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TITLE:

Immersive Audio Design Tools:
Exploring Affordances and Interaction Modalities for Spatial
Sound Experiences

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Abstract

School of Architecture

Master of Science

Immersive Audio Design Tools: Exploring Affordances and Interaction Modalities for Spatial Sound Experiences

by Yanting DENG

This article explores the future development of spatial audio design interfaces based on the spatial audio design platform Sound Hologram system. The system was developed using wavefield synthesis (WFS) and motion tracking technologies. The research focuses on two main aspects: exploring the unique affordances of soundscape systems and testing interaction modalities for soundscape design. Based on these explorations, several suggestions are provided as conclusions for future interface development of soundscape software. The study begins by examining the current status and issues of spatial sound synthesis in the context of computer-aided composition. Through interviews with the platform designer and initial users, several affordances, design scenarios, and modalities are identified. Based on the findings, a new interface is designed and mocked up in Figma. This design integrates original interfaces, which were previously separated across three software platforms, providing greater convenience for designers in prototyping soundscapes. Two rounds of user tests were conducted with a group of master's students from the School of Architecture. The user tests included both quantitative and qualitative evaluations to examine the enhancement of creativity and efficiency of new interfaces design. As a result, conclusions and interface design guidelines are provided for future development.

Contents

1	Background, Problems and Research Question	1
1.1	Introduction and Research Question	1
1.2	Sound Hologram Platform: A Brief Introduction	3
1.3	Traditional Interface Design	6
1.3.1	Tangible User Interface Design Principles	8
	Affordance-Based Tangible Interaction Principles from Gong et al. into Spatial Sound Interface Design	9
1.3.2	Graphic User Interface Design Principles	10
1.3.3	Case Studies of Traditional Design Interfaces	12
	Case Study: Exploring Innovative Virtual Reality Mu- sic Video Experiences	13
	Case Study Analysis: Audiovisual Immersion in Björk's VR Experience and Its Application in Sound- scape Interfaces	13
1.4	Soundscape Interfaces Design principles	14
	Case Study: Incorporating Tonal Music Theories in Au- ditory Interface Design	15
1.5	Intersections of Two Areas	16
	Case Study: Full-Body Interactions in "A Very Real Looper" (AVRL)	17
1.6	Conclusion	18
2	Method:	
	Interface Design Logic and User Test	19
2.1	Research Methods and New Interface Design	19
2.1.1	High-Level Design Based on User Scenarios	21
2.1.2	Interface Design Details	24
	Point Setter	33
	Path Setter	34
	Space Setter	35
2.2	Workshop and Survey Design	35

2.2.1	Participants' Background	37
2.2.2	The first workshop and survey	39
2.2.3	The second survey	42
	User Test 2: Evaluating Interface Modalities	43
3	Results	45
3.1	Survey 1: General Design Test Outcome and Analysis	45
3.1.1	Question 1: What activities would you create using our sound design platform?	45
3.1.2	Question 2: Creating an Environmental Sound Design	46
3.1.3	Question 3: Creating an Interactive Art Design	48
3.1.4	Question 4: Creating a Musical Performance Design . .	49
3.1.5	Quantitative Questions about User Satisfaction	50
3.2	Survey 2: Tangible Modality Comparisons Outcome and Anal- ysis	55
3.2.1	Tangible vs. Traditional Interface	55
3.2.2	Point Setter - Position Tracker Integration	56
3.2.3	Curve Setter - Simulating Dynamic Sounds	57
3.2.4	Cube Setter - Defining Sound Areas	58
3.2.5	Interface Improvements and Limitations	58
3.3	Conclusions Toward Interfaces and User Feedback	59
	Enhanced Immersion and Interactive Experience . . .	59
	Tangible Interface Advantages	60
	Challenges and Opportunities	61
3.4	Future Possible Development	62
	Integrating Tangible and Graphical Elements	62
	Enhanced Responsiveness and Reduced Space Depen- dence	63
	Precise Positioning and Visualization in GUI	63
	Bibliography	65

