Sonic City

Interactive sound sculpture based on graphical notations

Master Thesis

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Abstract:

This thesis explores the integration of sonification-focused graphical notations within interactive sound sculptures to enhance engagement in music compositions, especially for individuals with diverse backgrounds. The research introduces "SonicCity", an interactive sound sculpture leveraging unconventional graphical notation methods using familiar tangible objects. Through iterative design and technical implementation in Max/MSP, SonicCity translates physical interactions into dynamic sound manipulations, creating an immersive auditory experience. Evaluation indicates successful user engagement and potential for democratizing music-making, despite ongoing development needs. The project signifies the promise of innovative graphical notations in redefining musical experiences.

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Abstract:

Dette speciale udforsker integrationen af sonifikationsfokuserede grafiske notationer inden for interaktive lydskulpturer for at forbedre engagement i musikkompositioner, især for personer med forskellige baggrunde. Forskningen introducerer "SonicCity", en interaktiv lydskulptur, der udnytter utraditionelle grafiske notationmetoder ved at bruge genkendelige fysiske objekter. Gennem iterativ design og teknisk implementering i Max/MSP, oversætter SonicCity fysiske interaktioner til dynamiske lydmanipulationer, hvilket skaber en dybdegående auditiv oplevelse. Evalueringen indikerer succesfuld brugerengagement og potentiale for at demokratisere musikskabelse, på trods af igangværende udviklingsbehov. Projektet signalerer løftet om innovative grafiske notationer i at omdefinere musikalske oplevelser.

Indhold

Preface

As any achievement in the art and science world, the efforts that have been put in a project are very rarely the ones of only one human being. This master thesis should not be an exception. I would like to acknowledge first and foremost my supervisor Dan Overholt, for encouraging, guiding and supporting me throughout the extensive journey of research and creation. I would also like to express gratitude to Kinan Sarak, my external mentor, as inseparable part of this project in the role of creator of the initial idea and whose expertise in graphical notations and previous work we have done together significantly influenced the creative process.

"Thank you"is due also to Jesper Greve and Peter Williams of AAU Manufakturet, for their guidance during the construction phases, contributing to the realization of this innovative project. I simply cannot leave out also my collegues and teachers part of SMC program, especially Marco Timossi, not only for all the advice, critiques and suggestions that have been given to me, but also for all the work they are doing which has served as a great inspiration to me. Closing with deep thanks to my little explorer, Marta – her unwavering patience and the uniquely fresh perspective that only a child could offer have been instrumental in shaping this project.

At its essence, this project aims to introduce an interactive sound sculpture designed to showcase a composition through graphical notations. Departing from conventional approaches, it draws inspiration from the extensive lexicon of graphical notations, presenting an innovative method that incorporates tangible objects. The interactive sound sculpture seamlessly blends graphical notations with tangible elements, providing an immersive musical experience. Participants actively shape the sonic landscape, contributing to the composition process and adding a dynamic dimension to the artwork.

In the creation of this sound sculpture, particular emphasis was placed on tailoring it for art spaces. The design philosophy centers on offering a distinctive and inclusive experience for individuals of all ages, contributing to the rich tapestry of diverse artistic environments. As Perry Cook has pointed out, in many cases "musical interface construction proceeds as more art than science, and possibly this is the only way that it can be done" (2001).

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Kapitel 1

Introduction

In the expansive realm of sound art, the exploration of sonic landscapes transcends traditional boundaries, reaching far beyond the confines of conventional music notation. Rooted in the conviction that everyone should have the opportunity to engage with and contribute to the world of sound, this research navigates the intersection of sound art, graphical notations, and interactive experiences. The overarching goal is to democratize musical creation, offering an accessible entry point that is both enriching and gratifying for participants regardless of their musical background. As the digital era reshapes our approach to creating and experiencing music, the demand for inclusive and accessible sound art becomes increasingly apparent [37]. The design in mind when creating SonicCity was to align it with the vision of breaking down barriers, offering a low-entry fee to sonic exploration through innovative projects [17], such as an interactive sound sculpture. The emphasis on multisensory engagement in sound art underscores the idea that experiencing sound goes beyond just hearing it.

Central to the success and inclusivity of sound art projects is the incorporation of graphical notations. Unlike conventional musical scores, graphical notations offer a more intuitive and adaptable visual language that transcends the boundaries of traditional music notation. The primary motivation behind the development of graphical notation interfaces was to devise a system of musical representation that could be easily interpreted and performed by individuals without formal musical training or who don't consider themselves musically literate. This democratization of musical expression would then allow for a broader audience to engage with and appreciate sound art.

This thesis delves into the interplay between sound art, graphical notations, and accessibility through the design of an interactive sound sculpture crafted for musical interaction. The project aims to provide a fun and accessible platform for engaging with music, catering to individuals regardless of their musical expertise. By melding sound with visual elements and interactivity, the sculpture offers a unique exploration of how technology can elevate and diversify musical experiences. Subsequent chapters will detail the background , design, implementation, and user engagement of this interactive sound installation, highlighting its potential to make music more interactive and engaging for all.

1.1 Motivation and Goals

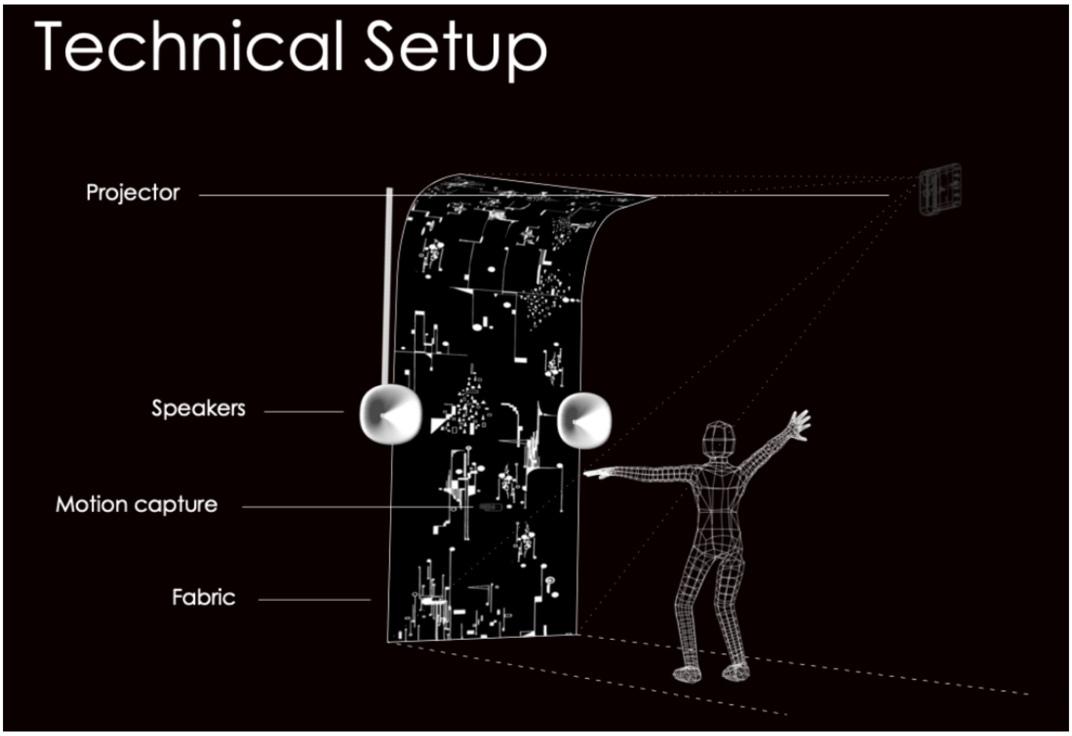
In my musical journey, beginning at an early age, traditional notations have been a cornerstone for comprehending melody, harmony, and rhythm. They provide a structured language essential for understanding the fundamentals of musical compositions. From a personal perspective, though essential for a comprehensive grasp of music, these notations can often be challenging to read and interpret, potentially hindering intuitive engagement and enjoyment. Another aspect of the constraints they pose becomes evident when we deal with electronic music. The rigid structure of sheet music may inadvertently limit the spontaneity and fluidity of musical expression.

Recognizing these constraints, I started researching alternatives, particularly exploring graphical notations within the context of electronic music creation. This shift proved remarkably useful, providing a more flexible and intuitive approach to navigating soundscapes. Inspired by the innovative possibilities presented by graphical notations, interfaces, and instruments in the realm of sound art, I began exploring alternative avenues for expression in composing and performing electronic music.

Departing from a collaborative project with Kinan Sarak focused on graphical notation composition, our exploration took an intriguing turn with the introduction of the "Kropskomponist"installation 1.1. In this setup, individuals engage in the act of composing through body movements, a unique and immersive experience that marked a significant milestone in our journey.

As we explored various interactive possibilities, the evolution of our concept naturally led us to the fascinating idea of sonifying objects using graphical notations. This shift from body-centric interaction to the manipulation of tangible objects introduced a new layer of creativity and engagement. Users now wield the power to shape the sonic landscape by interacting with physical elements, transcending conventional boundaries in music creation. This exploration naturally led me to embark on a project to create an interactive sound sculpture, where individuals use objects to craft a unique soundscape. This interactive experience involves manipulating various aspects of the sounds, introducing an element of exploration and play.

In the context of the interactive sound sculpture project, it became apparent that the music creation process would lack impact without the incorporation of a graphical notation system. This system serves as a structured framework, enabling



Figur 1.1: Simulation of the Kropskomponist concept installation . The body movements would be translated as graphical notations on the fabric infront of the user.

dynamic interaction to be expressive and meaningful. It acts as a visual language guiding and enhancing sonic exploration, ensuring that the sounds produced contribute purpose and coherence to the overall musical composition.

1.2 Research question and problem statement

1.2.1 Research question

Does integrating sonification-focused graphical notations, enhanced by incorporating objects into the graphical vocabulary, improve engagement with music compositions, especially for individuals with diverse backgrounds interacting with interactive sound sculptures in creative spaces?

1.2.2 Problem Statement

This project explores interactive sound sculptures as a means to democratize music-making, utilizing intuitive interfaces and innovative sonification techniques. By integrating objects into graphical notations, the aim is to craft a dynamic platform that enhances engagement with music compositions for individuals with diverse backgrounds. The challenge lies in designing an intuitive system that facilitates active participation in shaping a dynamically non-linear sonic environment. Bridging the gap between visual representation and auditory exploration, this research seeks to make musical expression accessible and captivating within the realm of sonic exploration.

Kapitel 2

Background and Inspiration

2.1 Understanding Graphical Notations Through History

Graphical notations serve as visual representations of musical elements, offering an alternative to traditional written notation [1]. These visual languages provide a way to encode and communicate musical information and enable a more intuitive and expressive interaction between the composer, performer, and audience. By offering a visual framework for interpreting musical elements, graphical notations enhance the accessibility and inclusivity of music creation, making it more approachable for a diverse range of individuals. In the following sections, we will delve into the rich history of graphical notations, tracing their development and evolution over time. This historical exploration will shed light on the diverse sources and inspirations that have contributed to the creation of graphical notation systems. By understanding the historical context and influences, we can gain insights into the motivations behind the adoption and adaptation of graphical notations by various composers and artists. This journey through will provide a comprehensive view of how graphical notations have emerged, transformed, and diversified, shaping the landscape of musical expression. Additionally, we will explore the impact of technological advancements on the evolution of graphical notations, considering how these visual languages have adapted to the changing tools and mediums available to artists and musicians.

2.1.1 Composing with Graphics

The historical exploration of graphical notations uncovers an interesting intersection where visual elements meet musical expression. With roots in the use of curvilinear graphic shapes to symbolize musical gestures, as observed in the Paleobyzantine chant of the ninth century, this integration extends across cultures like the Japanese shomyo and the Buddhist Tibetan chant [25]. The historical connection between music and color adds an intriguing dimension. Aristotle, in De Sensu (350 B.C.E), acknowledged the link between color and sound, a concept reflected in medieval Europe where color guided the representation of pitch in early music notation [44] Beyond its role in traditional music notation, color becomes a versatile tool in graphical notations, enhancing the visual language used to convey musical nuances.

The origins of graphic notation unveil their early manifestations within the sphere of American composers connected to John Cage, such as Morton Feldman [4]. His Projection 1 for solo cello (1950-51), can be described as a graphic score, characterized by rectangular shapes arranged in a grid. It provides performers with nuanced instructions on style, pitch range, and note durations. A departure from this approach is evident in Earle Brown's December 1952 (1954) who unlike Feldman, discards the grid-based layout, allowing the graphic elements to float freely in empty space . Moreover, Brown refrains from offering explicit instructions or a legend for interpreting the score, signaling a distinctive shift in the evolution of graphic notation. In Folio and 4 Systems (1954) he states that "all of the other characteristics of a sound — frequency, intensity, timbre, modes of attack-continuation-decay — are infinitely divisible continua and unmeasurable."[7]. This demonstrates his recognition of graphic notation as a means to investigate the continuous sequence within the acoustic parameter domain. It also functions as a medium for conveying a form of understanding that goes beyond the limitations of language [25].

Brown's investigations followed two avenues: first, the creation of "mobile scores"that allowed performers to arrange sections of notated material; and second, the incorporation of graphic elements. This included a conceptually "mobile"approach to inherently fixed graphic elements, enabling an endless range of performance interpretations based on the performer's immediate reactions to intentionally unclear graphic cues within the performance context.

Both Feldman and Brown worked with another aspect of graphical notations called Open Form. This approach marked a pivotal moment for improvisation, allowing performers to interpret the piece in any sequence and orientation. "Composition begins with any sound and proceeds to any other,"writes Feldman as instruction in Intermission 6. Open Form scores diverged from traditional ones by not providing the familiar pitch and rhythmic information. Instead, they presented a variety of information that could be conveyed through graphics or verbal instructions. In striving to achieve a form perceived as "open form"in the sense of "expressing an eternal time field,"composers crafted forms where the order of events remained undetermined.[10]

Three years later in 1956, Stockhausen tried a similar approach where a set of 19 fragments are presented on a single page, and the instructions tell the performer to make their own path through them. Then he introduced an interesting idea: taking details like tempo, dynamics, and how to play from one fragment and using them in the next. This brings two important results. First, it makes the piece more complicated because each part is influenced by both itself and the one before it. Second, the composition goes beyond just a mix of random pieces; it becomes like a map of connected parts. In this way, the composition becomes more than just the sum of its individual parts.[39]

Other composers, such as Anestis Logothetis (1921-1994), Anthony Braxton (1945-), Barry Guy (1947-), Guillermo Gregorio (1941-), actively engaged with graphical notations. Through their individual works, each contributed novel elements and intriguing ideas, expanding the possibilities of utilizing graphical notation. This collective exploration highlights the vast field that graphical notation offers for both expression and performance.

2.1.2 Graphical Interfaces

With the grand entrance of digital machinery into the electronic music arena, the beginning of the era of sound and music computing was marked. In a time when technology was less advanced than today's computers, researchers and composers grappled with materials like valve oscillators, celluloid and photocells, captivated by the dream of visualizing sounds and exploring new dimensions in music [25].

In 1787, German physicist and musician Ernst Chladni introduced what we can consider as first visual representations of sound in his work "Entdeckungen über die Theorie des Klanges"[9]. Termed Klangfiguren, these images displayed a unique and precise correlation with specific tones. It marked the inaugural instance of a non-arbitrary visual depiction of sound, distinct from human conventions seen in musical notation.

Rudolph Koenig's 1862 manometric capsule, captured by Edward L. Nichols and Ernst George Merritt, marked the first visual recording of an acoustic phenomenon. Early researchers focused on speech sounds and language, connecting sound wave shapes to letters [24]. The desire to visualize sound raised scientific and philosophical questions about sound, image, and meaning. Rilke's vision in "Primal Sound"hinted at using technology to reproduce unheard sounds, driven by a quest for hidden meanings in anatomical features like the coronal suture [2]. Regarding this, Thomas Levin suggests that the motivation to hear these unheard signals is not driven primarily by scientific curiosity or a purely aesthetic pursuit; it aligns more closely with what we currently label as data sonification [25].

László Moholy-Nagy (1895–1946) was a Hungarian painter and photographer as well as a professor in the Bauhaus school. He was known for his work in various artistic disciplinesas well as typography, and sculpture. As a key figure in the avant-garde, he envisioned a future where composers could use phonographic vocabulary to create novel sounds directly in a "groove-script alphabet."Although early experiments faced technical limitations, Moholy-Nagy recognized the potential of optical sound technology, which allowed hand-drawn traces on film. Emphasizing the mastery of an "acoustic alphabet,"he foresaw the creation of music from unseen sound values through opto-acoustic notation. This marked a shift towards a human-centered perspective, emphasizing the language-like quality of these traces.[25]

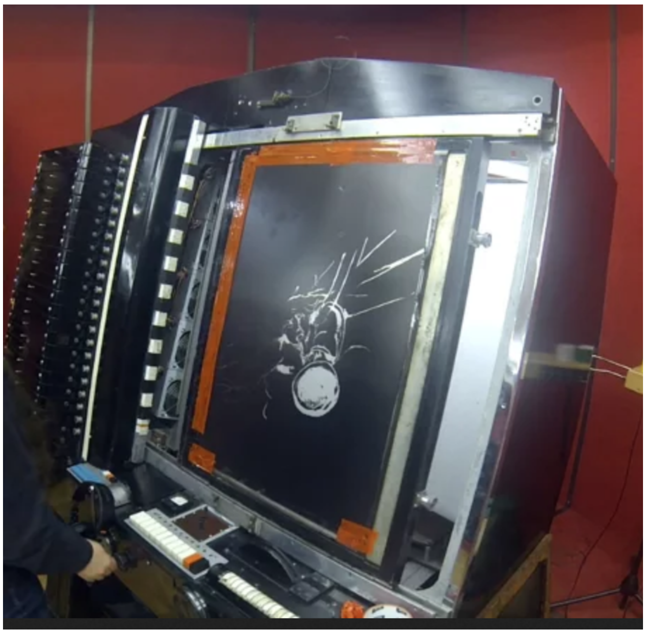
ANS synth, Oramics, Xenakis

The ANS synthesizer, Oramics, and UPIC share a common thread in their innovative approaches to sound synthesis and graphical notations. Each of these systems has played a significant role in expanding the possibilities of sound creation by integrating visual representation and manipulation into the sonic composition process.Together, these innovations strive towards a shared goal: to discover and facilitate more intuitive methods for music-making processes.

