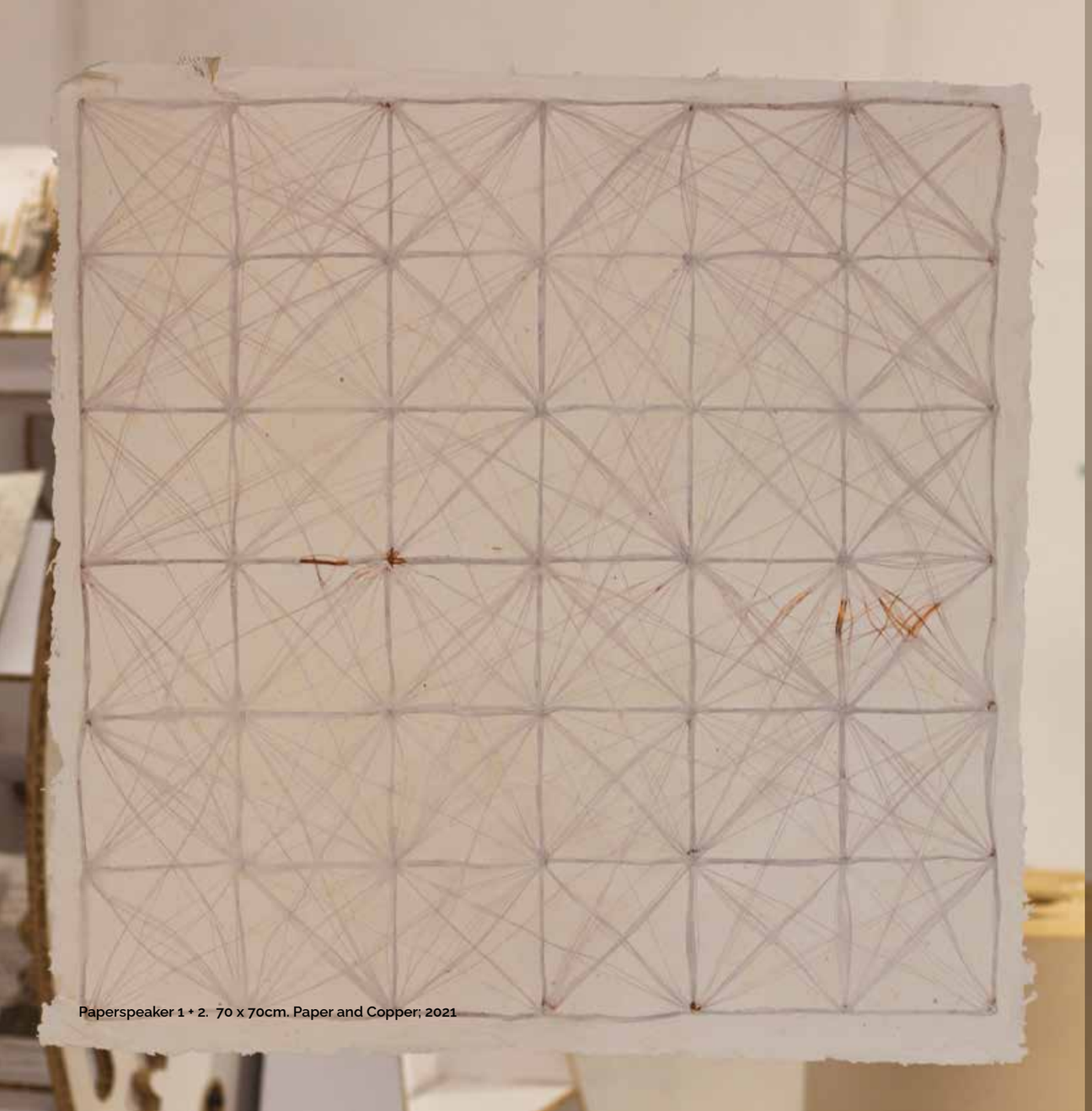


First layer inside paper





Papermaking stages



Paperspeaker 1 + 2. 70 x 70cm. Paper and Copper; 2021

Paperspeaker 1 + 2. 70 x 70cm. Paper and Copper. 2021 Photo credit: Mana Kaasik

4.4.2 LED CONSTELLATIONS

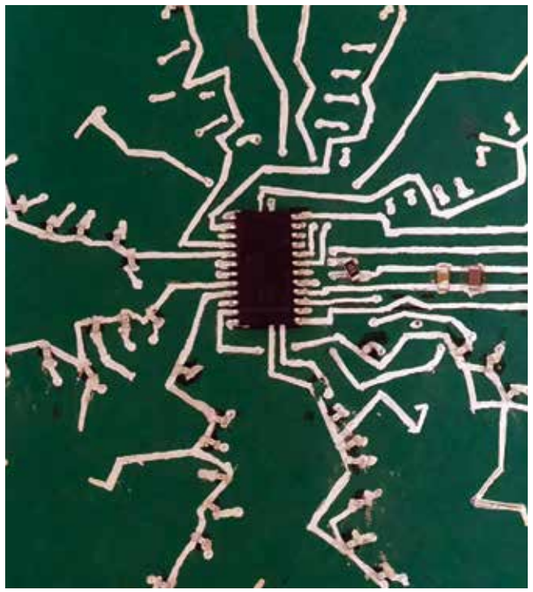
Hamonics, installation. 3 x 5 m, Woodcut and electronics 2021. Photo credit: Mana Kaasik

4.4. Archival Stargazing and LED Constellations

The installation consists of four woodcut prints and four electronic paintings. They pay tribute to the star maps and constellations of Tycho Brahe and Ptolemy and were inspired by the intricate drawings of the Uranometria and the astronomical diagrams and resources from the Tartu Observatory.