List of Figures

1	My Cat	xiii
1.1	Research scope of my thesis	2
1.2	The photo of the lab settings by Professor Daniel Rosenberg Munoz	3
1.3	The diagram about physical computing and settings in the lab, illustrated by Professor Daniel Rosenberg Munoz and student Shih-Hsueh Wang	4
1.4	Current workflow of Sound Hologram	5
1.5	The Optitrack tracking process by Professor Daniel Rosenberg Munoz	5
2.1	Over-all research method about combining affordances and interfaces formats	19
2.2	Design method diagrams about detailed parts of explorations and interfaces	20
2.3	Tracked Object with Sounds	25
2.4	Sound Attributes with Behaviors Drop Down	26
2.5	Sound Orbit Settings	27
2.6	Shoot Behavior Configuration	29
2.7	Shape Behavior Configuration	30
2.8	Custom Behavior Settings	31
2.9	Non-tracked Sound	32
2.10	Position Setter	33
2.11	Path Setter	34
2.12	Space Setter	35
2.13	Email invitation to participants about Sound Hologram demonstration	37
2.14	Google form screenshot of round 1 user test	39
2.15	Google form screenshot of round 2 user test	42
3.1	Free Design Outcome	45

3.2	Environmental Sound Design Outcome	47
3.3	Interactive Art Design Outcome	48
3.4	Musical Performance Design Outcome	49
3.5	Pie Chart of Navigation Ease Results	51
3.6	Pie Chart of Feature Understanding Results	52
3.7	Pie Chart of User Satisfaction	53
3.8	Pie Chart of Ease of Use	54
3.9	User test result: TUI compared to traditional interfaces	55
3.10	User test result: thoughts about point setter	56
3.11	User test result: thoughts about curve setter	57
3.12	User test result: thoughts about cube setter	58

List of Tables

2.1	Characters and Affordances	22
2.2	Scenarios Assumptions Table	23

List of Abbreviations

API	A pplication P rogramming I nterface
ATUI	A daptive T angible U ser I nterface
GUI	G raphic U ser I nterface
HOA	H igher O rders A mbisonics
MDes	M aster of D esign
MSBPD	M aster of S cience in B uilding P erformance and D iagnostics
MSCD	M aster of S cience in C omputational D esign
MSSD	M aster of S cience in S ustainable D esign
TUI	T angible U ser I nterface
WFS	W avefield S ynthesis

*To my dearly departed cat, Zaizai,
for all the times he supported me over past 19 years.*



FIGURE 1: I love him!

Chapter 1

Background, Problems and Research Question

1.1 Introduction and Research Question

As immersive experiences develop, spatial sound design has become a vital part of musical composition, mixed reality, and game design. Spatial sounds have not only enhanced the realism and immersion of auditory experiences but also provided new possibilities for creative artistic expressions. Although the development of audio technology has provided many methods for spatial audio rendering, including Wavefield Synthesis (WFS) and Higher Order Ambisonics (HOA), there are still numerous challenges to address in the interface design of soundscape creation. One of the most obvious problems is the lack of unified interfaces and methodologies that accommodate the diversity of sound applications, enabling advanced control.^{[1][2]}

Traditional user interface design focuses on how users interact directly with interfaces, emphasizing straightforwardness. With many shared design principles, this is radically different from user interactions in soundscape design, as the latter focuses more on how to manipulate sounds in a certain space to create immersive audio experiences. Soundscape user interaction design emphasizes user involvement and experiences. This not only requires users to consider spatial characteristics but also necessitates intuitive interfaces for direct control of properties. For example, many researchers have used gestures or motions to control sound directions, positions, and movements, along with visual feedback for spatial orientation.