The ANS synthesizer 2.1, developed by Russian engineer Evgeny Murzin in the 1930s-1950s, pioneered a unique method of sound synthesis. In essence, the sound in the ANS synthesizer was synthesized by combining numerous sinusoidal signals, effectively implementing an additive synthesis technique. These sinusoidal components, numbering up to 720, were meticulously generated through optical oscillators. Notably, these oscillators were tuned to a microtonal scale, offering a high degree of precision in frequency modulation. The amplitude of these sinusoidal signals was intricately controlled by a graphic score, which depicted amplitude trajectories within the time-frequency plane. This graphic score was etched onto a black-covered glass surface, providing the composer with a direct means to design the sound spectrum. This graphical representation of amplitude trajectories can be likened to what contemporary parlance refers to as a sonogram or spectrogram, showcasing the pioneering integration of visual and auditory elements in the ANS synthesizer. The ANS synthesizer, through its additive synthesis approach and graphic score control, laid the groundwork for later innovations in graphical notations and sonification techniques.[18]

Daphne Oram embarked on an ambitious endeavor to revolutionize sound composition with her visionary instrument. In her conceptualization, composers would utilize a symbolic alphabet to convey essential parameters, enabling the translation of freehand sketches on paper into recorded auditory expressions on magnetic tape. The instrumental core of the Oramics 2.3 featured ten 35mm film loops, providing a canvas for composers to intricately sketch waveforms and envelopes. These graphical representations underwent scanning by photocells, serving as controls for oscillators and filters to generate the desired sound. Although the instrument faced challenges in completion and practicality, Oram collaborated with notable composers such as Thea Musgrave, Hugh Davies, and Tristram Cary,

[1] https://catskillsmusic.com/product/pepe-deluxe-general-deluxe/.



Figur 2.1: The ANS synthesizer at the Glinka Music Museum in Moscow. [1]

showcasing its potential for artistic innovation in sound composition. [23]

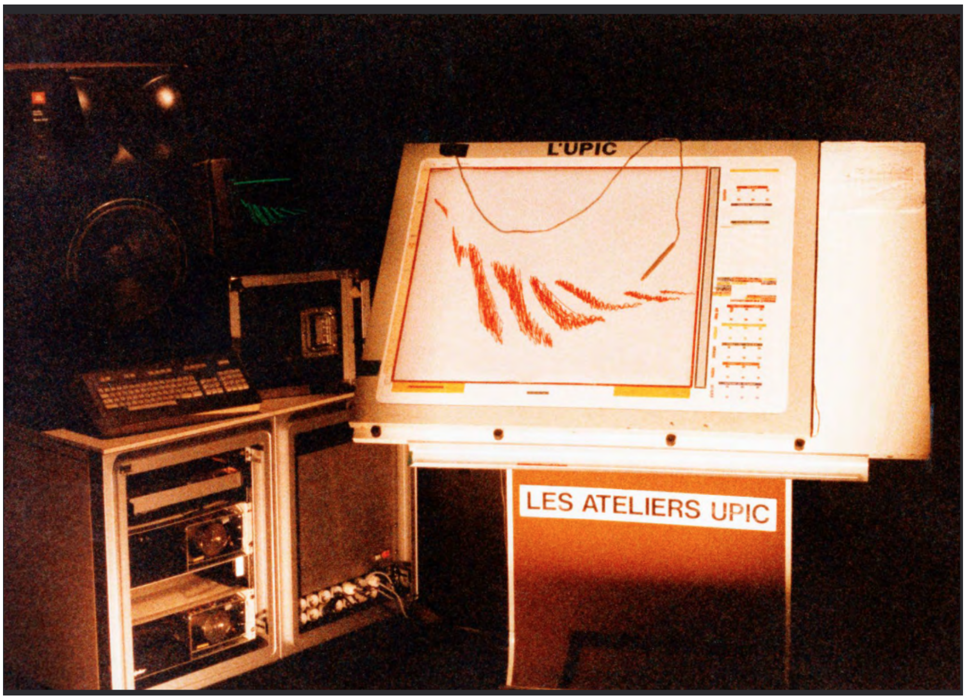
Figur 2.2: Promotional photo from around 1966, Oram is depicted working on the analogue volume control section. To the left of the film tracks, there are three digital pitch control tracks followed by the vibrato track.[2]

[2] https://www.daphneoram.org/oramicsmachine/

The UPIC (Unité Polyagogique Informatique CEMAMu) system [40], designed by Iannis Xenakis, represents a pioneering intersection of graphical notation and sound synthesis. Developed in the late 1970s at the Centre d'Études de Mathématique et Automatique Musicales (CEMAMu), UPIC allowed composers to create music by directly drawing on a graphic tablet. This revolutionary approach enabled a seamless translation of visual input into sonic output.[42]

Composers using UPIC could visually represent various musical parameters, such as pitch, dynamics, and timbre, on the tablet. The system then interpreted these graphical elements, transforming them into audible compositions. Unlike traditional instruments or synthesizers, UPIC provided an innovative means for composers to explore unconventional soundscapes through graphical gestures.

Iannis Xenakis envisioned UPIC as a tool that would liberate composers from the constraints of traditional notation, offering a more intuitive and direct connection between their artistic ideas and sonic realization. The system has left a lasting impact on the field of electronic music, emphasizing the creative potential of graphical interfaces in shaping musical expression.[42]



Figur 2.3: The UPIC[3]

[3]https://zkm.de/en/from-xenakiss-upic-to-graphic-notation-today

Alvin Lucier and David Tudor

Alvin Lucier and David Tudor,pioneers of avant-garde experimental music, have significantly shaped the landscape of sonic exploration. Lucier's concept of "intrinsic scores"challenges traditional musical notation by incorporating implicit graphic elements within electronic circuitry [25]. The visual representation in Lucier's works emerges from the physical arrangement and behavior of electronic components, presenting a unique form of graphic notation. Performers interpret these graphic elements indirectly by observing the electronics' behavior, creating a visually grounded approach to performance. The embodied understanding of graphic elements occurs through direct physical interaction, transforming visual cues into sonic expressions. David Tudor's "Rainforest IV"introduces a tangible form of visual notation through the arrangement of objects. Each object serves as a visual score, collectively contributing to the overall visual landscape of the sonic environment. The collaborative nature of the piece involves performers actively contributing to the graphic notation by selecting and placing objects. This shared language of visual representation guides collective improvisation and sonic exploration. The arrangement of objects in "Rainforest IV"not only contributes to the visual landscape but also serves as a graphic representation of spatial and sonic relationships. The visual score communicates how each object contributes to the overall sonic tapestry, offering performers a graphical guide for their interactions. [8]

Both Lucier and Tudor share a deep-seated affinity for integrating technology as a creative medium. Their pioneering use of electronic components transcends mere utilitarianism, elevating these tools to integral elements of the artistic process. This aspect of their work raises broad inquiries into the evolving relationship between technology and art, probing the ways in which technological advancements shape and redefine artistic expression.

Spatial considerations in Lucier and Tudor's works introduce a spatial dimension to the sonic experience. The deliberate arrangement of elements impacts not only how we perceive the sounds but also how we engage with the artistic expression. These spatial dynamics open avenues for research into the psychological and perceptual aspects of spatial sound, enriching our understanding of how the physical arrangement influences the overall artistic experience.

Dynamic interpretation, a hallmark in both artists' compositions, delves into the fluidity of musical expression. The absence of a fixed score invites performers to actively shape the sonic outcome, emphasizing the improvisational and interpretative nature of experimental music. This aspect prompts reflection on the evolving roles of composer, performer, and audience within the context of experimental sonic exploration.

2.2 Graphical Notations and Electronic Music

The complicated dance among graphical notations and digital music composition stands as a charming realm inside the huge landscape of sound artwork. In the area of digital music, traditional notation systems, rooted in a time/pitch lattice logic, often stumble whilst seeking to seize the nuanced beauty of synthesized soundscapes [43]. The knowledge has made researchers look for other ways with graphic notation emerging as a transformative bridge.

The electronic music landscape, with its reliance on grid-based logic in digital sequencers, calls for notational systems that align seamlessly with the dynamic nature of sound creation. It is for this purpose that graphical notations intersect with electronic music composition to offer composers an intuitive and more expressive means of representation for their sonic ideas.

Dino Rešidbegović's paper, "Composition and Notation of Parameters in Electronic Music: Approximate Reductionist Graphical Notation,"delves into this very challenge. The paper underscores the critical role of notation in contemporary music composition, particularly in the realm of electronic music. With the proliferation of technology and information, composers, students, and professors are faced with an overwhelming array of tools and methodologies. Amidst this complexity, there emerges a need for innovative approaches to notation that can effectively convey the intricate relationships between electronic parameters and compositional structures. [32]

The integration of graphical notations with electronic music composition enriches the compositional terrain by ensuring harmonious coordination between visual articulation and sonic exploration. This symbiotic relationship between graphical notations and electronic music composition serves as a dynamic force that empowers composers to delve deeper into sonic expression and artistic innovation.

Examining the works of pioneers such as Karlheinz Stockhausen ("Mikrophonie I"), John Cage ("Fontana Mix"), Iannis Xenakis (UPIC system), Morton Feldman ("Projection 1"), Cornelius Cardew ("Treatise"), and Hugh Davies ("Shozyg") underscores the practical application and impact of graphical notations in electronic music. These composers embraced visual representation as an integral part of their compositions, exemplifying the potential of graphic notation to navigate the complexities of electronic soundscapes.

2.3 Unifying Composition and Instrument in a Sound Sculpture

With the emergence of cross-genre sound art, visual artists have increasingly utilized musical graphics, showcasing a heightened interest in individual handwriting expressed through musical visuals. This interest contrasts with composers' focus on establishing a new normative graphic canon. [35]

Aligned with this exploration of music creation influenced by the interplay between graphic compositions and tangible interfaces, this research delves into the realm of sound sculptures. Here, the graphic composition undergoes a transformative shift, evolving into an instrument within a public art space.

In this context, it is essential to consider Nelson Goodman's differentiation between two types of artistic expressions: autographical signatures, which are unique and bear the artist's personal touch, and allographic notations, which are standardized and can be reproduced without an original source [14]. This distinction lays the groundwork for understanding the complexities of artistic representation and the evolving relationship between composition and instrument in contemporary art forms.

The mid-1970s witnessed several visual artists, like Gerhard Rühm and Rolf Julius, exploring the intersection of visual art and music. Rühm ventured into visual music, creating Lesemusik and Notenüberzeichnungen, while Julius focused on the structure of sound and its combination with visual elements [33]. Similarly, William Engelen's Verstrijken (2007) transcribes musicians' daily routines into a graphic score, blurring the lines between visual representation and musical performance.[11]

The system implemented in SonicCity further challenges these traditional distinctions. By embedding the graphic composition within the instrument, it blurs the boundaries between composition and instrument, culminating in a unified entity where composition and instrument become indistinguishable. This concept resonates with Eric Maestri's idea of inherent compositions, where the boundaries between composition and instrument vanish, resulting in a seamless fusion.[22]

In this innovative context, participants engage with dynamic musical landscapes. Graphical notations play a key role in shaping the musical experience, blending elements of composition and instrument to challenge traditional boundaries and offer new perspectives in music creation.

2.4 Tangible Interfaces and Public Spaces: Design Strategies

2.4.1 Intuitivness and simplification

Creating tangible interfaces for public spaces necessitates a deliberate focus on intuitiveness, simplification, and accessibility. In the realm of Digital Musical Instruments (DMI), recent advancements in music technology have led to the emergence of Accessible Digital Musical Instruments (ADMIs). A systematic review of ADMIs by Emma Frid (2019) underscores the significance of designing interfaces that users can intuitively grasp. Leveraging established interaction metaphors and streamlining gestural mappings are identified as pivotal elements. Such an approach ensures that individuals with varying levels of musical or technical expertise can seamlessly engage with the interface, promoting a more inclusive and enjoyable public experience.

The evolution of ADMIs not only addresses the technical nuances of interface design but also underscores the broader societal implications of accessibility and inclusion. As ADMIs gain traction across diverse musical contexts, it becomes crucial to cater to the diverse needs and abilities of potential users. Incorporating adaptable features, such as customizable control parameters and intuitive feedback mechanisms, can markedly enhance the user experience for individuals with disabilities or those with limited musical training. By emphasizing inclusivity in design, ADMIs have the potential to democratize music-making, granting individuals from all backgrounds and abilities the chance to creatively interact with music in public spaces. This comprehensive approach not only enriches the musical landscape but also cultivates a sense of community and shared enjoyment among users, highlighting the transformative impact of accessible technology on the future of public musical interactions.[12]

2.4.2 Mappings and Affordances

In electronic musical instruments, the conventional idea that an instrument solely comprises an interface and a sound generator is being redefined. The nuanced relationship between these components, referred to as the "mapping layer,"plays a crucial role in shaping the instrument's character and functionality. Hunt, Wanderley, and Paradis, in their study on parameter mapping in electronic instrument design (2010), highlight that this mapping serves not only as a bridge between the interface and the sound generator but also significantly shapes the instrument's sonic attributes and user interaction dynamics [44]. The intricacies of this mapping can deeply influence an instrument's responsiveness, expressiveness, and intuitiveness. Therefore, careful consideration of mapping strategies is paramount in electronic instrument design to optimize both sonic output and user experience, allowing for innovative and engaging musical interactions.[16]

2.5 State of the Art

In the subsequent section, this paper will uncover a carefully selected array of projects develloped in present days, that have been instrumental in influencing the evolution of SonicCity. They serve not only as informative reservoirs but also as vital benchmarks and offer inspiration and direction to the course of research in this domain. To shape the conceptual and practical facets of SonicCity these projects have been explored in detail by the author.

Scrapple

Figur 2.4: Scrapple Installation 2005.[4]

The Scrapple 2.4 installation by Golan Levin is a pioneering project in the realm of real-time, tangible, and spectrographic performance instruments, introducing several key innovations that redefine the state of the art. It seamlessly integrates augmented reality (AR) into sound art, providing users with dynamic visual feedback. The AR overlay includes a Current Time Indicator, a grid for pitch and time subdivisions, and glowing halos around detected objects. This integration enhances compositional precision through precise visual cues. Unlike traditional systems, the instrument employs a tangible interface using a table with a dry-erase

[4]http://flong.com/archive/projects/scrapple/index.html

surface. Users engage by drawing or arranging objects, each representing a sound-producing mark in an active spectrographic score. This tangible approach allows for intuitive and expressive interaction./

At the core of Scrapple's innovation is its representation of a spectrographic score on the table's surface. Objects placed on the table contribute to the evolving spectrogram, establishing a direct link between visual representation and sonic output. This graphical notation approach redefines real-time music composition.

Scrapple introduces dynamic visual cues, such as glowing halos around detected objects, providing feedback on successful detection and enhancing the understanding of the system's timing and tempo. These features contribute to a user-friendly design accessible to individuals of varying musical expertise. To ensure a spatially regular and clean spectrographic image, Levin incorporates sophisticated image processing techniques. Correction for lens distortion and perspective warping address challenges related to image accuracy and AR image registration. These techniques are crucial for accurate spectral synthesis.[20]

This installation redefines the landscape of spectrographic performance instruments through its augmented reality integration, tangible interface, innovative graphical notation, dynamic visual cues, and advanced image processing techniques. These elements collectively mark Scrapple as a significant advancement in the state of the art for real-time, tangible, and spectrographic performance instruments.

2.5.1 Tangible Scores

Tangible scores have emerged as a groundbreaking innovation in the domain of musical interfaces. Their integration with concatenative synthesis has set new standards in gesture-to-sound mapping [5]. A distinctive feature of these tangible scores lies in their inherent graphical notation, seamlessly embedded within their circuitry [30]. This graphical notation provides performers with a visual representation of musical structures and gestures, enhancing both the tactile and visual dimensions of music creation.

Leveraging advanced melodic descriptors such as Mel Frequency Cepstral Coefficients (MFCC) [5] and the Bark Frequency Cepstral Coefficients [36], these systems enhance the intricacy of real-time timbral recognition. Machine learning algorithms further amplify this responsiveness, pushing the boundaries of musical expression.

Their adaptability shines particularly in live concert settings. Here, tangible scores empower performers to explore improvisational avenues while ensuring the continuity and coherence of the musical narrative [36]. The graphical notation embedded within these scores offers a dual advantage: it guides the performer's

[5]https://tamlab.kunstuni-linz.at/projects/tangible-scores/

Figur 2.5: One of the many Tangible Scores.[5]

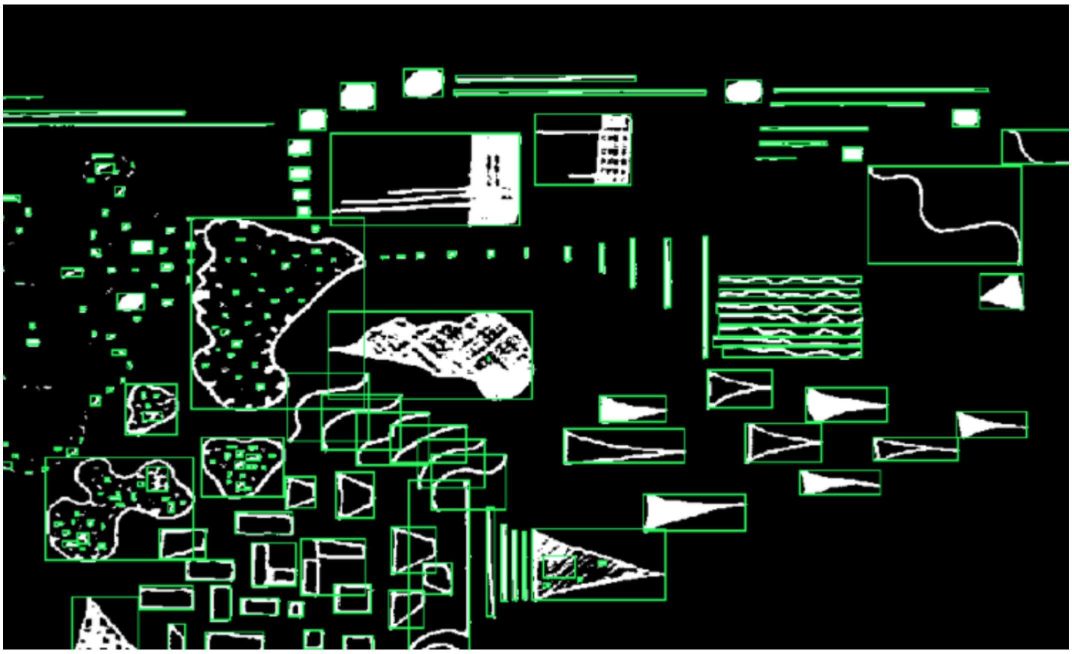
physical gestures while also serving as a visual roadmap for interpreting and modulating sound [30]. This flexibility paves the way for seamless integration with diverse sonic environments, and offers artists an unparalleled freedom in crafting their sonic visions. [36].