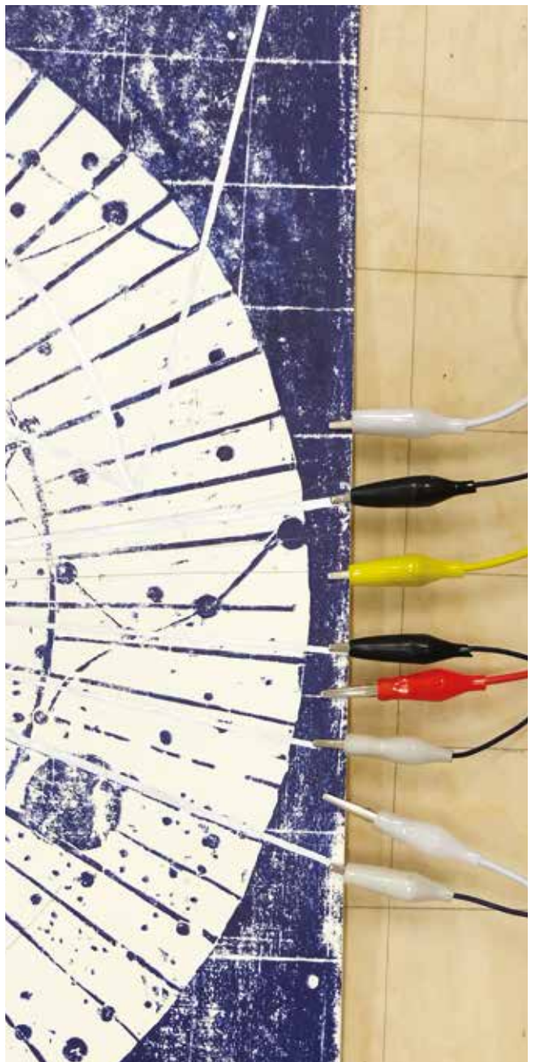
The four woodcuts were created entirely by hand. The idea was to contrast a very traditional process with a very modern approach and embracing both the new and the old together. The designs were loosely based on the concept of four - the four elements, the Tetrad - a representation of the kosmos and the four elements. Each circular motive is set against an imagined map of the stars. The works were printed on a very fine, transparent washi paper from Awagami, so the LEDs could shine through the paper. Full images of the pieces are on the final pages of this chapter.