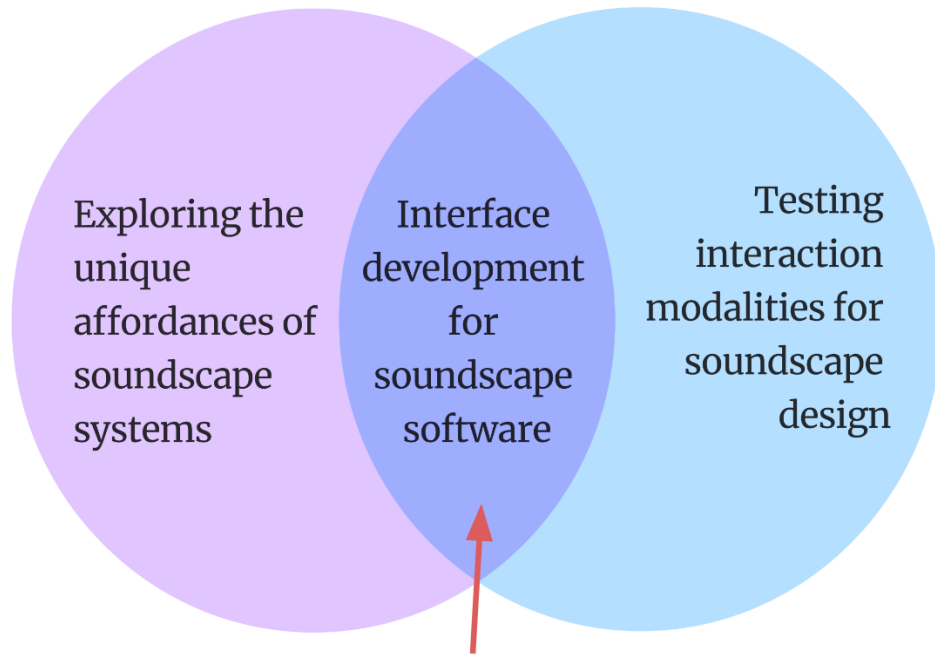


FIGURE 1.1: Two Parts to Explore: My research aims to explore the future development of spatial audio interfaces, combining two parts: 1) exploring the unique affordances and 2) testing the modalities and concluding their efficiency.

Given this background, my research question can be formulated as: What are the special modalities of a spatial sound design platform, and how does the resulting interface influence user experience? This research aims to discuss how to efficiently integrate traditional user interface design principles with the unique requirements of soundscape design. Specifically, it explores how the intersections of these design fields can address existing problems in the diversity of soundscape applications and user interactions. We are specifically discussing the Sound Hologram platform, which integrates WFS and MT to create immersive 3D audio experiences. The modalities of soundscape design interfaces, interactive patterns, and their influences on users' auditory experiences and spatial interactions will be discussed in the following chapters.

1.2 Sound Hologram Platform: A Brief Introduction

The Sound Hologram Platform is installed in MMH127 at Carnegie Mellon University. This space is called 4D lab and used by students and faculty to prototype and test next-generation interactions within environments.



FIGURE 1.2: The lab settings, as photographed by Professor Daniel Rosenberg Munoz.

The Sound Hologram platform is still under construction and in the process of being published. I learned about the system in the course 51-679 Spatial Computing at CMU. This course, taught by Daniel Rosenberg Munoz, explores the intersection of spatial computing and design, focusing on using spatial elements as interactive interfaces. The curriculum covers motion tracking, Unity integration, and wave field synthesis, providing students with hands-on experience in project planning, development, and documentation. Classes meet every Friday from 9:00 am to 11:50 am and involve a mix of lectures, tutorials, and practical activities.

During the course, I first designed prototypes in which sounds occur at a distance from tracked objects. After discussing with Miles Scharff, the main

designer and implementer of this system who recently graduated with a degree in Physics and Music Technology from Carnegie Mellon University, and John Kolar, a classmate currently pursuing a Master of Science in Music and Technology, I learned about the initial ideas involving musical band compositions. Inspired by the potential applications, I decided to explore the modalities and affordances. Our user interface designs and tests are based on this platform, and all discussions revolve around its settings.