2.5.2 CABOTO

CABOTO [25] is an innovative system designed for performing electronic music through graphical notation. It integrates hand-drawn sketches with advanced technology to interpret and translate these graphical elements into real-time sound synthesis. The system employs optical and symbolic-raw hybrid scanning techniques to interpret hand-drawn graphical notations. The optical scanner captures overall mass or luminance, providing an unpredictable source for sound synthesis. Meanwhile, the symbolic-raw approach identifies and classifies shapes based on their contours and waveforms.

CABOTO employs a unique mapping strategy that draws inspiration from studies on human perception and waveforms. Research by Ramachandran and Hubbard, derived from K¨ohler, indicates a human brain feature linking shape and

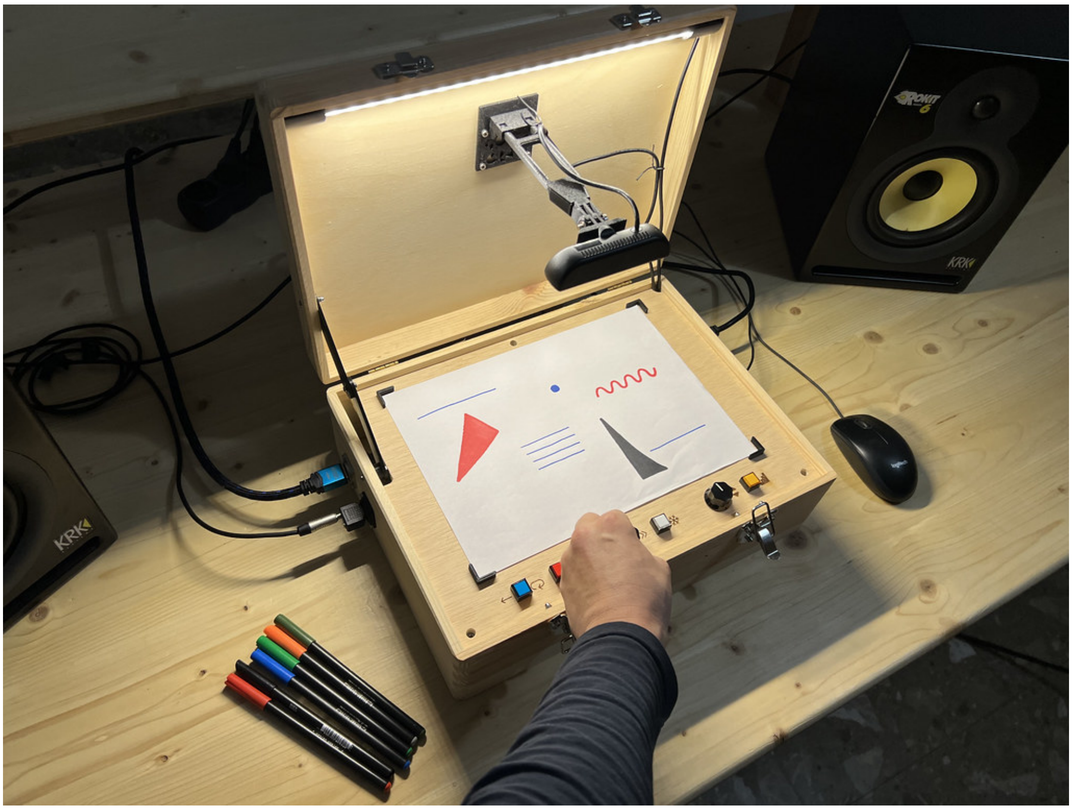
[6]https://www.nime.org/proceedings/2018/nime2018$_{p}aper$0010.pdf



Figur 2.6: CABOTO's Blobs recognition applied to the example score.[6]

sound [31]. In CABOTO, this concept translates to the graphical representation of sound pressure waves. A sharper waveform corresponds to a harsher sound due to its complex spectrum, while a sinusoidal-like shape produces a smoother sound with fewer spectral components. This understanding has been integrated into the system's sound synthesis processes to create a polymorphic mapping. Different synthesis strategies are employed for various sonic events, allowing for a diverse range of sound outputs based on the interpreted graphical shapes [25].

CABOTO is designed with a modular logic, integrating various software components through Open Sound Control. The image processing module is developed using Max/MSP with additional optimization in Java and C++. The sound synthesis engine is built in Supercollider, providing a flexible framework for complex sound event generation [25]. In live performances, the system operates with a light table, camera, laptop, audio interface, and MIDI controller. The audience is presented with a visual projection of the score, the navigators' scopes, and trajectories. The live setup allows for real-time modifications to the score and offers a unique interactive experience for both the performer and the audience [25].



Figur 2.7: The Sonògraf physical form. For broader use a software simulation version was developed.[7]

2.5.3 Sonògraf

Very similar to CABOTO, the "Sonògraf"stands as a graph based electronic audiovisual instrument. Designed with the aim of enhancing music education in primary schools, this innovative tool transforms drawings or collages into musical compositions as gestural strokes and geometric figures are converted into electronic sounds. Equipped with a range of buttons and potentiometers, the Sonògraf offers real-time manipulation of the "sonification"properties of the drawings. Users can control the speed, tempo, and pauses of the resulting music, as well as determine its scales and tonalities, providing an interactive and customizable musical experience.[29]

Beyond its educational application, the Sonògraf features audio and video outputs, enabling it to be showcased in audiovisual concerts suitable for diverse audiences. This multifaceted instrument not only serves as a learning tool but also as a performance device.

[7]https://www.playmodes.com/home/sonograf/

The Sonògraf has been crafted to ensure intuitive playability for users of all ages, emphasizing intuitive learning and connecting the realms of visual and musical expression.[29]

2.5.4 Every Vessel

Every Vessel presents a fascinating approach to graphical notations, translating musical compositions into tangible sculptures. Conceived by the avant-garde trio Flamingo, consisting of Chris Heenan, Adam Pultz Melbye, and Christian Windfeld, along with media artist Chandrasekhar Ramakrishnan, this multimedia project seeks to intertwine music and visual art in a innovative manner.

The project's core lies in its implementation of advanced technologies. Drawing inspiration from Edgar Varèse's notion of music as "organised sound,"Flamingo developed specialized software [41]. This software employs digital signal processing and artificial intelligence to 'listen' to their musical compositions. By identifying the underlying organizing principles of the music, the software translates these auditory patterns into spatial units.

These spatial units, imbued with the essence of the music, are then recombined and sculpted to create unique artworks. Each sculpture serves as a visual representation and tangible embodiment of a specific musical composition.

In terms of presentation, Every Vessel transcends conventional exhibition formats. During Flamingo's month-long residency at Kunsthal Nord in Aalborg, Denmark, in May 2017, the project unfolded as a dynamic performative installation. After each of their three daily concerts, the musical performance was transformed overnight into a new sculpture. Over the course of the residency, this process resulted in the accumulation of 72 distinct sculptures, each narrating a unique musical journey.[27]

Figur 2.8: Sculptures after performances.[8]

2.5.5 Other sources of inspiration

In the process of developing SonicCity, inspiration was drawn from various projects that influenced certain design decisions. While some of these projects are not directly related to graphical notations, they provided valuable insights and ideas that have been integrated into the project's framework.

Orbita by Playtronica 2.9 is a music device that interprets color, gesture inputs, and spinning motion into MIDI data, allowing for real-time control over sound parameters through its integrated interface [38].

Incorporating the design of a Lazy Susan as its foundation, Lazy Susan translates musical body gestures into sounds through sonic feedback, modulated by turning speeds and analog filtering using objects like finger cymbals and papers 2.10 [45].

[8] https://www.kunsthalnord.dk/UserFiles/Kataloger/2017-05-06$_{E}veryVessel.pdf$

[9] https://orbita.playtronica.com/

Figur 2.9: Orbita. [9]

Figur 2.10: Performance with Lazy Studies at Stanford University. [10]

[10]https://www.youtube.com/watch?v=aEKjL76IT-w

Akko Goldenbeld's "Citymusic"installation sonifies the heights of buildings in Eindhoven and Amsterdam using a piano and a rollable city map, where buildings trigger piano notes based on their height as the hammer lifts and falls [13].

These varied influences have shaped SonicCity's design and have enhanced its functionality and user interaction by providing insights into more dynamic musical experiences.

Kapitel 3

SonicCity

3.1 Shaping Graphical Notations through Sonification

SonicCity presents an innovative approach to graphical notations by emphasizing sonification over traditional compositional elements. In this system, the musical score is inherently encoded within the software , awaiting activation through user interaction. In SonicCity, graphical notations are reimagined as tangible objects that represent specific musical elements within the composition. These tangible graphical objects serve a dual purpose: to visually communicate the musical score, guiding users on how to interact with and interpret the composition while also facilitating the conversion of these visual cues into audible feedback.

Properties such as object height, color, placement, and arrangement of these objects directly influence sound parameters, turning them into sonified entities. This dynamic integration of visuals and sound transcends static musical note representations, transforming the graphical score into an active participant in the sonification process.

Users are empowered to actively shape the auditory landscape by manipulating these sonified graphical elements, making the music-making experience both interactive and intuitive. Through SonicCity, the intricate relationship between visual and auditory dimensions is explored, emphasizing the symbiotic relationship between visual representation and sonic expression. The system delves into how we understand and interact with sound in a tangible and engaging manner.

3.2 Objects for Graphical Notations Vocabulary

In the realm of art, where audiences often have limited time to engage with exhibits, the design of a sonic sculpture should strike a balance between being easily understandable and inviting, without becoming monotonous or losing its intrigue too quickly. SonicCity achieves this delicate balance by adopting an unconventional graphical notation approach that incorporates familiar urban objects into its design to clearly communicate their form of interaction.

This departure from traditional graphical notation methods, which typically rely on abstract shapes, symbols, or waveforms, serves to enhance the sonic experience by leveraging our innate ability to recognize and understand real-world objects. Research supports this innovative approach, indicating that the use of identifiable objects can significantly amplify user engagement and comprehension of the sonic sculpture [3].

By associating specific sound parameters with common urban objects, SonicCity empowers users to creatively shape the auditory landscape of a cityscape. Drawing upon the principles of 'graphic notation,' which emphasize the relationship of the score to pitch as noted in [28], the metaphorical association of building heights with pitch in SonicCity mirrors this concept. This intuitive connection between visual elements and sound parameters not only facilitates meaningful contributions to soundscape creation but also ensures the sonic sculpture remains inviting and accessible to individuals with diverse backgrounds and varying levels of musical expertise.

SonicCity's design philosophy aims to align itself with interaction design principles [19], emphasizing transparent relationships between physical actions and resulting sounds. The incorporation of recognizable objects further promotes inclusivity within SonicCity's sonic environment, enabling a broader audience to feel actively involved in the collaborative art of sound and sculpture creation.

In Section 3.5.3 Fig.3.10, all interactive elements for the graphical vocabulary are presented.

3.3 Sound Design

For the sound design of the interactive sculpture, the artistic goal was to compose a piece reminiscent of a futuristic cityscape. Drawing inspiration from composers such as John Cage, Brian Eno, and other contemporary producers who engage in the composition of IDM (Intelligent Dance Music) , the objective was to create a harmonically pleasing yet ambient composition. The aim was to provide a sense of immersion, evoking emotions and transporting listeners to an imaginative urban environment.

The overall aesthetic vision was to craft a sonic landscape that reflects the bustling energy and dynamic atmosphere of a futuristic city. By blending ambient textures with melodic elements, the intention was to create a captivating auditory experience that captivates the audience's attention while allowing for moments of introspection and contemplation.

The creative process involved experimenting with various sound synthesis techniques and sonic textures to capture the essence of a futuristic cityscape. Additive synthesis was chosen as the primary synthesis method due to its capability to generate complex sounds by combining multiple sine waves. This method resonates with the metaphorical concept of stacking blocks, where individual sine waves represent the foundational elements that, when combined, create a harmonious and intricate sonic texture.Through the manipulation of sound parameters and the integration of real-world sounds, such as urban ambiances and technological noises, the goal was to construct a multi-dimensional sonic environment that resonates with the audience.

In terms of user experience, a focus was put on providing a seamless and intuitive interaction with the sound sculpture. By designing the sonic elements to respond dynamically to user input, the aim was to enhance the sense of immersion and engagement. The mood of the composition fluctuates, mirroring the ebb and flow of excitement within the cityscape, allowing users to influence the trajectory of the sonic journey through their interactions.

3.4 Tangible Interaction and Design Evolution

While the manipulation of building blocks doesn't directly show participants what is happening in the software, the act of arranging these physical objects on the surface becomes a form of tangible and embodied graphical notation. The visual representation and control are transferred from the digital realm to the physical space, creating a more intimate experience for the participants.

In this scenario, the graphical notation is manifested in the physical arrangement of the building blocks, and the software acts as the underlying engine that translates these physical interactions into sonic output. The graphical representation is implicit in the tangible actions, offering a different dimension to the concept of graphical notation where participants engage with both the physical and digital aspects of the composition process.

3.4.1 First Iteration

Departing from the initial concept developed by Kinan Sarak, as depicted in 3.1, a new design has taken shape. Sarak's original concept operated akin to a 3D printer, employing laser movement guided by a G-code implementation. In this innovative design, entire objects could be precisely positioned and subsequently sonified. However, recognizing the intricacies and precision demanded by such an advanced approach, we envision this as a prospect for future iterations. The design, while promising, necessitates more time and the incorporation of expensive technical appliances to fully realize its potential. In light of these considerations, we have opted for a simpler version, making certain concessions in aesthetics to prioritize feasibility and practical implementation for the current stage of development. This strategic decision allows us to lay a robust foundation, facilitating gradual advancements toward the envisioned sophisticated iteration in subsequent phases of the project.

Figur 3.1: Concept design for the sound sculpture developed by Kinan Sarak.

In envisioning the first iteration of our project, we have deliberately shifted our focus toward a model that prioritizes human interaction over an extensive reliance on motorized components. In this simplified rendition, the initial movement and positioning of the surface are conceptualized as a gyroscope-inspired motion 3.2. Rather than incorporating an intricate system of motorized elements, our design features a static laser. The crux of the interaction lies in the movement of the gyroscopic "plate."This deliberate choice not only streamlines the technical aspects but also encourages a more immersive experience for participants. By utilizing the gyroscope motion, individuals can dynamically engage with every object on the surface, adding an element of tactility and personal involvement to the overall sonic exploration. This approach, while sacrificing some of the complexities of the advanced model, aligns with our vision for an accessible and engaging initial iteration of the interactive sonic sculpture.

Unfortunately, the gyroscopic movement had to be excluded in this version due to technical challenges arising from the interference with the distance sensor measurements during plate movement.

Figur 3.2: Very early prototype of the gytoscopic movement structure.

3.4.2 Current Iteration

For the current iteration, a significant modification was made to enhance stability and control by transitioning the surface from a vertical to a horizontal orientation. This alteration not only ensures a more robust foundation but also facilitates improved precision and maneuverability in the movement dynamics. As surface, a metal "lazy Susan"turntable is used not only to facilitate physical interaction with the sound sculpture but also as a strategic choice for the functionality of the algorithm's implementation. The patch utilizes blob recognition video processing technique and the turntable's rotating movement ensures that the camera detects the objects effectively, enhancing the overall interactive experience by requiring kinetic engagement with the composition.

The Lazy Susan was mounted inside a frame crafted from a single piece of acrylic. This material was selected primarily for its transparency, allowing users to maintain focus on the turntable and accompanying objects. The acrylic was laser-cut and bent to achieve the desired shape. The design and positioning of the frame were deliberately chosen to offer users an unobstructed and immersive interaction with the elements.

Departing from the initial concept of designing a singular object for interaction, the project's focus has evolved towards creating a diverse set of objects to enhance user engagement and flexibility. This shift was inspired by the principles discussed in 3.2, emphasizing the importance of maintaining a cohesive visual language even when incorporating multiple elements.

The central idea of constructing a miniature cityscape emerged, offering users a more dynamic environment to interact with. To bring this concept to life, a variety of materials and techniques were employed to create distinct yet harmonious elements within the city.

Firstly, a series of modular building blocks were 3D-printed. These blocks were inspired by the design aesthetics of a 3d printable game[1] , adapting its modular and scalable nature to suit our project's needs. The 3D-printed blocks not only provide a base for building and customizing the city but also add a tactile and three-dimensional aspect to the user experience.

To introduce color and diversity into the cityscape, LEGO bricks were incorporated as vibrant, interchangeable elements. These colorful LEGO pieces serve as interactive components that allow users to their city, reflecting their creativity and preferences.

Additionally, to add a unique touch to the city, three fully crafted buildings were designed using paper materials and embedded with magnets. These magnetized buildings offer a stable and fast way for users to attach and position them within the city layout for both visual appeal and interactive possibilities.

3.5 Technical Implementation

This section provides a comprehensive overview of the intricate technical components, methodologies, and processes involved in the creation and operation of the sculpture. The system architecture as shown in Fig.3.6 is comprised of the sound sculpture interfaced with a distance sensor, which transmits data to an ESP32 microcontroller, and a camera directly connected to the laptop. This data is then processed and managed by a Max/MSP [2] patch executing on a laptop.