Woodcut



MAX7219 test

These prints hang on either side of the LED pieces. The LED pieces were far more experimental and technical to create. The concept for them came about in the cyanotype project of chapter 4.2.3 and took two years of development. There were many issues, considerations and steps which went into the final design, some of which will be covered here. Firstly, how to control and illuminate certain LEDs to create constellations and patterns. The first attempts used a MAX7219 - a microchip designed to control the scrolling LED grids. The MAX7219 proved to be limited in what you could do with them and the patterns and animations you could create.



Paper LED test

In the end addressable LEDs were chosen for their flexibility and the animations were generously designed by Roman Fomow of Synestetica Studio in Ukraine . The full documentation with code, vectors and the steps can be found in the appendix.

The second issue was how to paint with conductive ink. Here there were several options - screenprinting, using a pen and plotter, inkjet printing - all of which were tried and tested. In the end, the conductive silver traces were painted by hand, using light masking tape to shape the lines. The ink then had to be heated to 120°C for a minimum of five minutes - in order for the ink to work. Many attempts were tried at this stage - iron, oven, sauna - but all failed. It was a stroke of luck to find a giant laminator which could heat the lines to the correct temperature.

The silver lines are traced on both sides of the paper - with the signal which controls the LEDs weaving in and out of the paper.

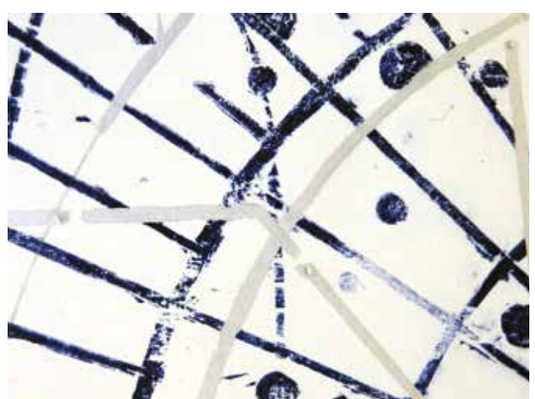
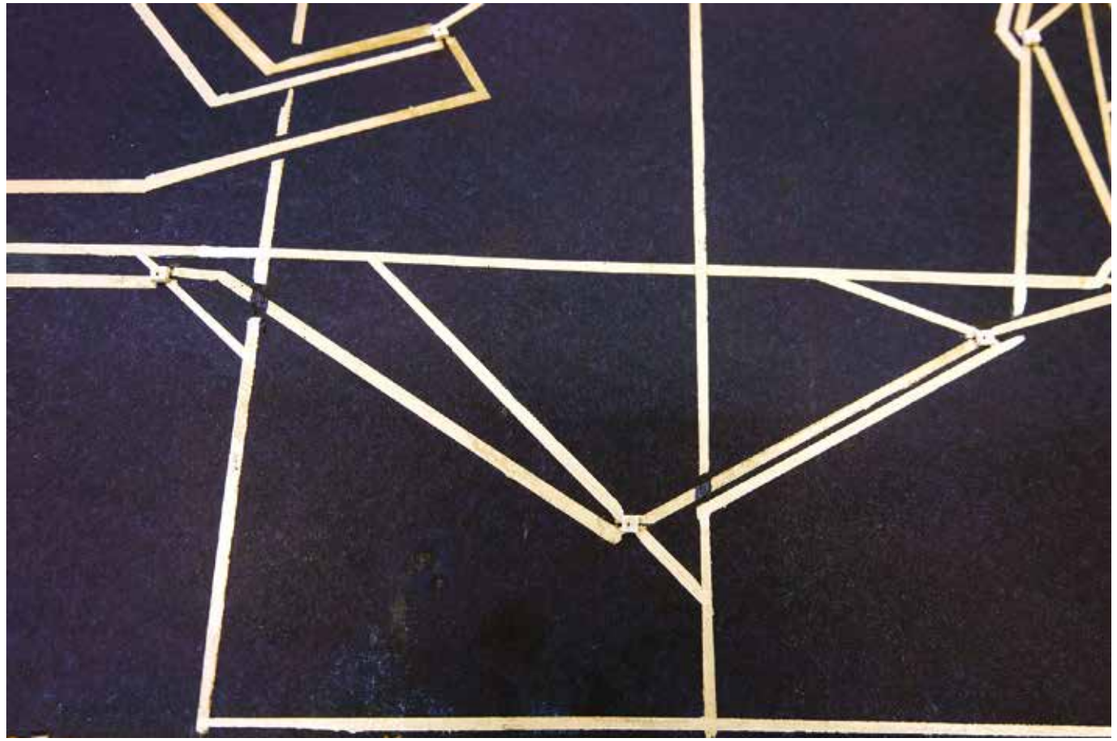