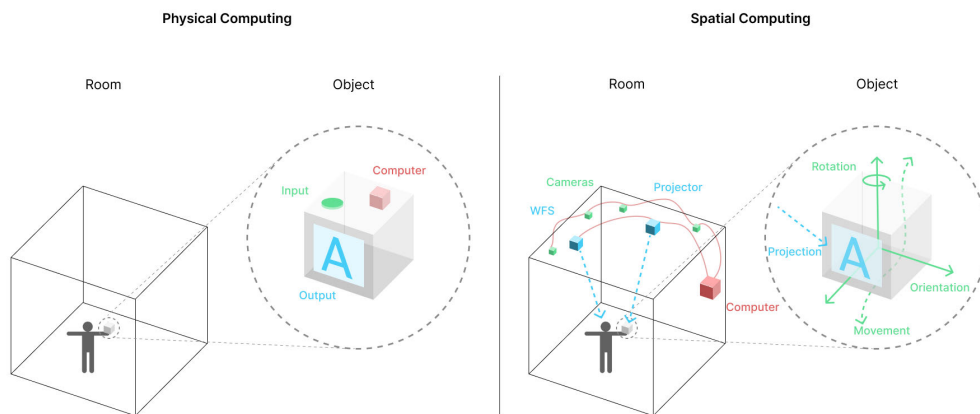


FIGURE 1.3: The diagram about physical computing and settings in the lab, illustrated by Professor Daniel Rosenberg Munoz and student Shih-Hsueh Wang

Professor Rosenberg Munoz is using this shared resource to build the Sound Hologram system with the motion tracking cameras and the 64-channel speaker array. The Sound Hologram system is a creative platform that enables designers to generate, position, and move sound in a certain space (MMH127 in this research) in response to gestures and object movements, thus creating an immersive sound experience. The main technologies it integrates are Wave Field Synthesis (WFS) and Motion Tracking (MT) using advanced software for integration (ROS) and visualization (Unity).

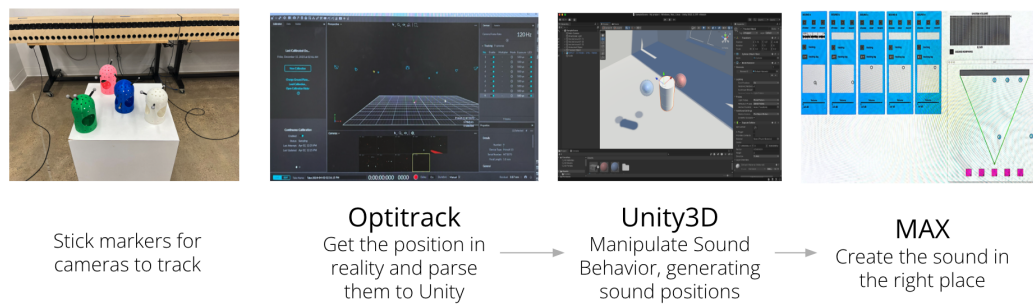


FIGURE 1.4: The original workflow involves using cameras to track objects in physical space, then sending the position data in real-time to Unity3D. In Unity, virtual 3D objects are used to generate sound positions and send them to MAX, creating sounds in the corresponding place in the lab.

Miles Scharff worked as one of the research assistants of Professor Rosenberg and implemented parts of the system's functionality. Most importantly, he designed the sound logic in MAX, cooperating with the 64-channel speakers to create immersive sound effects. Other students, including John Kolar, are still developing the system for further functionalities and applications.

Currently, the system can track physical objects and gestures, generating, positioning, and moving sounds in real-time. It integrates with Optitrack systems, Unity3D, and MAX as the sound editor. A 64-channel speaker array is being developed to project sounds in space. This system is modular and scalable for future expansions.

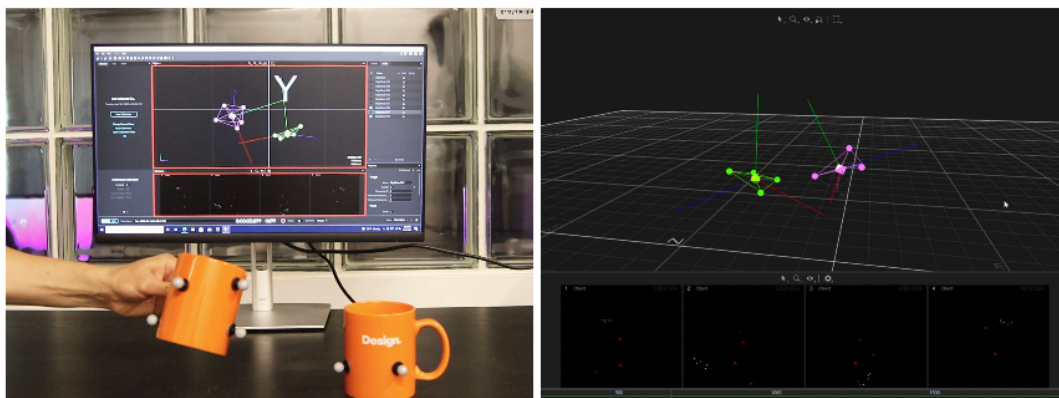


FIGURE 1.5: The Optitrack tracking process by Professor Daniel Rosenberg Munoz.