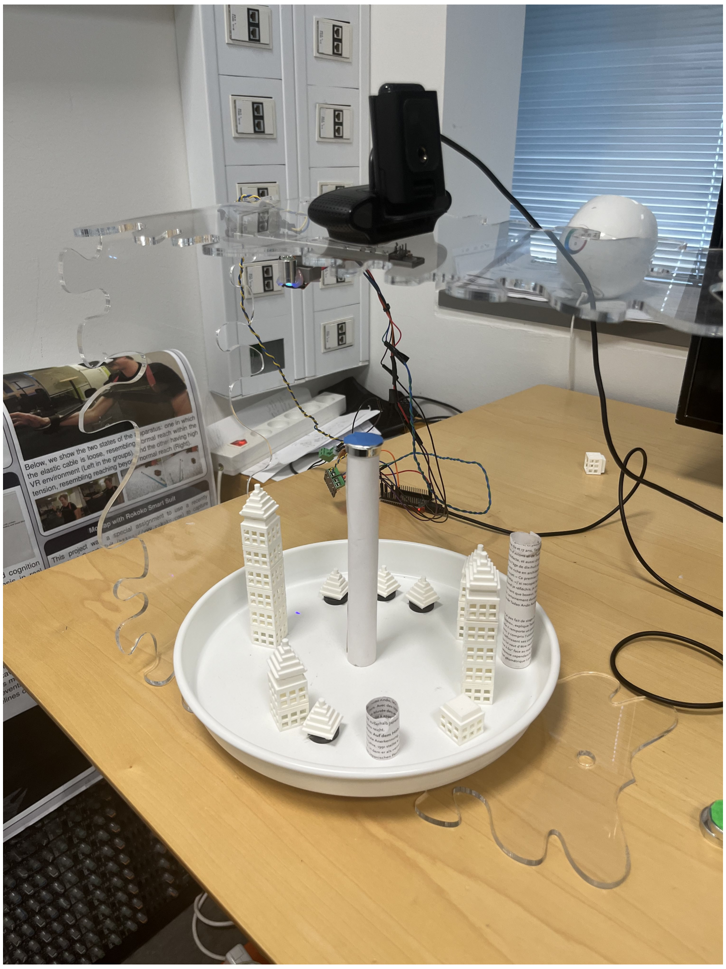
3.5.1 Hardware Components

The backbone of the sound sculpture comprises two primary hardware components: the Time-of-Flight (ToF) distance sensor and a Logitech 1080HD camera . These devices serve as sensory input mechanisms, capturing essential data from the physical environment to inform the real-time sound manipulation processes.

- **Time-of-Flight (ToF) Distance Sensor (ToF 1020):** The ToF distance sensor plays a critical role in capturing height data from objects within the sculpture's vicinity. Utilizing infrared light, the sensor precisely measures distances, providing invaluable feedback on the spatial arrangement of objects. To facilitate accurate distance measurements, a laser light was employed as a visual

[1] https://www.printables.com/en/model/71469-skybridge-the-board-game

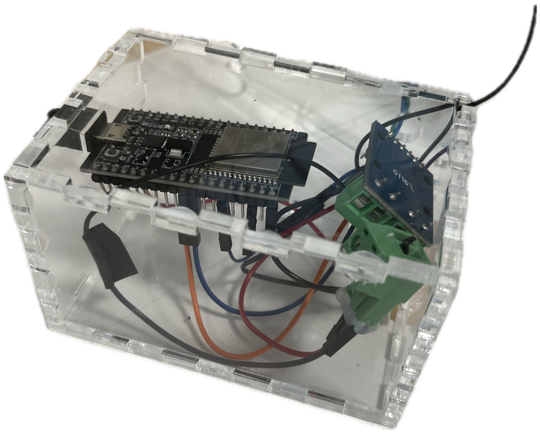
[2] `https://cycling74.com/products/max`



Figur 3.3: Current prototype for SonicCity.

indicator to mark the point being measured by the distance sensor. The laser light was aligned and positioned precisely to correspond with the sensor's measurement point. For enhanced spatial interactions, both the distance sensor and the laser light were mounted on a motorized fader as shown here 3.4. Initially, the motorized fader was programmed to oscillate at randomized intervals, moving back and forth at a moderate speed to introduce spatial variability. However, due to the inherent noise associated with the Pulse Width Modulation (PWM) control mechanism, this oscillatory movement was omitted in the prototype stage. An enclosure was laser cut to host all wiring from the system connected to the ESP32 together with an H-Bridge for the motorized fader 3.5.

Figur 3.4: The distance sensor and laser mounted on the fader.



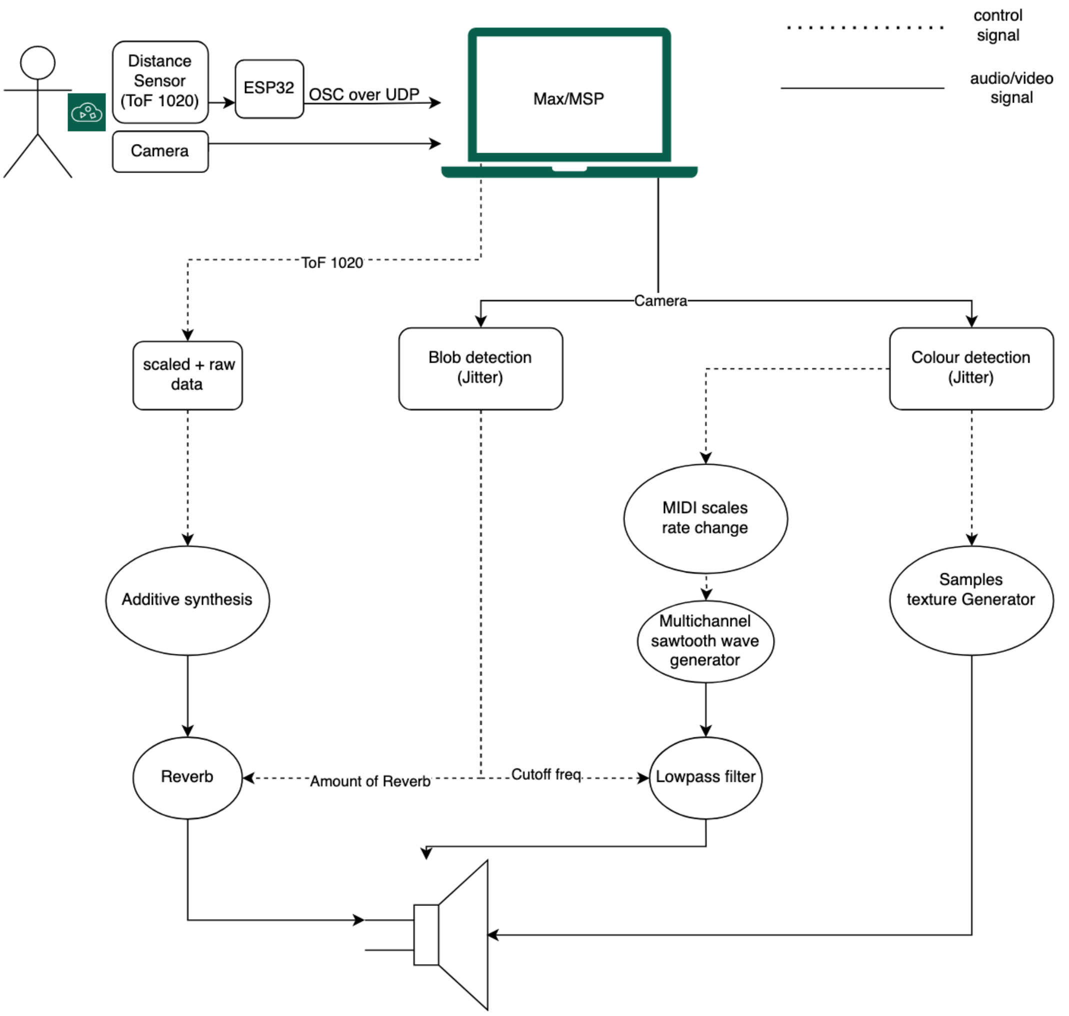
Figur 3.5: Enclosure for ESP32.

- **Logitech 1080HD Camera:** The Logitech camera serves as the visual input device, capturing color and number of objects information from the environment. This camera's high-resolution capabilities enable accurate color detection and object identification, facilitating dynamic interactions within the sculpture.

3.5.2 Software

Max/MSP serves as the central processing unit for interpreting sensor data and generating corresponding sound outputs, orchestrating a symphony of digital algorithms and processes to bring the sculpture to life.

Custom scripts and algorithms are developed within Max/MSP to translate sensor inputs into dynamic sound manipulations. These processes enable the sculpture to respond in real-time to changes in the physical environment.



Figur 3.6: System Architecture and Signal Flow Diagram of SonicCity.

Data Processing

The ToF distance sensor data is initially processed using an ESP32 microcontroller, serving as an intermediary between the physical sensors and the digital processing environment of SonicCity.

Using the Arduino framework, the code reads raw distance data from the ToF sensor connected via I2C. This raw data undergoes preliminary filtering using a simple exponential smoothing algorithm within the microcontroller.

After filtering, the ESP32 formats the data into OSC messages using the OSC (Open Sound Control) protocol. These OSC messages encapsulate the filtered distance value, which is then transmitted over Wi-Fi using UDP to a predetermined IP address and port, in this case is the laptop running the Max/MSP patch.

The processing and scaling process in Max/MSP is explained in Table 3.1 and the Max/MSP implementation of data reception and scaling can be seen in Fig. B.1

Step	Description
UDP Message Reception	The system uses the `udpreceive` object to listen for UDP messages on port `4000`.
Routing	The `route /sensorvalue` object directs incoming messages based on the `/sensorvalue` prefix.
Line Object	The `line 1.` object initiates a linear ramp or transition.
Clipping	The `clip 20. 400.` object ensures that incoming values are bounded between `20` and `400`.
Scaling	The `scale 20 300 1. 0.` object linearly scales the clipped values between `20` and `300` to a new range between `1.` and `0.`.
Range Division	The scaled values are split based on the heights of building blocks.
MIDI Note Generation	The system maps the divided values to a 10-note MIDI scale, with the lowest values corresponding to the lowest MIDI notes and the highest values to the highest MIDI notes.

Tabel 3.1: Max/MSP ToF Data Processing and Scaling Steps

The video processing workflow 3.7 in Max with Jitter starts with the Video Source from Camera, which is captured using the `jit.qt.grab` object.

The video stream then splits into two main paths:

- **Color Tracking Path** B.2:
  - `jit.rgb2luma`: Converts RGB to Luma.
  - `suckah`: Tracks specific colors in the video.
- **Blob Processing Path** B.3:
  - `jit.op @op *`: Adjusts brightness and contrast.
  - `jit.slide`: Smoothens video frames.
  - `jit.op @op >`: Segments video based on pixel intensity.
  - `jit.op @op -`: Calculates frame differences for motion detection.

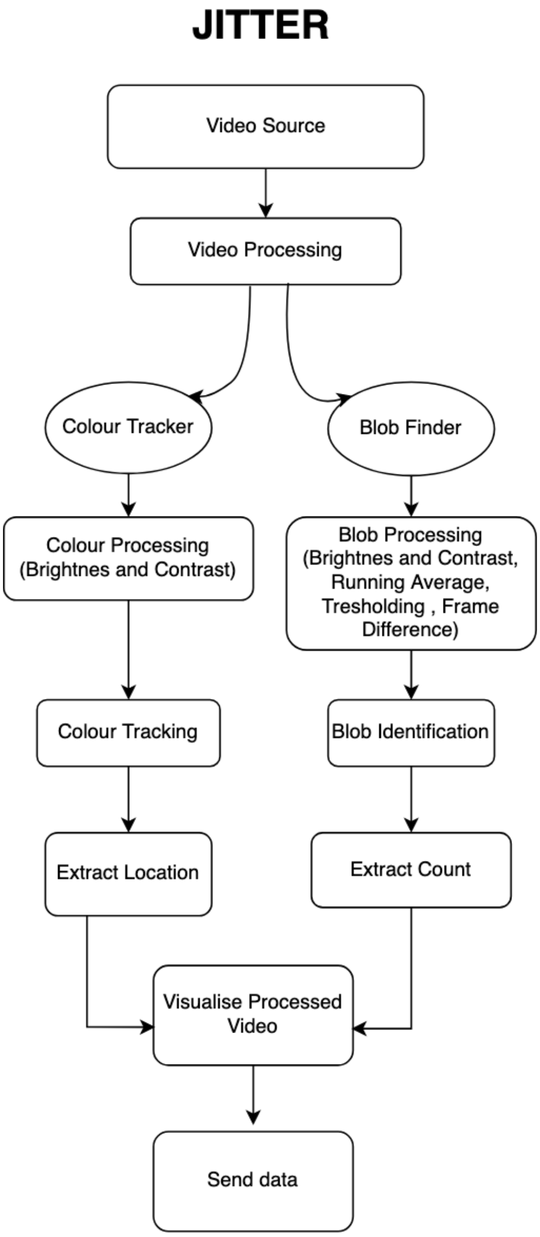
After processing, the **Blob Identification** stage uses:

- `jit.findbounds`: Locates blob boundaries.
- `jit.centroids`: Computes blob centroids.

The final **Visualization** stage employs:

- `jit.window/jit.pwindow`: Displays the video.
- `jit.xfade/jit.op @op +`: Overlays blobs and centroids on the video for visualization.

The process is visualised in Fig. 3.7



Figur 3.7: Video Processing Workflow in Max with Jitter

Additive Synthesis Implementation

Additive synthesis involves the combination of multiple sine waves (partials) to create complex harmonic structures. At the heart of additive synthesis in Max/MSP lies the `cycle~` object, which generates a sine wave at a specified frequency. This object serves as the fundamental building block for creating individual sine wave components, also known as overtones. To shape the amplitude of these sine waves over time, the function object is employed to generate an ADSR (Attack, Decay, Sustain, Release) envelope. This envelope dictates how the amplitude of the sine wave evolves from zero to maximum and back to zero over a set duration, typically defined using the set domain message.The true power of additive synthesis in Max/MSP is realized when multiple oscillators are combined to create a single, harmonically rich tone. Each oscillator's frequency can be set by multiplying the fundamental frequency (controlled by the cycle object) by integer or non-integer values, allowing for both traditional harmonic overtone series and experimental inharmonic relationships.

For this specific implementation, the integration of inharmonic elements deviates from the traditional approach of using only integer values for frequency multiplication. This deviation allows for the exploration and creation of non-standard harmonic relationships and textures, resulting in more diverse and unconventional soundscapes.

In the realm of additive synthesis within Max/MSP, oscillators derive their frequencies through the multiplication of the fundamental frequency, controlled by `cycle~` , with both integer and non-integer values. This approach enables the creation of traditional harmonic overtone series as well as innovative inharmonic relationships.

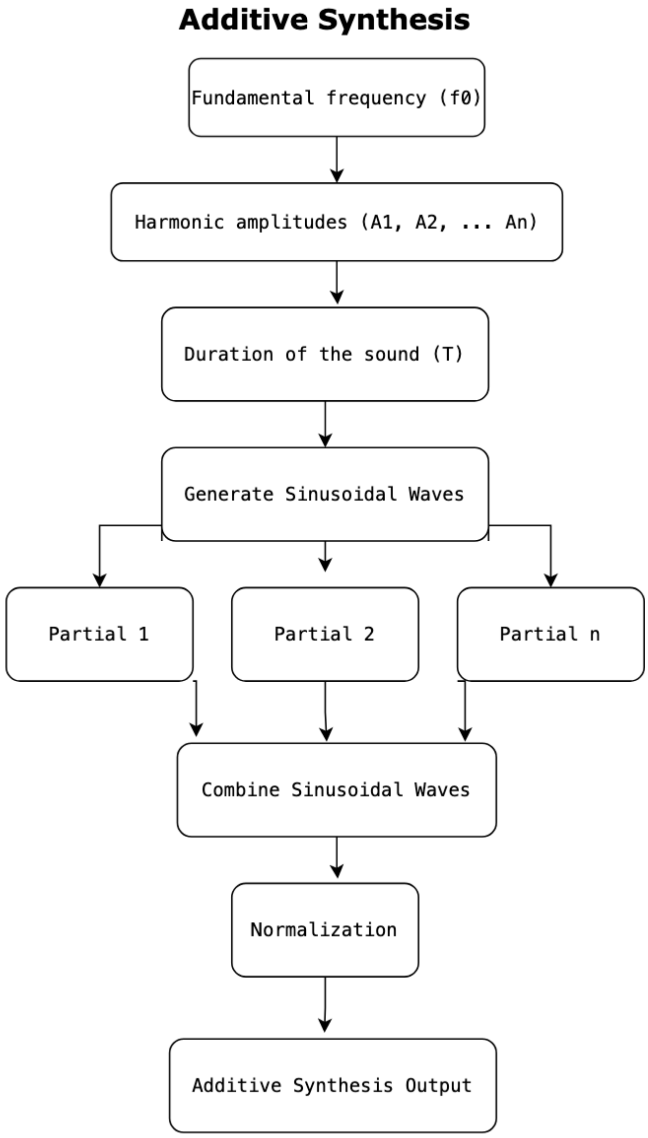
In this specific implementation, a departure from conventional frequency multiplication techniques is observed through the integration of inharmonic elements. The modulation of the additive synthesis model by scaled sensor data establishes a direct link between the sensor input and the primary harmonic components of the auditory output. The scaled sensor data, ranging from 0 to 1, introduces inharmonicity by modulating the partials with fractional values.

Conversely, the non-scaled data from the distance sensor, quantified in millimeters, shapes the remaining partials of the additive synthesis. These data points instigate distinct inharmonic textures based on the raw distance data, devoid of any normalization or scaling.

The inherent instability and jitter associated with the distance sensor contribute to the unpredictability evident in the non-scaled sensor data. This variability, when combined with the modulation of the scaled sensor data, culminates in unique sonic artifacts and intricate harmonic structures.

This approach facilitates direct sonification, wherein the fluctuations in the sensor data are audibly represented through the modulation of inharmonic partials.

Sonification serves as a means of translating numerical data into tangible auditory experiences, providing an intuitive method for data interpretation [15].



Figur 3.8: Additive Synthesis Implementaion Process

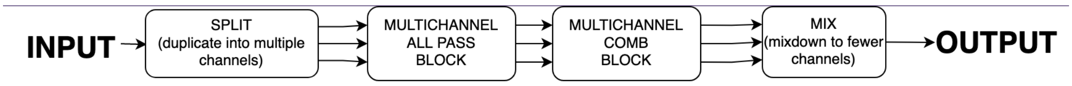
Texture Generator

The implementation of the texture generator B.4 uses at its core `mc.groove` to produce textured sounds by manipulating pitch and time. It starts with loading audio into a buffer named "sound"which `mc.groove` references. The audio loops continuously for seamless playback. A 16-channel signal is provided to `mc.groove` , enabling multi-channel processing. Real-time pitch and time variations are introduced using a deviation function controlled by a slider. This setup allows users to experiment and easily create dynamic sonic textures. Color-coding the 3 texture generators serves as a visual and conceptual aid to distinguish between various sound textures. The choice of colors—red, blue, and green—corresponds to the specific sonic characteristics and emotional associations of each sample as explained in 3.2.