Fig. 4.4.2.4 - Silver traces

Painting on the traces



Attaching the LEDs

Each LED is powered by a power and ground line - which is the grid pattern on the painting. Each side of the painting has a power and ground line, which connects to each LED. Each LED is soldered to the conductive trace - as the silver ink, when applied in a thick enough amount, can actually provide a stable enough surface for soldering - at a lower temperature. The soldering combined a good amount of superglue was sufficient to make a strong connection.

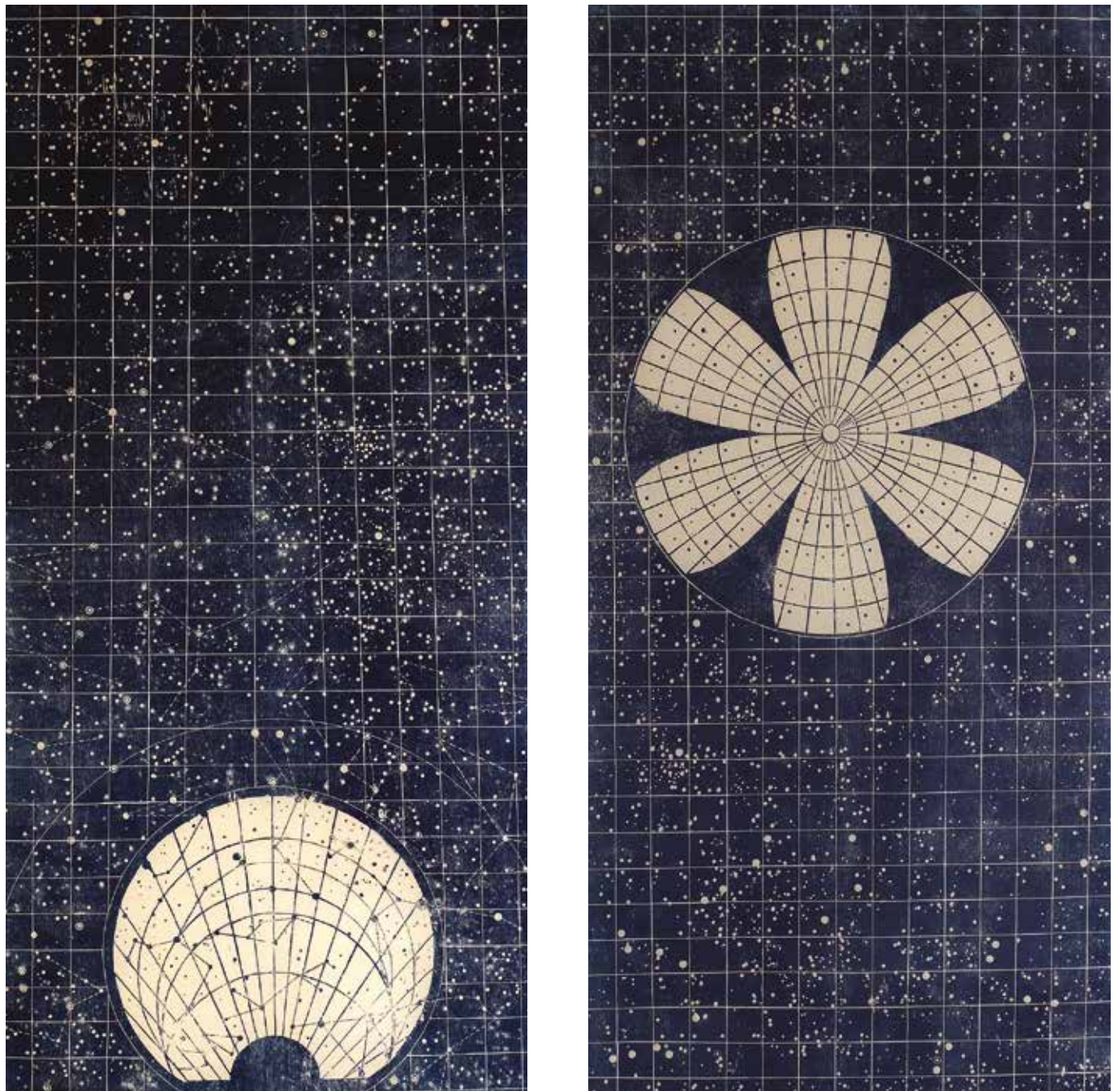
The pieces look to accentuate the fragility of the prints against the strong graphic designs of the LED pieces – paying homage to the art of papermaking and its historical craft tradition.