There are 10 cameras and 4 3D printed plastic objects with trackers in the lab. Each object can be assigned an ID and tracked with rigid-body technology to monitor its 3D positions, orientation, speed, and movements, including rotation. With the ID, the positions and other information can be parsed into Unity3D for further manipulations.

1.3 Traditional Interface Design

In the past years of research and practical experiences in user interactions, designers have fostered common principles on basic design guidelines. In the research "User Interface Design Principles for Interaction Design," the authors discuss the evolution of user interface (UI) design principles in the context of increasing technological interfaces and user diversity.^[3] They assert that mere mimicry or repetition does not enhance user accessibility or functionality. They concluded the shared principles for interface design, which encompass creating a clear starting point, designing an evident exit strategy, ensuring internal design consistency, respecting familiar interface conventions, offering tangible feedback on user actions, and elucidating the core content.

Graphical User Interface (GUI) is an important part of the design. However, it should be determined the exact proportion of Tangible User Interface (TUI) utilization versus the incorporation of GUI elements. Research comparing TUI and GUI has revealed a distinct preference for TUI among users. Nonetheless, TUI is associated with higher error rates. The most appreciated aspect of TUI is its perceived realism, while the strengths of GUI lie in its reliability and efficiency.

Specifically, we can observe applications in past design work. To enhance the usability of design tools, Qiao Jin et al. introduced AR-MPro, an augmented reality (AR)-based tangible programming tool for music visualization. AR-MPro combines augmented reality with tangible programming to help children learn programming concepts through interactive music visualization. This system uses low-cost materials and allows children to create customized AR effects, making the learning process more intuitive and engaging. This innovative approach aims to enhance creativity and broaden participation in computing among young learners.^[4]

Furthermore, the co-creation ability is highly addressed in past research. Waldner et al. introduced "Tangible Tiles," a tangible user interface designed to enhance collaboration on digital tabletops. The system uses transparent plexiglass tiles tracked by an overhead camera to manipulate digital content projected onto a tabletop. Their user study compared Tangible Tiles with a touch screen and traditional paper prints, highlighting that Tangible Tiles support two-handed interactions and allow simultaneous manipulation of digital objects by multiple users, fostering more effective collaborative work compared to standard touch screens. Despite some usability challenges, the findings suggest that TUIs like Tangible Tiles can offer a more natural and intuitive collaborative experience, combining the physical affordances of real objects with the flexibility of digital data manipulation.^[5] Similarly, the concept of co-creative tangibles, as explored in the RHYME project, highlights how embedded digital technologies in everyday objects can foster collaboration and creativity among users. These smart objects, such as interactive pillows equipped with sensors and network capabilities, transform simple interactions into multimodal experiences. The RHYME project demonstrates how these tangibles enable users, including those with severe disabilities, to engage in music and visual creation, thereby enhancing their social and cognitive development. The success of such initiatives emphasizes the transformative power of co-creative tangibles in promoting active participation and enriched interaction in both personal and communal contexts.^[6]

An applied example of the potential of TUIs in soundscape design can be observed in Vetter's work, "Tangible Signals," which introduces a set of TUI prototypes aimed at enhancing interactive physical displays of sound and music data for visually impaired users. These prototypes, including tangible pins, strings, and wheels, leverage sensor technology combined with mechanical actuators to facilitate both manual and software-based interactions. These TUIs create a collaborative platform where users can physically manipulate and engage with sound data, promoting a more inclusive and intuitive workflow. The research underscores the potential of TUIs to support collaborative tasks by providing a tangible representation of digital information, thus bridging the gap between physical and digital interfaces for visually impaired musicians.^[7] In my subsequent studies, I also observed that users appreciate the collaborative and interactive characteristics of TUIs, which suggests significant potential for TUIs in soundscape interface design.

In the following sections, the principles of tangible interfaces will be introduced, providing a foundational understanding of their key concepts and mechanisms. Additionally, several application examples will be examined in detail to illustrate their practical implementations and benefits. This discussion will serve as a background for the next chapter, where I explored the design of collaborative interactions in tangible interfaces.