Reverb Implementation

Reverberation can be effectively simulated through a straightforward approach leveraging the concept of quantity strategy. By integrating numerous delay elements, a reverb effect can be synthesized. In this method, each delay represents a reflection within a simulated space, with its duration akin to the room size, and the extent of feedback determining the decay time. Employing the versatile `mc.` object in Max/MSP, a series of comb and allpass filters are generated to emulate these delays and reflections. Combs, characterized by their feedback delays, play a pivotal role in this process. Introducing variability and naturalism, the deviate message enables the incorporation of random delay values, contributing to the overall reverb texture. Crucially, by distributing delays evenly, the resulting effect closely resembles traditional reverberation. This approach maintains clarity while offering a nuanced understanding of how simple structures, when strategically orchestrated, can result in complex acoustic phenomena. Object Detection and Reverb Control: Blob detection algorithms within the Jitter identify objects in the camera feed. The number of detected objects influences the `dry/wet` signal, creating dynamic sonic feedback based on environmental factors.

The Max/MSP implementation can be visualised and described in more detail like this:



Figur 3.9: DSP schematic for multichannel reverb implementation.

- **Stereo Input Signal:** Represents the incoming stereo audio signal.
- **Channel Multiplexing:** This operation combines the stereo channels into a single multichannel signal to facilitate parallel processing.
- **Gain Attenuation Matrix:** This component attenuates the signal to prepare for the subsequent stages of filtering.
- **Channel Expansion:** This process replicates channels to create multiple parallel signal paths, effectively increasing the number of channels for more complex filtering.
- **Filter Bank:** This is where the actual reverb effect is synthesized. The combination of allpass and comb filters (represented by `mc.allpass~` and `mc.comb~` in Max/MSP) introduces reflections and decay to simulate reverberation.
- **Channel Reduction:** Post-filtering, this step reduces the number of channels back to stereo by summing and averaging the multiple parallel processed channels.
- **Stereo Downmixing:** The final stage combines the processed channels into a stereo output signal, ready for playback or further processing.

Multichannel Sawtooth Wave Generator

The implementation of the sawtooth generator B.5 is centered around the manipulation and generation of multichannel audio. A main element within this audio processing ecosystem is the `mc.saw~` object. This object is specifically designed to enable the creation of multiple sawtooth waves across different channels. The integration of this multichannel capability serves to enhance the spatial dimension of the audio output while creating a more immersive and expansive sound field. Complementing the `mc.saw~` object, the patch further incorporates various `mc.` prefixed objects, each contributing to the nuanced manipulation and shaping of the multichannel sawtooth waves. Together, these components facilitate dynamic sound sculpting, encompassing spectral shaping, amplitude modulation, and spatial distribution control. The resulting composition is a harmoniously balanced and dynamically expressive multichannel audio experience. Musical Scale and Rate of Change: An implementation of `mc.saw~` in Max/MSP facilitates the playback of musical scales at different rates of change. The rate of change between scales is determined by the sensor data and is color-coded to provide visual feedback.

3.5.3 Mappings

Fig.3.10 displays the mappings between the sculpture's elements and the sound engine parameters. It shows how each interactive part of the sculpture directly influences or controls specific functions in the software.

Element	Description	Mapping
Building Blocks	Modular components used to create varying heights, influencing pitch and partials modulation in additive synthesis. Lower heights equate to lower pitches, and taller heights result in higher pitches.	Object Height → Additive Synthesis
Red Lego	The red color represents more disruptive or intense sounds within the texture generator, adding dynamic and attention-grabbing elements to the soundscape.	Red → Texture Generator 1
Blue Lego	This color signifies subtle wind sounds within the texture generator, contributing to the ambient backdrop of the sonic environment.	Blue → Texture Generator 2
Green Lego	The green color is associated with bird sounds in the texture generator, introducing natural and organic sonic textures reminiscent of outdoor environments.	Green → Texture Generator 3
Lowest Circular Building	Symbolizes a rapid rate change between the 3 music scales.	Color-Coded Cap → MIDI Scales Rate Change
Middle Building	Denotes a moderate rate change between the 3 music scales.	Color-Coded Cap → MIDI Scales Rate Change
Highest Building	Represents a slow rate change between the 3 music scales.	Color-Coded Cap →MIDI Scales Rate Change
Amount of Objects Placed	The number of objects placed on the spinning plate influences the sonic characteristics, determining the intensity and presence of reverb and controlling the frequency range of the low-pass filter.	Number of Objects → Reverb and Low-pass Filter

Figur 3.10: Mappings.

Kapitel 4

Evaluation

This chapter discusses the evaluation of SonicCity. The evaluation process involved inviting participants to interact with the sculpture, providing insights into their experiences and perceptions. During the evaluation sessions, participants were encouraged to manipulate graphical elements, interact with objects, and explore the sonic environment created by the sculpture. Their interactions were observed, and feedback was collected through structured questionnaires designed to assess various aspects of the experience.

The data obtained from the evaluation sessions provided valuable insights into several key areas, including engagement, interactivity, sound design, usability, and overall satisfaction. Each participant's feedback and responses were carefully analyzed to identify patterns, trends, and areas for improvement.

The evaluation process provided valuable feedback on the effectiveness of the sound sculpture in engaging participants, facilitating interaction, and delivering a unique auditory experience. The findings from this evaluation will inform future iterations of the sculpture, guiding enhancements and refinements to optimize its artistic and interactive qualities. In the following sections the methods used and the research behind them will be explained, as well as how data was gathered and analyzed, concluding with understanding survey responses and presenting test results.

4.1 Evaluating User Experience

In assessing the user experience of the sound sculpture project, the evaluation process centered on two primary aspects: interactive experience and audiovisual perception. These two dimensions were carefully designed to encapsulate the extent of user interaction and engagement with the project, covering both the tangible interactions with the sculpture's physical components and the perception of its auditory and visual elements.

4.1.1 Interactive Experience

The interactive experience section delves into the depth of engagement and participation users have with the sound sculpture's physical components and interface. This encompasses users' actions in manipulating the sculpture, including interactions with the objects as graphical notations, as well as the resulting feedback. Drawing from methodologies in New Interfaces for Musical Expression (NIME),and DMIs evaluation tactics [34] this evaluation explores novel interaction methods for creating music through technology.

Inclusivity and Accessibility: This aspect evaluates the ease of use and approachability of the sound sculpture, considering factors such as clarity of instructions, comfort during interaction, and likelihood of engagement in various settings.

Engagement and Interactivity: Assessing the degree of involvement and interaction experienced by participants while manipulating objects and exploring the sonic environment. This includes active engagement, encouragement of exploration, level of interaction, desire for continued engagement, and perceived adequacy of interaction time.

4.1.2 Audiovisual Perception and Design

The audiovisual perception and design section focuses on how users perceive and interpret the auditory and visual elements of the sound sculpture. This encompasses subjective experiences of the sounds produced, understanding of graphical notations, and integration of these elements to create a cohesive audiovisual experience.

Sonification and Graphical Vocabulary: Evaluating the effectiveness of graphical notations and sonification techniques in facilitating interaction with the sound sculpture. This includes clarity and intuitiveness of graphical notations, consistency between visual representations and auditory outcomes, and their overall contribution to the unique and enjoyable experience.

Sound Design: Assessing the quality and variety of sounds produced by the sculpture, as well as the relationship between visual appearance and auditory outcomes. This considers factors such as enjoyment of sounds, resonance with personal preferences, and overall satisfaction with the auditory experience.

4.2 Methods

The tests were conducted on campus at AAU Copenhagen in Augmented Performance Lab. The aim was to create a setup that provides participants with an experience akin to being in an art space, where they can engage with the sculpture in an interactive and immersive manner. Example seen in Fig. A.2 A total of 18 participants from different ages and backgrounds engaged with the sound sculpture.

The study consisted of three phases: introduction, interaction with the sculpture, and completion of the questionnaire.

4.2.1 Introduction phase

During the introduction phase, participants arrived at the designated location and were briefed on the study's objectives and procedures. They were then asked to provide informed consent for the recording of their interactions with the sound sculpture. Additionally, participants responded to a series of questions regarding their musical background and prior experience with interactive systems. These inquiries aimed to establish a baseline understanding of the participants' familiarity with music and technology, which could potentially influence their interaction with the sculpture during the subsequent phases of the study.

The choice of questions for the personal survey was carefully considered to ensure relevance to the project and gather pertinent information from participants. Each question was designed to elicit responses that would provide insights into participants' musical background, familiarity with interactive systems, and exposure to art spaces.

Tabel 4.1: Questions relative to participants' background and experiences

1	Are you currently or have you been involved in playing a musical instrument? If yes, please specify the level of proficiency in playing.
2	Do you have any experience in music composition or production? If yes, please specify the level of proficiency in producing/composing.
3	Are you familiar with the concept of graphical notation in music?
4	How often do you visit art spaces or exhibitions?
5	Have you previously interacted with interactive art installations?

The question regarding involvement in playing a musical instrument aims to gauge participants' level of musical proficiency, which can influence their interaction with the sound sculpture. Proficiency levels can indicate varying degrees of familiarity with musical concepts and techniques, potentially impacting participants' ability to engage with the sculpture's interactive features effectively.

Similarly, inquiring about experience in music composition or production helps to identify participants who may have a deeper understanding of musical structures and elements. This knowledge can influence how participants perceive and interact with the sound sculpture's auditory components, such as their ability to discern different sounds or appreciate compositional techniques.

The questions about graphical notation and sonification serve to assess participants' familiarity with key concepts relevant to the project. Understanding these concepts is crucial for participants to comprehend the visual and auditory aspects of the sound sculpture effectively. Participants who are familiar with graphical notation and sonification may have an easier time interpreting and engaging with the sculpture's graphical representations and sonic transformations.

Additionally, questions about visiting art spaces and interacting with interactive art installations provide context for participants' exposure to similar artistic experiences. This information helps understanding participants' prior encounters with interactive artworks, which can influence their expectations, attitudes, and engagement with the sound sculpture during the study. After filling in the personal survey each participant was taken towards the sound sculpture where next phase would take place.

4.2.2 Interaction phase

During the interaction phase, participants were introduced to the physical components of the sound sculpture, including the objects and their placement. They were instructed on how to manipulate these objects and where they should be placed within the sculpture's environment to achieve desired sonic outcomes. Additionally, participants were guided on how their actions with the objects would influence the sound parameters, such as pitch, texture, and reverb. This comprehensive overview ensured that participants had a clear understanding of how to interact with the sculpture effectively. To facilitate their engagement, a screen displaying information about the graphical vocabulary was placed in front of them A.1. This allowed participants to refer to the graphical vocabulary at any time, even while actively engaging with the sculpture. After that they were given 10 minutes to interact with SonicCity. A timer was set to ring upon completion of the designated time period, reminding participants that their interaction time had concluded. This approach aimed to ensure a more accurate assessment of their experience and preferences. By providing a structured interaction session with a defined duration, participants were better equipped to evaluate aspects such as whether they felt the allotted time was sufficient or if they desired more time to engage with the sound sculpture.

4.2.3 Evaluation Phase

In the final phase, participants were asked to complete a questionnaire comprising both quantitative and qualitative components. The quantitative section consisted of questions rated on a scale from 1 to 5, aiming to gauge participants' overall satisfaction, level of engagement, and perception of various aspects of the sound sculpture. Additionally, open-ended questions encouraged participants to reflect on their personal experiences, connections, and interpretations of the sound sculpture. These questions aimed to gather insights into the subjective impact of the sculpture, any challenges encountered during interaction, and suggestions for future enhancements or iterations. Overall, this phase sought to capture participants' holistic impressions and nuanced perspectives on their interaction with the sound sculpture.

4.3 Questionnaire

The choice of questions and scales in the evaluation of the sound sculpture was carefully considered to ensure a comprehensive assessment of various aspects of the participant experience. Drawing inspiration from established evaluation methodologies such as the System Usability Scale (SUS) [6], Likert scales [21], and tailored questionnaires from fields like human-computer interaction (HCI) and user experience (UX) research [26], the questionnaire was adapted and customized to fit the unique context of the sound sculpture project.

Questions were curated from different questionnaires, each selected for its relevance to specific aspects of the sound sculpture experience. For example, questions related to engagement and interactivity were inspired by HCI research on user engagement and interactive systems. Similarly, questions about sound design and overall satisfaction drew from UX research methodologies aimed at evaluating user satisfaction with interactive experiences.

The scales used in the questionnaire were designed to capture nuanced responses while maintaining simplicity and ease of interpretation. A 5-point Likert scale was employed, where 1 represented a negative response or disagreement, and 5 represented a positive response or agreement. This scale allowed participants to express their opinions on a spectrum from negative to positive sentiments, providing granularity in their feedback. Furthermore the inclusion of statements covering various sentiments aims to prevent response bias and provide a comprehensive assessment of participants' experiences. The decision to implement a 1 to 5 scale, where 1 indicates a negative response and 5 denotes a positive response, is supported by several considerations. Firstly, this scale is straightforward and easy for respondents to understand. They can quickly grasp that lower numbers represent negative sentiments, while higher numbers signify positive sentiments. This simplicity enhances accessibility, making the questionnaire more inclusive to a broader range of participants, including those unfamiliar with complex survey formats. Given the substantial number of 24 questions, this decision was made to streamline the participants' experience, ensuring efficient and less burdensome decision-making. Additionally, the uniformity of using the same scale across all questions ensures consistency in respondents' interpretation and application of the scale, thereby facilitating clear and coherent data collection and analysis.The adoption of the 1 to 5 scale aligns with the research objectives by effectively capturing general sentiment and attitudes towards the project while minimizing unnecessary complexity. In Appendix A Table A.1 is presented the set of 24, 1 to 5 scale questions, where the sections were not visible to the participants who evaluated the sound sculpture, but rather as a unified questionnaire and for terminology like mappings and graphical notations written explanation was given beforehand.

The open-ended questions are included in the survey to elicit qualitative responses from participants. They provide an opportunity for individuals to express their thoughts, feelings, and experiences in their own words, allowing for a deeper understanding of their perspectives. These questions help capture nuanced insights that quantitative measures alone may not fully capture, enriching the overall analysis of the sound sculpture's impact and potential areas for improvement:

Tabel 4.2: Open Ended Questions

1	How did the sound sculpture resonate with you on a personal level? Were there moments or elements that you found particularly meaningful or intriguing? Share any personal connections or interpretations you formed during your interaction.
2	Considering your musical background, how did your experience with graphical notations influence your interaction with the sound sculpture?
3	If you faced any challenges or difficulties while engaging with the sound sculpture, please describe them. Additionally, if you have ideas or recommendations on how these challenges could be addressed or overcome, we would appreciate your insights.
4	Thinking about the concept of the sound sculpture, are there specific features or elements you would like to see in future iterations? This could include new interactive elements, different sonic possibilities, or any other ideas you think would enhance the overall concept.

4.4 Data Analysis

4.4.1 Statistical Analysis

When analyzing data, it's crucial to stick to a consistent method for calculating average ratings across different aspects of the sound sculpture project. This structured approach helps ensure that we can thoroughly understand what participants thought about specific parts of the project. Ensuring methodological coherence throughout the analysis enhances the credibility and reliability of our interpretations, while also ensuring clarity and accessibility for a wider audience.

The data obtained from the survey responses underwent processing in MATLAB using a weighted average formula to determine the mean rating for each question. This formula, represented as:

$$\text{Mean Rating} = \frac{\sum_{i=1}^{n}(r_i \cdot f_i)}{N}$$

where

- r_i represents the rating value (ranging from 1 to 5) for each response i,
- f_i represents the frequency of each response i,
- n denotes the total number of response categories,
- N represents the total number of responses.

This formula facilitates the calculation of a weighted average, where the frequency of each rating is multiplied by its associated value, and the products are summed across all response categories. The resulting sum is then divided by the total number of responses to derive the mean rating.

The development of this formula is rooted in statistical methodology for summarizing survey data. By considering both the frequency and intensity of respondents' ratings, it offers a comprehensive representation of the collective sentiment towards specific aspects of the sound sculpture project.

4.4.2 Comparative Evaluation

A comparative analysis involves examining and contrasting participants' interactions, experiences, and feedback with the sound sculpture based on their personal backgrounds, experiences, and survey responses. By comparing and analyzing individual and collective feedback, challenges, suggestions, and insights across diverse participants, we can identify patterns, trends, differences, similarities, and unique cases. This comprehensive examination enables to understand the influence of personal factors on user engagement, understanding, satisfaction, and interaction with the sound sculpture.

Before going into the results, it's essential to understand how participants were categorized based on their personal data. To better interpret the results, participants were segmented into two key domains based on their background and experience:

Musical Background

Understanding participants' musical background offers insights into their familiarity and expertise with music:

- **Novices** (35%): Participants with little to no musical background may approach interactive installations with fresh perspectives, free from traditional musical conventions.
- **Intermediate** (40%): Those with some musical experience but not professionally trained might have a foundational understanding but could be more open to experimentation.
- **Professionals** (25%): Individuals with advanced musical training might approach interactive installations with a deeper understanding of music theory and composition, potentially influencing their interactions.

Interactive Experience

The level of participants' interactive experience provides context on their familiarity with interactive installations:

- **Beginners** (30%): With minimal exposure, beginners might find interactive installations more novel and engaging, potentially exploring them with curiosity.
- **Intermediate** (50%): Those with moderate experience may have a balanced approach, combining curiosity with some level of understanding.
- **Advanced** (20%): Participants with extensive experience likely possess a deeper understanding of interactive installations, potentially leading to more nuanced interactions and feedback.

Novices' feedback can serve as a litmus test for the sculpture's low entry barrier concept. Their experiences and interactions could indicate if the sculpture effectively caters to individuals with no musical background. On the other hand, professionals offer deeper reflections that shed light on the sculpture's ceiling of explorability and intricacies.

4.5 Results

4.5.1 Quantitative Data

The following presentation highlights the mean ratings provided by participants on a 1 to 5 scale for each question related to their interaction and perception of the sound sculpture. Plot of mean ratings can be seen in Fig. 4.1

The data analysis of participant responses regarding the sound sculpture's inclusivity and accessibility revealed a generally positive perception. Participants found the sculpture approachable and easy to use, with a mean rating of 4.333.