Hamonics, installation. 3 x 5 m, Woodcut and electronics 2021. Photo credit: Maha Kaasik

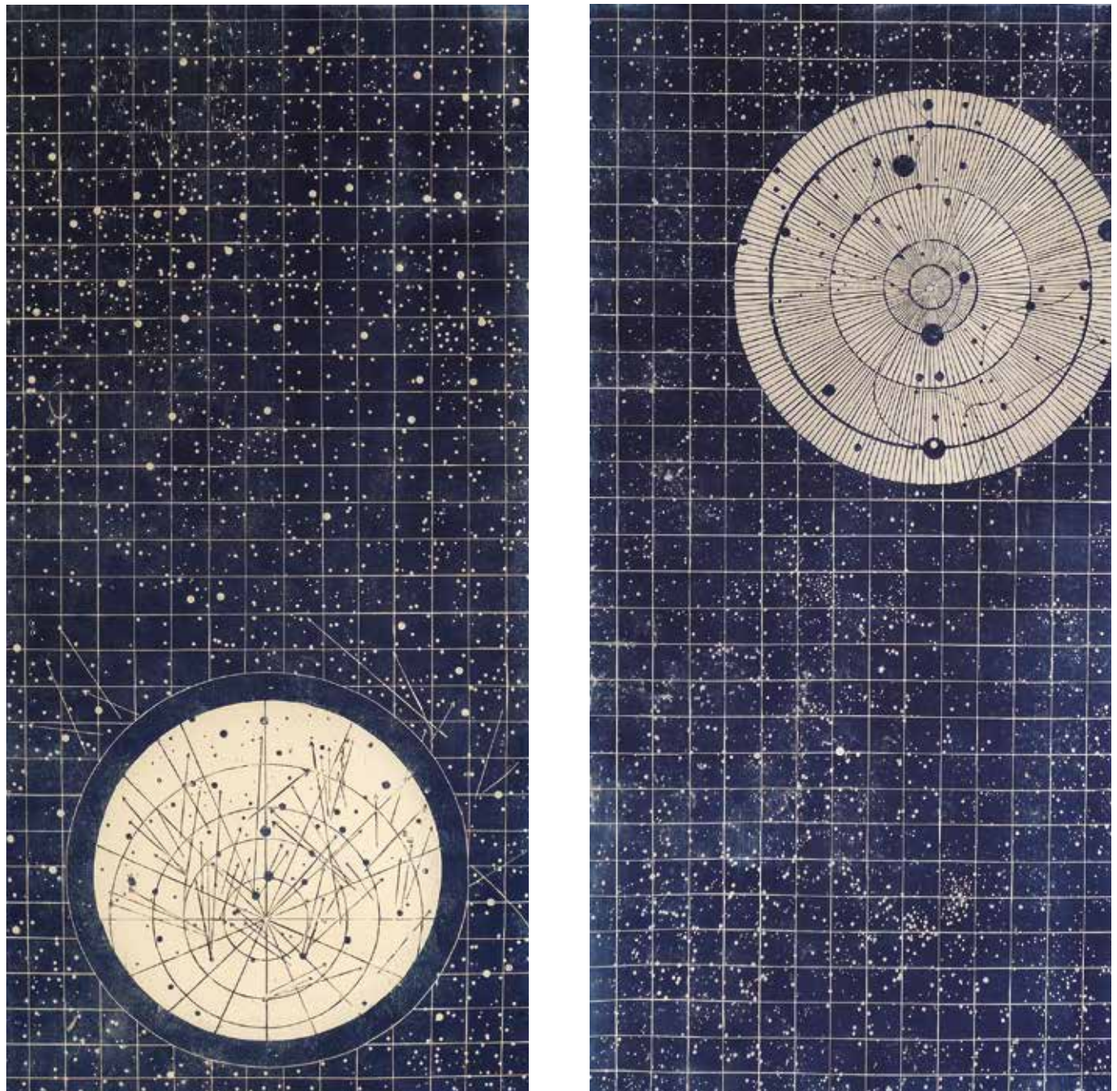
Hamonics, installation. 3 x 5 m, Woodcut and electronics 2021. Photo credit: Mana Kaasik