1.3.1 Tangible User Interface Design Principles

Specifically, the Sound Hologram system interacts with tracking objects to position sounds within a space. Thus, its interface adheres to the design principles of Tangible User Interfaces (TUI). According to research by O. Zuckerman and A. Gol-Oz, the importance of physical objects in the design of interaction can be explained by five theoretical themes:

"Five theoretical themes explaining the importance of physical elements in interaction design:

The first theme, **thinking through doing**, emphasizes the role of physical interaction in cognitive processes.

The second theme, **performance**, describes how actions are faster and more nuanced compared to symbolic cognition.

The third theme, **visibility**, describes the role of artifacts in collaboration and cooperation.

The fourth theme, **risk**, explores how the uncertainty and risk attributes of physical co-presence shape interpersonal and human–computer interactions.

The fifth theme, **thickness of practice**, suggests that embodied interaction is a more prudent path.

In sum, various theoretical explanations, both within and beyond HCI literature, imply that tangible interfaces should be superior to graphical interfaces in regard to performance and learning."^[8]

During the interface design process for the platform, the integration and collaboration of TUI with software is a key point to convey the modalities of the system. Furthermore, a segment of the user testing is dedicated to evaluating how well the new interface encapsulates and conveys the modalities inherent to TUI.

Affordance-Based Tangible Interaction Principles from Gong et al. into Spatial Sound Interface Design

According to research, the development of spatial sound interfaces highly benefits from the integration of TUI design principles. Contributions based on principles that utilize the affordance of physical objects in the user's environment are particularly outstanding. Gong et al. explored tangible interactions based on usability and user-defined spaces. The findings provide a framework to enhance the intuitiveness and effectiveness of spatial sound manipulation.^[9]

Gong et al. defined key affordance elements that can be applied to spatial audio interface design. These affordances, including the size, shape, and motion of objects, help define how users interact with sound elements in 3D spaces physically.^[9] In the context of our Sound Hologram platform, there is currently only one kind of interactive physical object—3D printed plastic eggs. However, future studies could utilize various affordances to simplify the manipulation of complex spatial sound interactions, making the process of sound design more visible and intuitive with higher interactivity.

The inspiring study by Gong et al. discovered a set of user-defined gestures that vary according to the input requirements of the spatial task. These gestures ranged from simple clicks and swipes to more complex operations such as squeezing or rotating objects. This research deeply explored how users interacted with different objects based on their roles. These findings can instruct us on how to develop a more user-friendly interface for the Sound Hologram platform. With user-defined gestures, interfaces can fit users' habits and expectations more naturally.

Gong et al. have ideas similar to ours about Sound Hologram interfaces. By quickly and efficiently assigning sound properties and locations, users can benefit from TUI.^[9] The concepts about ATUI showed that interfaces could dynamically adapt to users' current assignments and available physical characteristics. This method can significantly simplify the process of creating soundscapes, especially when they are complex and dynamic.

According to the research, the future of spatial audio interfaces could focus on creating a more adaptive system considering the affordances of the real-world conditions and user environments. This requires the system to detect and interpret usable physical objects, thus expanding a smooth ability for physical interactions.^[9] This view can be applied to our Sound Hologram

system, where sounds can be easily controlled and interacted with using gestures or trigger areas.

In summary, the research by Gong et al. emphasizes designs based on affordances that have the potential to enhance user and space interactions.^[9] Our Sound Hologram system has already incorporated many related affordances. By applying these principles and validating our platform, we can provide more immersive and straightforward experiences for users, allowing them to engage in spatial sound design and design future interactions in a way that is effective and consistent with their natural gesture language.

1.3.2 Graphic User Interface Design Principles

The graphic user interface has a long history, and its design principles can be traced back to 1995, when Marcus claimed that GUIs have certain principles:^[10]

A GUI design must account for the following:

- A comprehensible mental image (metaphor)
- Appropriate organization of data, functions, tasks, and roles (cognitive model)
- Efficient navigation schema among these data and functions, tasks, and roles
- Quality appearance characteristics (the look)
- Effective interaction sequencing (the feel)

Marcus emphasized three basic principles of visual communication: organize, economize, and communicate.