However, some participants reported confusion regarding interaction methods (mean rating: 3.944) and perceived challenges with object interaction (mean rating: 3.833). Despite these challenges, participants expressed a high likelihood of approaching and interacting with the sculpture in an art space, with a mean rating of 4.778 for this aspect.

Regarding engagement and interactivity, participants reported feeling actively involved in shaping the sonic environment through object manipulation, with a mean rating of 4.222. Interaction with the objects encouraged exploration and experimentation, as indicated by a mean rating of 4.556. Participants expressed a strong engagement with the sound sculpture, with both finding the interaction with the sculpture engaging and expressing a desire to interact more, as reflected in their mean ratings of 4.1667 each. However, some participants still expressed getting easily bored during interaction, which resulted in a mean rating of 3.611.

In terms of user-friendliness, some participants indicated a need for technical support or prior knowledge (mean rating: 3.944), but didn't find instructions for interaction unclear or confusing (mean rating: 4.278). Participants also did not feel uncomfortable or frustrated at times when engaging with the sound sculpture, resulting in a mean rating of 4.2778. Generally the interface was rated easy to understand and manipulate, with a mean overall rating of 4.11.

In assessing participants' experiences with sonification and graphical vocabulary, the findings were generally positive. Participants rated the use of graphical notations through objects and colors as clear and intuitive, with a mean rating of approximately 4.056. Slightly lower, but still positive, with mean rating 3.94 was rated the statement that graphical notations consistently enhanced their interaction with the sound sculpture. Some participants felt that the connection between objects and corresponding sound parameters was unclear or disconnected, leading to a lower mean rating of approximately 3.444 for this aspect. Nevertheless, creating music through objects was perceived as a unique and enjoyable experience, with a mean rating of approximately 4.556.

Regarding mappings, some participants were reluctant their actions resulted in accurate and consistent sonic outcomes, with a mean rating of approximately 3.722. Additionally, participants felt that mappings effectively facilitated their interaction with the sound sculpture, leading to a mean rating of approximately 4.000 for this aspect.

Participants' perceptions of sound design was the section that scored lowest results, compared to the rest. Most participants noted that the relationship between the appearance of objects and the sounds produced was lacking connection , resulting in a mean rating of 2.944. Others enjoyed the variety and quality of sounds, leading to a higher mean rating of approximately 4.333. Some sounds were perceived as unappealing or not resonating with preferences, resulting in a mean rating of approximately 3.5.

Overall satisfaction with the sound sculpture was generally positive. Participants found the overall experience enjoyable and satisfying, with a mean rating of approximately 4.444. Contrary to the statement indicating a reluctance to recommend the sound sculpture to others based on their experience, participants expressed a strong inclination to recommend it, resulting in a notably high mean rating of approximately 4.778 for this aspect.

4.5.2 Qualitative Response

Participants provided valuable insights into their experiences with the sound sculpture and offered suggestions for future improvements. Many users expressed a deep appreciation for the tangible and immersive qualities of the sculpture, emphasizing its physical and tactile dimension. One participant remarked, "The thing I enjoyed the most was the physical and tactile dimension of it,"highlighting the unique engagement it provided. Another user mentioned, "Its appearance, the creative approach to music/making it enabled, the sounds it produced and the interaction it proposed contributed to an incredible experience."

Regarding their musical backgrounds, participants found graphical notations to be more engaging and intuitive, particularly if they had limited musical experience. This accessibility was underscored by comments like, "Graphical notation seemed more fun and engaging than the traditional way."Another participant expressed, "Less thinking more intuitive fun!". Users with more musical knowledge also found graphical notations refreshing, appreciating the departure from traditional music notation.

Thinking about future iterations, users desired enhanced sonic variety and improved user control. They suggested clearer distinctions between sounds produced by different objects and smoother interaction mechanisms. For example, one participant suggested, "Clearer distinctions between sounds produced by different objects,"while another mentioned, "Faster object removal and freer laser positioning."Additionally, users expressed interest in more customizable options for personalization, such as the ability to modulate effects introduced by colored objects or combine their effects in more nuanced ways. Some users also mentioned specific challenges they faced, such as feeling overwhelmed by the complexity of interactions or experiencing difficulties in discerning specific sounds.

From all answers we can take out that the immersive experience provided by the sound sculpture was valued, participants appreciated the accessibility of graphical notations, but sought clearer distinctions in sound and improved user control for future iterations. Their varied perspectives underscored the importance of flexibility and inclusivity in design, catering to users with diverse backgrounds and preferences.

4.5.3 Comparison with personal survey

The data reveals that among the 18 participants, novices in music (5 respondents) display limited engagement with interactive art installations or sculptures (1 respondent). In contrast, both intermediates and professionals exhibit a higher interest in interaction art. Specifically, 8 out of 9 intermediates and all professionals (5 respondents) have experience with interactive art. This suggests a positive correlation between musical proficiency and interest in interactive art, especially among intermediates and professionals. Therefore, a comparative analysis can be effectively conducted for the three across both musical and interactive art expertise. The comparative analysis across novices, intermediates, and professionals reveals that the sound sculpture successfully caters to individuals with varying musical backgrounds. While there are areas for improvement and refinement identified through both open-ended feedback and 1 to 5 scale ratings, the overall response is overwhelmingly positive.

Novices generally provided positive ratings on the 1 to 5 scale for their experience with the sound sculpture, indicating its accessibility and universal appeal. Open-ended feedback from novices highlighted an intuitive design that allowed them to engage effectively with the sculpture, enjoying tactile interactions and creative exploration.

Intermediates displayed a range of ratings on the 1 to 5 scale, with many indicating a favorable experience with the sculpture. Open-ended responses emphasized an appreciation for the sculpture's depth and creativity, despite not having extensive musical knowledge or skills.

Professionals consistently gave high ratings on the 1 to 5 scale, reflecting a deeper understanding and appreciation for the sound sculpture's intricacies. Open-ended feedback from professionals emphasized the sculpture's unique features, tactile interactions, and potential for creative exploration at an advanced level.

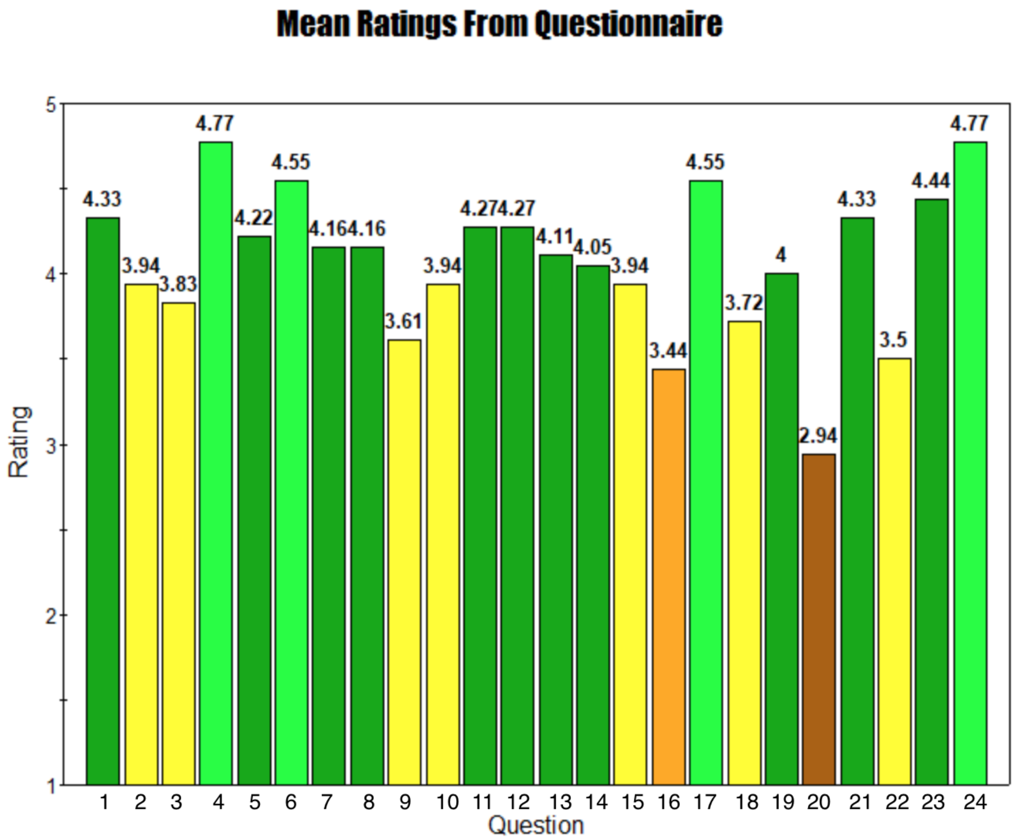
Across all skill levels, participants expressed a high level of engagement and immersion with the sound sculpture based on both open-ended feedback and 1 to 5 scale ratings. Tactile interactions and the intuitive design were universally appreciated.

However, some participants across all skill levels identified challenges with specific features or mappings of the sculpture, reflected in lower ratings on the 1 to 5 scale and open-ended feedback. Suggestions for improvement included clearer instructions, visual cues, and enhancements tailored to each skill level.

Participants familiar with graphical notation, particularly professionals, tended to rate its incorporation into the sound sculpture more positively on the 1 to 5 scale. Open-ended feedback indicated that the intuitive design allowed novices and intermediates to engage effectively with graphical notation, expanding their understanding and appreciation.

Across all skill levels, participants frequently associated colors and objects with sounds or musical elements, correlating with higher ratings on the 1 to 5 scale for perceived effectiveness in conveying musical concepts. Personal interpretations varied but were generally positive, reflecting the sculpture's versatility and adaptability to diverse skill levels. Overall Impressions and Recommendations by Skill Level

Regardless of musical background , a majority of participants expressed enjoyment and satisfaction with the sound sculpture across both personal survey findings and 1 to 5 scale ratings. The concept of a sonic city or landscape resonated well across all skill levels, offering a creative and immersive experience.



Figur 4.1: Questionnaire A.1 Color-Coded Mean Ratings from the Quantitative Questionnaire:

- Lime Green: Excellent Response (Above 4.5)
- Green: Very Good Response (4.00 to 4.49)
- Yellow: Good Response (3.50 to 3.99)
- Orange: Neutral Response (3.00 to 3.49)
- Rust: Not Good Response (2.50 to 2.99)

Kapitel 5

Discussion

5.1 Quantitative Data

After the presentation of the results, we can delve into a more detailed comprehensive analysis of each section of the evaluation regarding the questionnaire with statements rated from 1 to 5.

Engagement and Interactivity: The high ratings for engagement (4.222) and the desire to interact more (4.1667) suggest that participants were largely captivated by the sculpture's interactive elements. These scores indicate that the design effectively retained participants' interest. However, the mean rating of 3.611 for moments of boredom stands out as a noteworthy dip. This suggests that while the sculpture generally engages users, there might be periods or aspects of interaction that are less stimulating or varied, leading to reduced interest over time.

User-Friendliness: The commendable mean rating of 4.111 for interface intuitiveness is a strong point, suggesting that the majority of participants found the design accessible. Although very close to a high rating of 3.944, the statement for a need for technical support or prior knowledge hints at room for improvement. This divergence implies that while the interface is generally intuitive, there might be specific features or functionalities that are less straightforward, requiring additional guidance or simplification.

Sonification and Graphical Vocabulary: The positive rating for graphical notations (4.056) indicates clarity and effectiveness. However, the mean rating of 3.444 for the connection between objects and sound parameters is notably lower. This discrepancy suggests that while the visual representations are clear, the mappings to sonic outcomes might lack consistency or intuitive alignment, creating confusion or unpredictability for participants.

Mappings: The mean rating of 4.000 for effective facilitation suggests that participants generally appreciated the role of mappings in guiding interaction. However, the lower rating of 3.722 for consistent sonic outcomes indicates a potential inconsistency issue. This result implies that while the mappings might guide interaction well, the resulting sonic outputs may not always align predictably with user actions, leading to confusion or dissatisfaction.

Sound Design: The notably low rating of 2.944 for the relationship between object appearance and sounds stands out as a significant area for improvement. This score highlights a perceived disconnect or lack of thematic coherence, suggesting that participants expect a more intuitive or meaningful relationship between visual aesthetics and auditory experiences. Conversely, the high rating of 4.333 for sound variety and quality indicates that while the thematic alignment may be lacking, participants appreciate the sonic diversity and richness offered by the sculpture.

Overall Satisfaction: The high overall satisfaction rating of 4.444 is a positive affirmation of the sound sculpture's appeal. Similarly, the exceptionally high recommendation rating of 4.778 underscores the participants' willingness to endorse the experience to others. These high ratings suggest that despite identified areas for improvement, the overall experience is highly enjoyable and impactful for participants.

5.2 Qualitative Response

The responses to the question about personal experiences with the sound sculpture reveal a wide range of positive aspects and a few negative points as well. Overall, there's a strong appreciation for the innovative and creative approach to music-making offered by the sculpture. Many respondents express admiration for its tangible and immersive qualities, which make the experience easy to approach and engaging for users of all backgrounds. The physical and tactile dimension of the sculpture is particularly highlighted, with users feeling connected to their bodies in new and special ways while interacting with it.

One of the most praised features is the instant feedback provided by the sculpture, which allows for meaningful interactions and sparks creativity and imagination. Users enjoy exploring and discovering the different sounds that can be produced, often drawing parallels to familiar experiences such as playing with toys or learning a new musical instrument. The clear and intuitive mappings between actions and sound outcomes are also appreciated, as they enhance the overall experience and make it accessible to a wide range of users.

However, there are some areas for improvement highlighted by the respondents. A few users mention dissonance between certain sounds, such as urban/city noises, and the overall experience of the sculpture. Others note a limited variation in the sound vocabulary, which could potentially hinder the creation of intentional compositions. Some users also express confusion or difficulty in understanding all aspects of the interaction initially, suggesting a need for clearer instructions or guidance.

There are minor issues raised, such as certain colors not matching their perceived sound associations and inconsistencies in sound representation. Despite these drawbacks, the overall sentiment is positive, with users enjoying the relaxing and immersive qualities of the sculpture and feeling a strong personal connection to its aesthetic and interactive elements. Many appreciate its playful and intuitive setup, which fosters a sense of creativity and connection to their inner child. Ultimately, the sound sculpture is seen as a unique and enjoyable experience that has the potential to resonate with a wide audience.

The responses regarding the influence of graphical notations on users' interactions with the sound sculpture paint a nuanced picture of how individuals with varied musical backgrounds perceive and engage with this aspect of the experience.

Several users with limited or no experience with graphical notation expressed initial confusion or difficulty in directly relating physical actions to abstract notations. For them, the tangible nature of the physical objects took precedence over the symbolic representations of musical elements. However, despite this initial struggle, many found the hands-on interaction deeply engaging, sparking emotions and desires for creation rarely encountered with more traditional electronic instruments. This suggests that while graphical notation may not have directly influenced their interactions, the overall tactile and immersive qualities of the sculpture contributed significantly to their enjoyment and engagement.

Conversely, users with some musical background, particularly those familiar with traditional music notation, found graphical notations to be more fun and intuitive. They appreciated the seamless process of creating notation during interaction, which eliminated the need to first learn musical notes. This suggests that the graphical notations provided a more accessible entry point for musical expression, especially for those who may not have formal training in music theory.

One participant, leveraging their musical expertise, aptly related the circular motion of the sound sculpture to the timeline structure of a Digital Audio Workstation (DAW). The spinning action, analogous to a perpetual loop in music composition, was intuitively perceived as a constant rhythmic foundation. Furthermore, the act of adding and removing objects within the sculpture was likened to the dynamic process of layering and modifying tracks in a music-making environment. This connection emphasizes the success of SonicCity in resonating with individuals familiar with music production, bridging the gap between tangible interaction and digital sound creation.

Users with a deeper understanding of musical concepts, such as scales and harmonies, were able to recognize patterns and musical relationships within the graphical notations. This enriched their experience and allowed for more nuanced exploration of sonic possibilities. However, there were also users who wished for more direct influence over the sonic structure, indicating a desire for greater control and customization in their interactions.

While graphical notations may not have been universally understood or influential in every user's interaction, they nonetheless added an element of playfulness and accessibility to the sound sculpture experience. For some, they served as a bridge between physical actions and musical expression, while for others, they offered a new and engaging way to create and interact with sound. Ultimately, the diverse responses highlight the importance of providing multiple entry points and modes of interaction in designing interactive musical experiences.

The challenges and difficulties encountered by users while engaging with the sound sculpture shed light on areas that may require refinement or improvement to enhance the overall user experience. Additionally, users provide valuable insights and recommendations for addressing these challenges.

Technical difficulties, such as the camera "seeing"objects beyond the plate or the time it takes for the sculpture to respond to input, also hindered some users' interactions. Improving the responsiveness of the sculpture and refining the object detection system could help address these issues and provide a smoother user experience.

Physical challenges, such as balancing the tower of objects or assembling structures in a solid fashion, were also mentioned accross many answers. Users suggest solutions such as using magnets for stability or differentiating the tops of objects with different colors to indicate their functions. Additionally, providing clearer instructions or introductory materials on graphical notation and its relation to the sculpture could help users better understand and navigate the interaction.

In reviewing user feedback on the sound sculpture, it's evident that there's a keen interest in enhancing both the sonic and interactive aspects of the experience. Users are seeking clearer distinctions in sound, more intuitive controls, and a greater degree of personalization. They're also interested in a balance between automation and manual manipulation, as well as educational features to deepen engagement. Overall, there's a strong desire for a more dynamic, immersive, and customizable experience with the sound sculpture.

5.3 Comparison

The comparative analysis across three skill levels—novices, intermediates, and professionals—revealed intriguing patterns and trends that warrant further discussion.

One of the standout findings was the universal appeal of the sound sculpture across all skill levels. Novices, despite lacking a musical background, found the sculpture accessible and engaging. This suggests that the intuitive design of the sculpture transcends musical expertise, allowing individuals with varying levels of musical knowledge to interact with and appreciate its features. This aligns with the notion that musical instruments should be inclusive and accessible to a broad audience, not just to those with formal training or expertise.

While novices appreciated the sculpture's accessibility, intermediates and professionals highlighted its depth and creativity. Intermediates, despite having limited musical background or experience, were able to explore the sculpture's nuances and complexities. Professionals, on the other hand, demonstrated a deeper understanding and appreciation for the intricacies of the sculpture, leveraging their advanced musical knowledge to engage in more sophisticated interactions. This suggests that the sound sculpture can cater to a wide range of skill levels, offering both simplicity for beginners and complexity for advanced users.