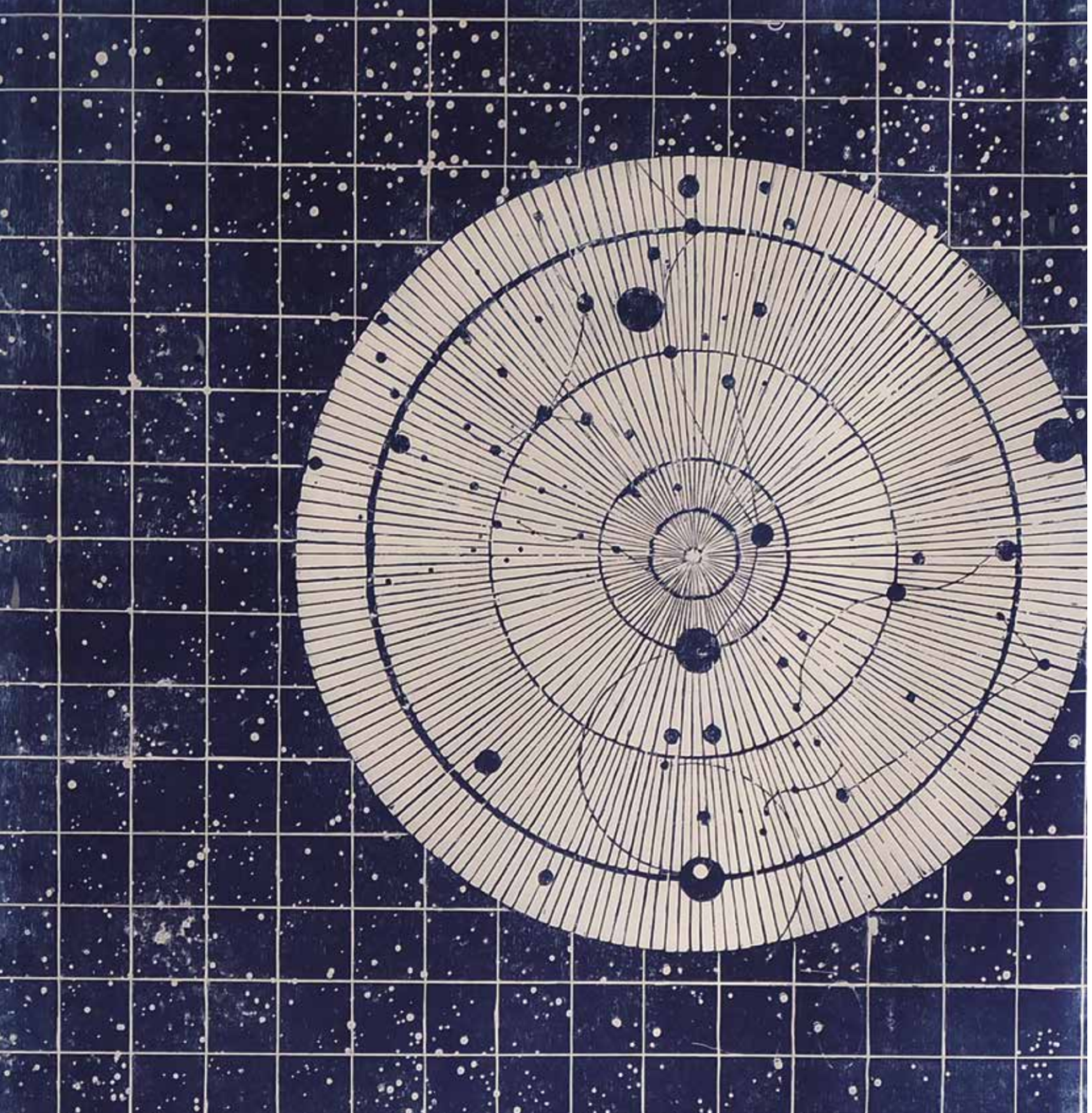
Hamonics, installation. 3 x 5 m. Woodcut and electronics 2021. Photo credit: Mana Kaasik