- Organize: Provide the user with a clear and consistent conceptual structure.
- Economize: Maximize the effectiveness of a minimal set of cues.
- Communicate: Match the presentation to the capabilities of the user.

When designing successful GUIs, development, usability, and acceptance factors are critically important. Marcus discussed how information-oriented, systematic graphic design can help improve visual communication in every

typical GUI component, including screens, windows, menus, dialogue boxes, control panels, icons, and pointers/cursors.

Marcus proposed four aspects of consistency:

- Internal consistency: Observe the same conventions and rules for all elements of the GUI.
- External consistency: Follow existing platform and cultural conventions across user interfaces.
- Real world consistency: Make the conventions consistent with real-world experience.
- Innovation: Deviate from existing conventions only when doing so provides a clear benefit to the user.

Marcus also discussed the importance of color in visual communication and proposed several basic principles for using color effectively, including color organization, color economy, and color communication. He noted that appropriate use of color can emphasize important information, identify sub-systems or structures, portray natural objects realistically, reduce errors of interpretation, and increase comprehensibility and appeal.^[10]

Up until now, there are already shared standards about design principles for GUIs. Radka Nacheva, in her research about the standards in GUIs, highlighted several key principles derived from international standards and leading usability experts. These principles include:^[11]

User interface design should be centered on usability, ensuring that interfaces are intuitive and satisfy end-user objectives. Key principles include:

- User-Centered Design (UCD): Focus on making systems usable by understanding user environments and tasks, specifying user requirements, producing design solutions, and evaluating designs against these requirements.
- Visibility: Important elements should be visible to help users understand their options.
- Consistency: Ensure uniformity in design, matching user expectations and maintaining consistency across different product versions.

- **Feedback:** Provide clear feedback on user actions to reassure them that the system is responding appropriately.
- **Constraints:** Use constraints to prevent errors and guide user actions.
- **Affordance:** Design elements should suggest their functionality, such as buttons appearing clickable.
- **Mapping:** Ensure a logical relationship between controls and their effects.
- **Error Prevention and Recovery:** Design systems to prevent errors and provide clear ways to recover from them.
- **Flexibility and Efficiency:** Allow users to tailor the interface to their needs and provide shortcuts for experienced users.
- **Aesthetic and Minimalist Design:** Avoid unnecessary elements, focusing on clarity and simplicity.
- **Help and Documentation:** Offer easy access to help and documentation.

These principles, combined with detailed guidance from standards like ISO 9241, provide a robust framework for creating user-friendly, efficient, and satisfying interfaces.

The above principles provide clear guidance for the design in the following chapters and will also support the conclusions in my subsequent chapters.

1.3.3 Case Studies of Traditional Design Interfaces

From the following examples, we can observe current interfaces involved with soundscape or audio design. These cases serve as illustrations of the current stage of design and highlight specific affordances emphasized by designers. By examining these examples, we gain insights into the design considerations and innovations that shape the development of soundscape interfaces and audio design tools.

Case Study: Exploring Innovative Virtual Reality Music Video Experiences

The case study "Paint of the Imagination" presents an interactive virtual reality (VR) work that reshapes the way traditional music videos are presented in virtual space. The case explores new ways of audiovisual responsiveness and interactivity, focusing on the narrative and user interaction of the music video. The case uses the creative process as a narrative, through the story of a child's journey to the moon, connecting his unique imagination to the universe around him. It guides the user's journey through a spatialized, fixed media piece and provides space for the user to freely add musical elements to the environment, thus enhancing interactivity and engagement. The research results provide a new perspective on the development of music videos in virtual space.

Audio-visual responsiveness in *Pigments of Imagination* is fundamental to improving the user experience and facilitates the user's decision-making process in virtual scenarios. By mapping musical elements to visual assets, a system is created that is capable of manual automation and real-time reactivity, providing a new form of artistic expression. This case introduces the concept of "pentimento," which refers to the behavior of an artist covering old layers of paint during the painting process. In VR experiences, this concept is used to enable interactions between users across time, allowing them to coexist with and build upon the sound and visual creations of previous users.