Across all skill levels, participants expressed a high level of engagement and immersion with the sound sculpture. This universal appeal underscores the effectiveness of the sculpture's tactile interactions and intuitive design in facilitating meaningful user engagement. However, the presence of challenges and areas for improvement—such as clearer instructions and visual cues—suggests that while the sculpture is generally well-received, there is room for enhancing the user experience to further boost engagement and immersion. Graphical Notation and Sound Perception

The incorporation of graphical notation into the sound sculpture was another interesting finding. While professionals familiar with graphical notation rated its implementation more positively, novices and intermediates were also able to engage effectively with this feature. This suggests that graphical notation can serve as a versatile tool for conveying musical concepts across different skill levels. Furthermore, the consistent association of colors and objects with sounds or musical elements across all skill levels highlights the sculpture's adaptability and versatility in facilitating sound perception and interpretation.

The feedback and suggestions provided by participants offer valuable insights for refining the sound sculpture in future iterations. Tailoring enhancements to address the specific needs and preferences of novices, intermediates, and professionals can further optimize the user experience and broaden the sculpture's appeal. Incorporating diverse sound options, improving stability, introducing new interactive features, and enhancing instructional or visual aids specific to each skill level are potential avenues for refinement.

5.4 Personal Observations From Video Recordings

Upon reviewing the video footage capturing participants' interactions with the sound sculpture, several intriguing insights emerged. Regardless of their musical background, participants were able to engage with all elements of the sculpture, possibly aided by the vocabulary guide provided. However, those with prior musical instrument experience showcased a more nuanced interaction style. Professionals, in particular, approached the sculpture not merely as an arrangement of elements but as a dynamic instrument. They utilized the distance sensor for tactile engagement, employing swift hand gestures to manipulate the colorful objects, generating rhythmic patterns. This showcased the depth and versatility inherent in the sculpture, suggesting its potential not only as an art installation but also as a live performance tool.

A consistent observation was the participants' response to the ten-minute time limit. Many continued beyond the allotted time, keen on concluding their improvised musical piece. Some expressed surprise at how quickly time had elapsed, feeling they had just begun their exploration. Others described their experience as immersive, noting sensations of being in a trance or feeling their entire body engaged in the interaction. These reactions underscore the sculpture's capacity to captivate and immerse participants deeply. Thus, the sculpture not only holds promise as an artistic creation but also as a transformative tool for immersive musical experiences.

5.5 Future Work

Even in its initial prototype stage, the design and implementation of SonicCity have demonstrated remarkable robustness and effectiveness, successfully meeting the goals set forth by this research. However, there are numerous areas ripe for improvement to prepare it for an official presentation to a wider audience. First and foremost, the structure of the frame requires refinement. A more stable and aesthetically pleasing design would not only enhance its visual appeal but also ensure its durability and longevity. The design of the objects within SonicCity also warrants attention. Investing in the development of better 3D models and introducing a wider variety of interactive elements would enrich the user experience and provide more creative avenues for exploration. The lazy susan and laser movement mechanisms could benefit greatly from motorization. Offering users the ability to control these components either separately or in tandem would elevate the interactive capabilities of SonicCity. A significant advancement would be to make the sculpture standalone by utilizing RNBO for Raspberry Pi. This would not only streamline its operation but also enhance its adaptability and connectivity with other devices. It would be beneficial to incorporate a visualization component where interactions could be visually represented through graphics. Adding layers of graphical notations would enhance the immersive experience and provide users with a clearer understanding of the underlying processes and interactions within SonicCity. There is also an exciting prospect of collaborating with Kinan Sarak to revisit and potentially integrate elements from his original concept. While the notion of a "city"may undergo transformation, there's potential for evolving towards a more unified and cohesive object or theme.

Kapitel 6

Conclusion

The SonicCity project presented an innovative approach to the fusion of visual and auditory arts, reshaping the paradigms of graphical notations through the lens of sonification. By encapsulating the musical score within a software interface, SonicCity invites users to actively engage with a dynamic and interactive musical landscape. This landscape, embodied by tangible graphical objects, facilitates a unique synthesis of visuals and sound, empowering users to shape and explore the auditory realms of a futuristic cityscape.

The use of familiar tangible objects as graphical notations not only enriches the sonic experience but also bridges the gap between abstract musical concepts and tangible real-world interactions. This strategy, backed by research indicating increased user engagement with identifiable objects, amplifies the inclusivity and accessibility of SonicCity's sonic environment.

From a sonic design perspective, SonicCity aims to immerse users in an ambient electronic music experience. By harnessing additive synthesis techniques and integrating ambient urban sounds, the project crafts a harmonious and intricate soundscape that resonates with both the aesthetic vision of a futuristic city and the emotional journey of its listeners.

In terms of tangible interaction, SonicCity transcends traditional boundaries by transforming physical actions into sonic outputs. Despite facing challenges with initial design complexities, the project's iterative approach prioritizes human-centric interaction, ensuring an immersive and engaging experience for participants.

Looking forward, while the project's current iteration lays a strong foundation, there remains vast potential for further advancements and refinements. Future iterations could explore more advanced technological implementations, to realize the project's full visionary potential. Additionally, addressing challenges experienced by participants during the evaluation should be taken into account and developed to enhance the user experience.

In conclusion, SonicCity stands as a testament to the transformative power of interdisciplinary collaboration, exploring means of conventional music-making and interactive artistry. Through its innovative approach and unwavering commitment to user engagement, SonicCity offers a fresh perspective on how we perceive, interact with, and experience sound and music composition.

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Bilag A

Appendix A Evaluation

Tabel A.1: Questions related to various aspects of the sound sculpture with scale of 1 to 5. Back to Evaluation Questionnaire 4.3 . For results 4.1

	Inclusivity and Accessibility
1	I found that the sound sculpture was approachable and easy to use.
2	I experienced confusion regarding how to interact with the sound sculpture.
3	I found the interaction with the objects challenging.
4	If I encounter the sound sculpture in an art space, I will likely approach it and interact with it.
	Engagement and Interactivity
5	I felt actively involved in shaping the sonic environment through the manipulation of the objects.
6	The interaction with the objects encouraged exploration and experimentation.
7	I found the interaction with the sculpture engaging.
8	I found myself wanting to interact more with the sound sculpture.
9	I easily got bored, and the time allocated for interaction was enough.
	User-Friendliness
10	I think I would need the support of a technical person or prior knowledge to be able to play the sound sculpture.
11	Instructions for interacting with the objects were unclear or confusing.
12	I felt uncomfortable or frustrated at times when engaging with the sound sculpture.
13	The interface was easy to understand and to manipulate.
	Sonification and Graphical Vocabulary
14	The use of graphical notations through objects and colors was clear and intuitive.
15	Graphical notations consistently enhanced my interaction with the sound sculpture.
16	The connection between the objects and the corresponding sound parameters felt unclear or disconnected.
17	Creating music through objects contributed to a unique and enjoyable experience.
	Mappings
18	I found that my actions held accurate and consistent sonic outcomes.
19	The mappings effectively facilitated my interaction with the sound sculpture.
	Sound Design
20	I found a strong relationship between the appearance of the objects and the sounds produced.
21	I enjoyed the variety and quality of sounds produced by the sound sculpture.
22	Some sounds were unappealing or did not resonate with my preferences.
	Overall Satisfaction
23	I found the overall experience of the sound sculpture enjoyable and satisfying.
24	I would not recommend this sound sculpture to others based on my experience.

Question 1: How did the sound sculpture resonate with you on a personal level?

1. Some of the sounds felt very sci-fi-y, and those I enjoyed more. The urban/city sounds were not nice, and didn't feel like it fit with the other sounds that well.
2. I found the sculpture meaningful and interesting in terms of creating music while using familiar objects and creating a city. It was more tangible and easy to approach as an experience and also very creative.
3. I found the height-to-pitch and speed-to-glide mappings really well executed and that, combined with the spinning of the plate, ended up being a quite immersive/hypnotic/meditative experience. Because of the circle metaphor, I kept reminding myself that everything comes back to the beginning, so if I didn't get the result I wanted/expected or missed adding/removing an element, I will get the chance next time 'round.
4. This sculpture resonated with me deeply. Its appearance, the creative approach to music/making it enabled, the sounds it produced, and the interaction it proposed contributed to an incredible experience. Never before had I seen a musical instrument like this one!
5. The thing I enjoyed the most was the physical and tactile dimension of it. While playing, I felt connected to my body in a very special and new way. I felt that I was playing an instrument!
6. I thought the installation was extremely engaging, although the overall sound vocabulary stayed more or less in the same space, a lot of particular and subtle changes could be accomplished when manipulating the objects /once the connections were made.
7. I felt like I could create my own song with subtracting and contracting objects, especially when I turned the turntable.
8. I enjoyed the idea that manipulating a physical space affected electronic music, that would otherwise be more or less static. The sculpture provided instant feedback to every alteration to the "cityscape"that made interactions feel meaningful.
9. I really liked the response to the object height; I felt like I could create some melodies.
10. I liked the birdlike sounds. Creating physical sound landscapes made my imagination go wild.

11. I really enjoyed spending time trying to figure out the different sounds that could be created. It felt like starting to play with a new synthesizer for the first time and being really confused but also excited about the possibilities if I spent the time to learn the different ways to interact with it.
12. It was very clear that the depth detected by the laser would affect the pitch of the performance and I enjoyed playing with this idea throughout the performance and was trying to spin the plate between objects of different heights so that I could alternate between different settings here and achieve some rhythmic effect with it.
13. It was also fun to use the red/green/blue as samplers and to bring sounds quickly in and out to make some rhythms.
14. I think that the green color sounded very green and the red color sounded somewhat red, but the blue color did not sound very blue.
15. It felt relaxing and quite immersing. Especially the combination of rotating the plate and having different heights was intriguing.
16. The sound sculpture was an interesting way to perceive height and color and clutter as noise. The reactiveness of the laser and the subsequent sounds produced I found interesting and the color of green resonated a lot with me, maybe because my favorite color is green and I love nature lol.
17. The connection between high and frequency was very intriguing and felt it made a lot of sense to represent sound in such a way. You could draw parallels to the hectic life in cities being engulfed in tall buildings and traffic passing by. I felt like the plate was presenting this to me.
18. I really enjoyed the quality of the sounds and the overall soundscape (which is quite important for me to keep engaging with the sound sculpture). I think the whole concept of a Sonic City was represented in an aesthetic way yet simple, and the soundscape and aesthetics of the culture supports each other.

Question 2: Considering your musical background, how did your experience with graphical notations influence your interaction with the sound sculpture?

1. I might have misunderstood graphical notation, since I thought it like sheet music. The only notation I have experience with is sheet music from playing the piano and guitar.

2. Graphical notation seemed more fun and engaging than the traditional way. And they also helped because you could make music directly than in trying to learn the notes first.

3. I liked the idea of setting the rate of change between musical scales - this adds a bit more "spice"for more musically educated users. From the more immediate interactions, I really liked the idea of navigating a concentric "map"using the laser pointer.

4. I have limited experience making music or art with graphical notation, but the choice of the objects/colors definitely resonated with my basic knowledge of it. I wouldn't say that graphical notations directly influenced my interaction with the sculpture because I struggled to make a connection between the physical objects and their abstract counterpart. Even though I was aware that these objects represent graphic elements shaping the composition, I was more drawn to their physicality, by the objects existing in front of me, that I can touch and manipulate with my hands. That being said, these objects represented an element of great interest for me. The hands-on, direct quality of the interaction really struck me deep, and arose emotions, desires, and interests for creation that I rarely encountered in more traditional electronic instruments.

5. Less thinking more intuitive fun!

6. Easy, interactive, and engaging.

7. Not very much. The fact that every notation was created on the spot made the creation and interpretation of them feel like one seamless process instead of two.

8. I don't think my musical background necessarily gave me much of an edge although I was tempted to find patterns and musical harmonies.

9. Despite no background, easy to put in practice.

10. It's not a way I play music every day but it's nonetheless inspiring.

11. I don't actually have experience with graphical notation, but just normal music notation.

12. I think that I very quickly was able to recognize the interaction between physical actions and the sonic outcome. I also have a good understanding of hardware and therefore knew how to interact with specific elements.

13. I also wish that I could have had more influence on the sonic structure and that my actions had a more direct influence on the sound.

14. Considering my background, I went into the interaction with the assumptions that there are mappings that clearly influence some parameters. This influenced the interaction insofar as I spent some time trying to figure these out, especially regarding the height of the object and the pyramid-like objects, that allowed having smaller height jumps.
15. My limited music background, it did not influence my interaction at all.
16. I felt connected and got associations to early electronic instruments such as the theremin, which by many is used as a highly intuitive instrument and very expressive. I loved that and it felt very fun to approach.
17. I have no personal prior experience with creating music from graphical notations (not that I am aware of). In the beginning, I tried to make the connection between the objects and notation and conducting in my head while playing, but I quickly gave up and tried not to use my brain while playing.
18. The circular motion was kind of like my timeline on a DAW in my mind, and the sipining was like a constant loop, and by adding and removing objects It would change it.

Question 3: If you faced any challenges or difficulties while engaging with the sound sculpture, please describe them.

1. The caps with colors on the inside did not seem to work as described. An idea, maybe I misunderstood or didn't read the instructions properly, but it didn't seem like I was able to change the pitch of the sounds. That would have been cool. Some of my peers once made a similar setup with the rotating disc, but it worked as a sequencer, so you could introduce different instruments, at different spacings, creating various rhythms and melodies.
2. The only thing that challenged me was to understand what exact sound its item does, based on its characteristics. e.g., spotting the sound the color blue does.
3. I didn't face any particular challenges that I felt I could not overcome.
4. The main challenges I encountered were physical and were related to my coordination, the speed at which I was able to build the buildings up and down, insert or remove the colors in the camera field, spin the plate, and perform all the other sound-shaping actions. This were positive challenges though, which encouraged me to keep playing and exploring the interface. I have to say, that's really what kept me going! I feel that all these little

challenges are what ultimately could make this project not only a sound sculpture but a musical instrument too. Because there is a lot to learn about how to play it, plenty of techniques to be discovered, and virtuosic gestures to develop.

5. Balancing the tower was tricky at times / the pieces moving when the wheel started spinning / some recommendations: use of magnets, legos / a more variety of colors and shapes / work on some mappings where the size of the objects also has an effect.
6. There were technical difficulties, which at times made it hard to discern whether my interactions were affecting the soundscape in the way they were supposed to.
7. Could not quite feel the difference when I was spinning the disk, otherwise was responsive and fun.
8. No difficulties.
9. I wish the structures were more stable and could sustain faster movement and more aggressive interaction.
10. I would say that it wasn't clear to me how the shapes of the objects actually impacted the performance. I spent more time playing with depth and the samples rather than the shapes of the objects. I also felt a bit bothered by the constant high-pitched sounds. I think the experience would be more comfortable if the background noise was a bit lower pitched.
11. I don't think that the pitch and the height of object was very clear to me I would have liked if it was more direct.
12. I also think that the color triggering samples quickly became very limited and wish I could have changed the way the color interacted with the sound even more. I didn't really understand the sound effect part so I don't have any strong opinions on that part.
13. Stacked-up cubes collapsed when spinning the disk too hard. As with some of the other objects, magnets could be cool to give it some stability.
14. The length of time that the sculpture took to respond to input was sometimes a little bit of a struggle but I can tie that down to addiction of fast reacting content on a smartphone. Although it would be nice to be able to sit in a comfortable position and experiment.
15. I felt the structures were a bit hard to assemble in a solid fashion, and was wobbly. Maybe the tops could have different colors to symbolize that they do different things.

16. I think this sculpture is very accessible, and I would like more time to explore it. Maybe a short introduction to graphical notation and how this piece relates to and makes use of it would be nice.
17. I don't have any recommendations as this is outside of my field of expertise.
18. I don't think I faced any challenges while interacting with the sound sculpture, I think it felt like a challenge to make it sound a particular way but I thought that was kind of the magic of it too.

Question 4: Thinking about the concept of the sound sculpture, are there specific features or elements you would like to see in future iterations?

1. See previous comment.
2. Different sonic possibilities, maybe the sound that its item does based on its characteristic, to be easy distinguished from the sound of other items. Maybe adding other kind of materials too more softer, so it can be accessible to younger children too?
3. I would have liked the ability to modulate the effects introduced by the colored bricks by either the spinning speed or the number of objects present. If that was already the case, I couldn't perceive the range of that mapping. Would be amazing if one could combine the effects of the colored bricks (routed maybe in the order of their introduction in the camera view?).
4. There are a few things I would like to see in future iterations.

   First and foremost, I would enjoy a more varied soundscape. Although there are various elements in the composition, they soon become repetitive and I wished for more changes. This might be because most of the processes are automated, and I did not really feel in control of shaping the sounds as much as arranging them in time.

   Then I'd really enjoy to be able to remove the objects from the plate faster. Sometimes I wished I could almost throw everything out of the plate to start anew!

   I felt that the position of the laser was a bit constraining. Even though I was able to move it back and forth in a straight line, I wished to be able to move it towards different directions. But I was able to make up for it by moving the buildings :)

Last, I think that having some form of visual feedback would have helped me in the first stages of the interaction. For example, seeing the line drawn by the distance data over time, or seeing the blobs appearing on a screen. I really enjoyed immersing myself in a purely physical and auditory experience though, that was priceless!