Hamonics, installation. 3 x 5 m, Woodcut and electronics 2021. Photo credit: Mana Kaasik



Architect of the Stars 1 -4. 150 x 75cm. Woodcut. 2021





Discussions and Findings

This research demonstrates success in certain areas. It does present a free and unrestricted investigation – with potential models for printmakers to embrace new and other forms of technology in their work. However, inevitable frustrations arose, often because the technology of printed electronics felt unobtainable and hard to access. It has to be acknowledged that this is a fast-growing field, and the research presented is only a starting point. As the technology mutates and becomes more readily accessible, there is no doubt that artists will continue to play with develop this area.

Without having the knowledge of an electronic engineer or specialist in the technical aspects of printed electronics, this Ph.D. research presented many limitations. With future projects, collaboration across disciplines would undoubtedly contribute to the outcomes. Although interdisciplinary collaboration was demonstrated, this could be furthered with the successful connection with an industry or research team working within the printed electronics field. The other issue was the limited access to the equipment and tools necessary, often unaffordable components and materials. Creating the final prints was a very long-winded process and sometimes has felt not the most practical use of materials or tools - having to paint on electronic traces by hand or appropriate a giant laminator.

However, many aspects of the project have proved successful, especially if viewed as an entirely novel artistic experiment. The final pieces do successfully combine the aesthetics of craft and print with new technologies. The works here will be made as readily available to artists as possible, with complete documentation online. The blog will include reviews on materials available – such as conductive inks and forms of LEDs or amplifiers, the code for each project and the designs which can be reprinted in a digital plotter or screen for any artists to take and modify. Technology has both elevated and destroy human beings and continues to do so, yet our infatuation with the new only accelerates to compel us forward. There is no doubt that the field of printed electronics will bring new prospects to art and science alike.

This thesis proves most beneficial if not viewed as a conclusion to a field of research but rather an introduction.

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