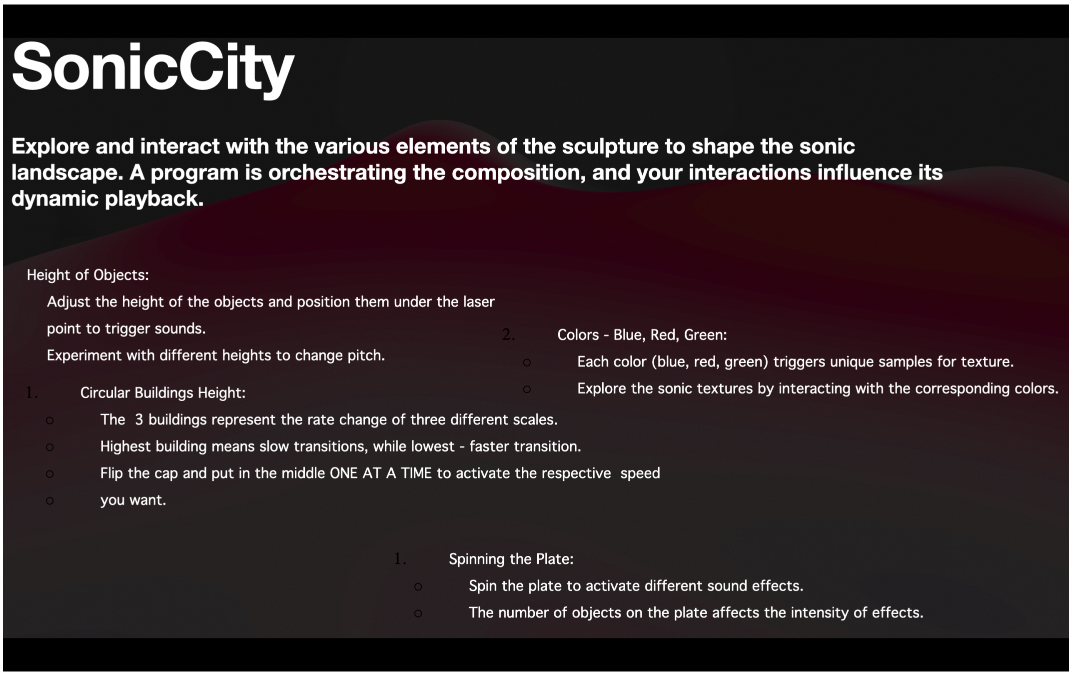
5. Some possibilities of having more personalized choice for the objects/ instead of having the blocks, shapes, and specific colors imposed on the user. Picking up the signal from the surface with microphones, being able to manipulate how the object sounds by the objects.
6. Different 3D buildings that give different sounds/components.
7. Motorizing the plate and motion sensor with adjustable speeds. Larger building blocks with different surface textures and slopes. Maybe a clearer connection between the amount of elements present and the effect on the sound.
8. Sometimes the sounds seemed quite chaotic and all over the place, maybe more specific harmonies and melodies would be cool!
9. Maybe sample intensity variety depending on some factor could be stronger.
10. I wish the sculpture would represent a dome of a city (or mountains or whatever structure) and the light would come from a "sun"that would sonify it along illuminating :)
11. It would be nice to be able to play around with more colors to bring in more samples in and out. It would also be cool to have a second, transparent plate to be able to block the camera from seeing things on the bottom plate, and being able to control this by moving both plates at the same time. I think that would make it easier to introduce more rhythmic effects.
12. Possibility for more physical automation, but still preserving the possibility to disable automation. Also being able to have an element or two more to interact with plus further possibility to interact with the already existing parameters.
13. Having an influence on the mixing of elements would also be awesome, like panning and volume of different elements.
14. The differently colored Lego objects felt a bit all-or-nothing and additive. Thus, when all colors were present on the plate it felt a bit "crowded"or "too much". It might be cool to have a blended or entirely new sound when different colors are combined.

15. Maybe preset compositions of objects/colors on the wheel to demonstrate the full capabilities of the sound sculpture.

16. Maybe the plate and sculptures could have a connection to the environment and maybe a symbolic relationship to the world we live in.

17. Improving the quality of the building blocks to make them more stable, and exchange the paper towers for building towers (cleaner aesthetics). More colors could be mapped to samples and you could introduce colored buildings (or nail polish lol). And maybe some modulation options that would change the soundscape more radically.

18. Maybe elements that could trigger beats or similar would be cool!

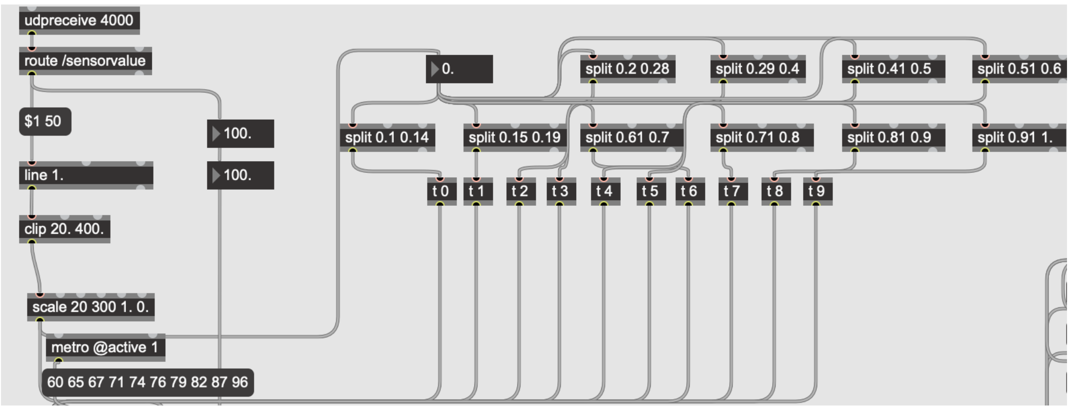


Figur A.1: Slide presented to the participants.4.2.2

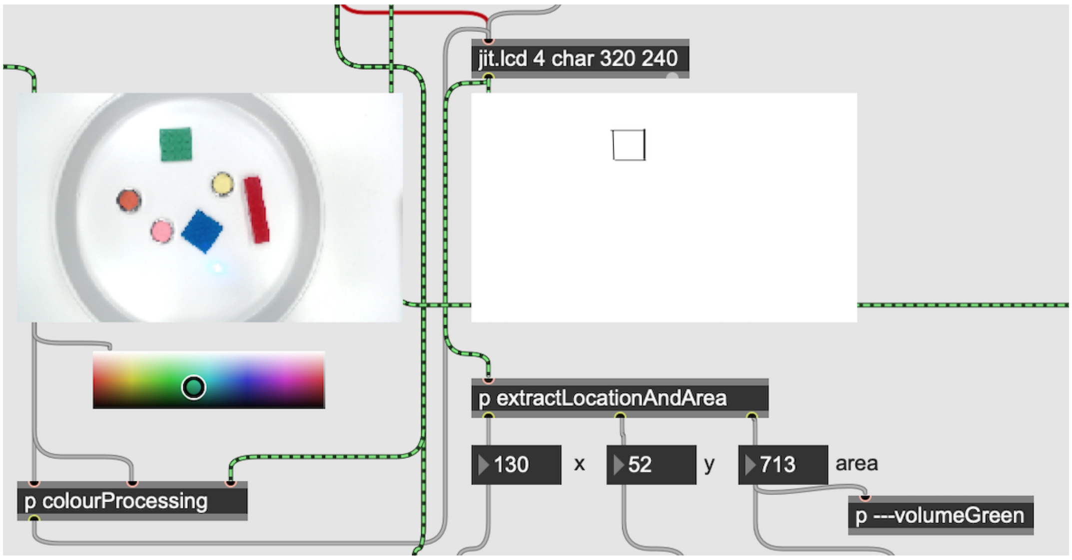
Figur A.2: Participant playing with SonicCity (written permission for photo obtained). Back to Evaluation 4.2

Bilag B

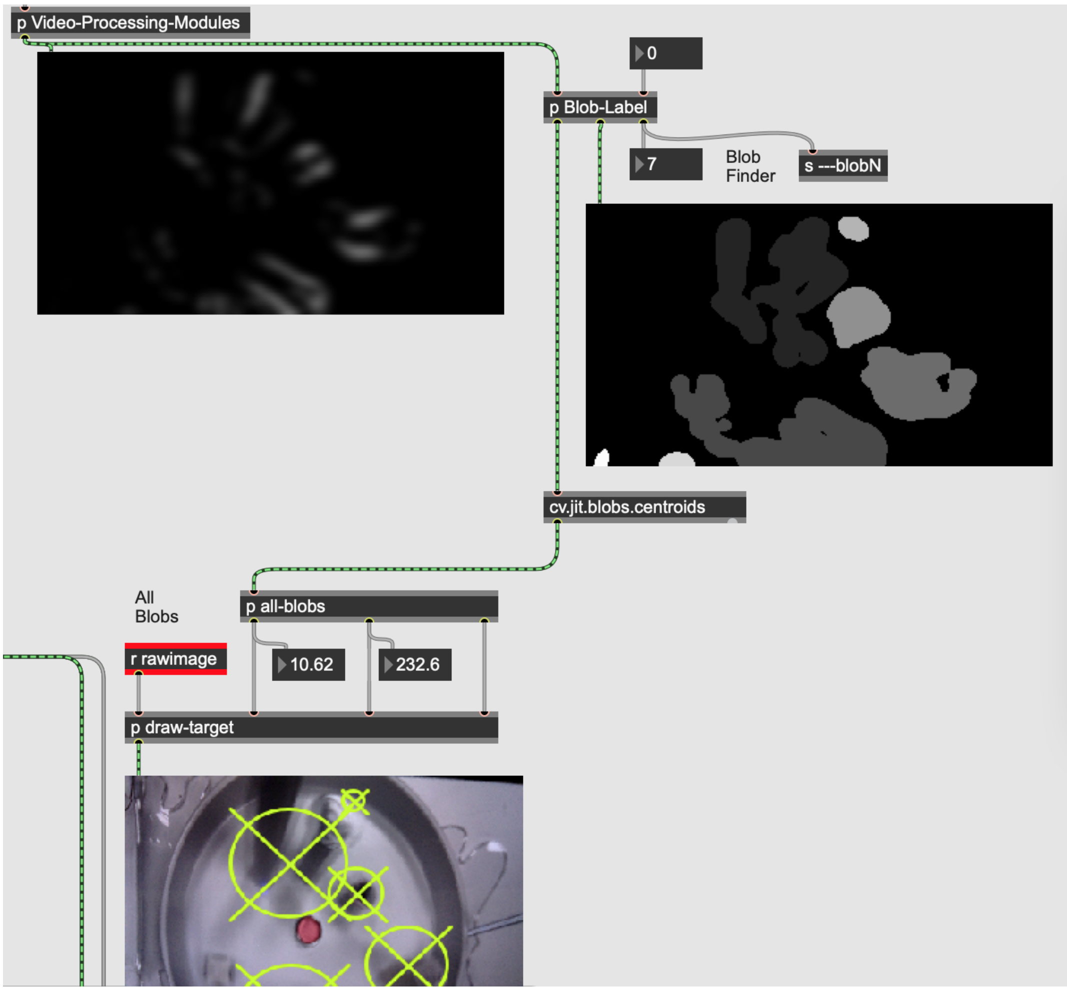
Appendix B Max/MSP Implementations



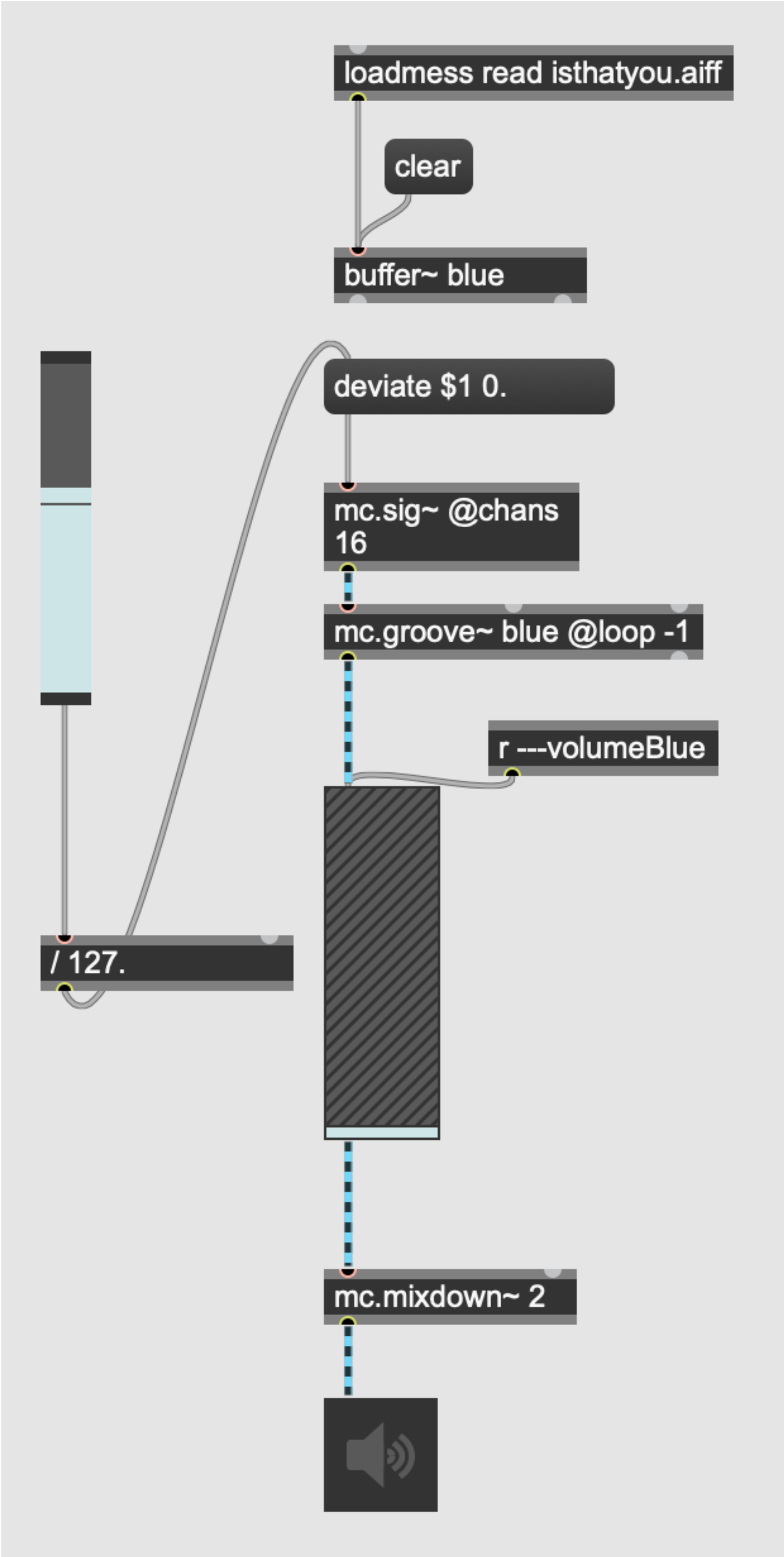
Figur B.1: ToF Sensor scaling. Back to Data Processing 3.5.2



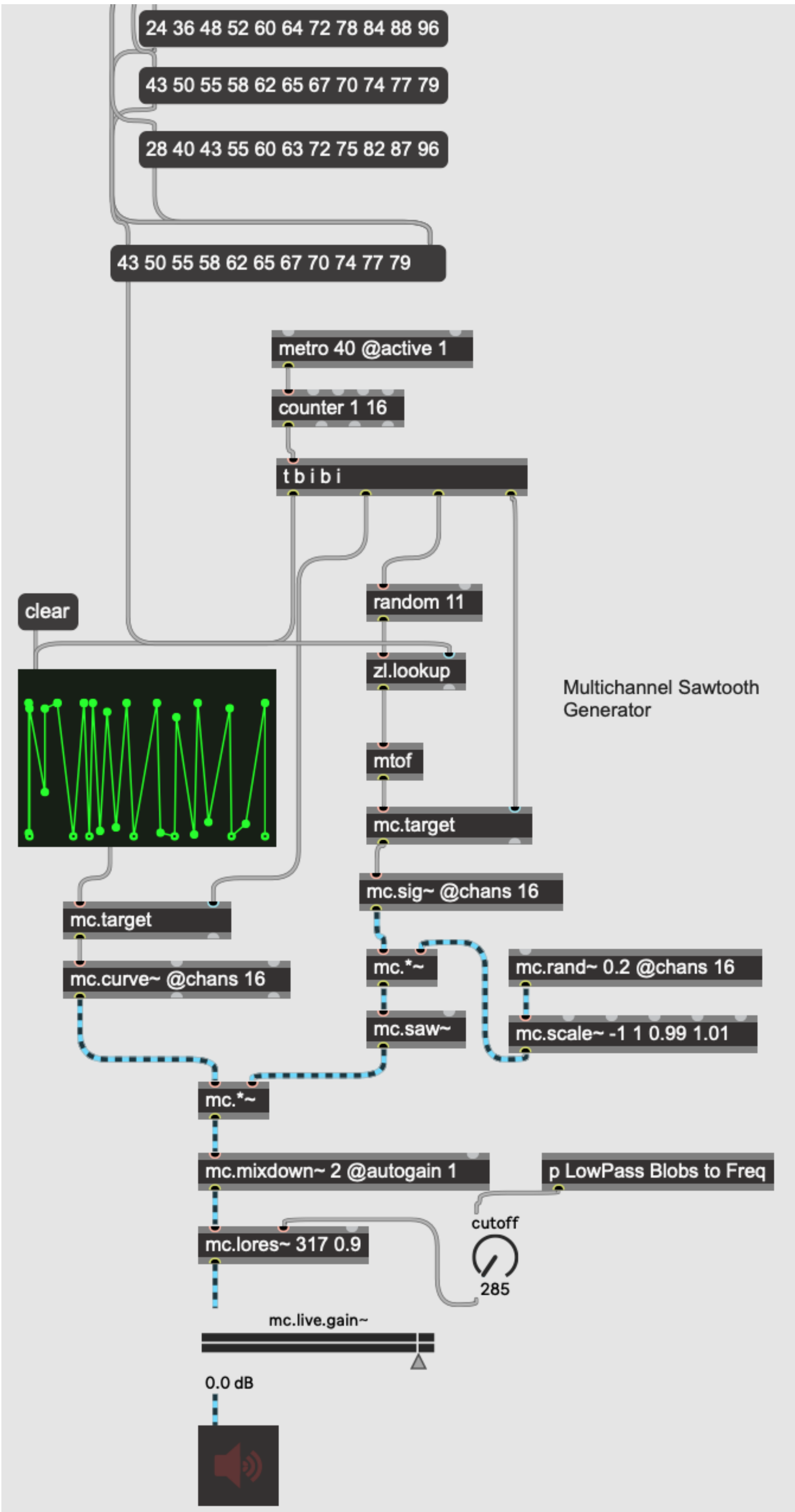
Figur B.2: Colour Tracker.3.5.2



Figur B.3: Blob recognition.3.5.2



Figur B.4: Texture generator. 3.5.2



Figur B.5: MIDI scales and Multichannel sawtooth generator. 3.5.2