Although the interaction design of our platform is still at a relatively early stage, this case provides ideas for possible future interaction design: how to provide a mode of interaction by overlaying sound. Such a model could even reverse the original subjectivity, allowing for a dynamic change in the part of the audience that participates.

Case Study Analysis: Audiovisual Immersion in Björk's VR Experience and Its Application in Soundscape Interfaces

Björk's VR experience utilizes dynamic interaction, where the user's movements and viewing angle change the audiovisual output to personalize the experience. The inspiration for this for our interface is that similar dynamic interactions can be realized in more complex soundscape interfaces by using motion tracking technology to adjust sound attributes based on the user's position and movement in space. This approach would not only make the

experience more engaging, but would also allow for a deeper exploration of the soundscape, thus enhancing educational and artistic exploration.

As analyzed in the case study, the flexibility of user interaction in Björk's VR video shows the potential for a highly customizable user interface. Users can choose their mode of interaction - be it touch, gesture, or even voice control - to manipulate audio elements. This adaptability will allow the technology to be used by a wider audience, including people with disabilities, thus expanding the scope and impact of the research.

The insights provide a valuable framework for understanding how immersive technologies can enhance user engagement through well-designed audiovisual interactions. By incorporating these principles into the development of soundscape interfaces, my research aims to create more intuitive and engaging environments that utilize the full potential of audiovisual immersion. This may revolutionize the way users interact with sound in a variety of domains, including virtual learning environments, therapy settings, and interactive installations.

1.4 Soundscape Interfaces Design principles

Soundscape interfaces demand unique design principles that differ markedly from those of traditional interfaces due to their focus on auditory experiences. These interfaces require the integration of sound design knowledge to manipulate and control sounds within an immersive environment effectively.

Specifically, due to the limitations and lack of interactivity in previous tools, J. Mathew et al. introduced the Spatial Audio Design Spaces framework (SpADS). Their work addresses challenges in manipulating and controlling audio objects within 3D audio environments. By conducting comprehensive analyses and interviewing professional sound engineers, they identified key issues in recording, rendering, mixing, and monitoring. The SpADS framework offers a structured approach to understanding and designing the spatial properties of audio objects, simplifying the interaction process and enhancing the flexibility and usability of object-based audio production techniques.^[12]

Feedback in soundscape interface design is also an important aspect to consider. Steven Gelineck and Dan Overholt introduced a new user interface exploring haptic feedback for 3D audio mixing. Their work compares different interaction paradigms using LEAP Motion for mid-air hand gestures

and Novint Falcon for active haptic feedback. The study aims to enhance speed, accuracy, and reduce the reliance on visual feedback. Results from their evaluation indicate a preference for the Falcon interface without visual feedback, as it allowed users to focus more on the spatial sound elements, highlighting the potential of haptic feedback in improving 3D audio mixing interfaces. This inspired me to explore more applications of TUIs rather than pure GUIs for audio manipulations, and the efficiency of combining different interfaces.^[13]

Case Study: Incorporating Tonal Music Theories in Auditory Interface Design

Minsik Choi's doctoral research explored the integration of tonal music theories into the design of auditory interfaces, aiming to create a progressive, explainable, and accessible system for sound design. This approach leverages musical progression and expectancy to enhance the systematization, explainability, and diversity of auditory interfaces.^[14]

Choi's study emphasized the importance of considering cognitive interactions with sound that go beyond simple auditory perception. This aligns with the soundscape interface design principle of creating intuitive and context-aware systems that dynamically respond to user interactions. By integrating tonal music theories, soundscape interfaces can leverage known patterns of musical expectation to guide user interactions more naturally and intuitively.^[14]

Choi's method emphasized the progression of sound rather than isolated sound events. This approach mirrors the structure of musical compositions where transitions and progressions play a critical role in the user's auditory experience. Soundscape interfaces can adopt this progressive design philosophy to create more cohesive and immersive auditory experiences. For example, transitions between different soundscapes could be designed to reflect musical transitions, making the changes more natural and less jarring for the user. The research advocates for a design methodology that is both systematic and explainable, grounded in the structured theories of tonal music. This approach can be particularly beneficial in educational or therapeutic settings where understanding the rationale behind sound changes is important. For instance, in therapeutic soundscapes, explaining the choice of certain sounds based on their expected psychological effects could enhance the therapeutic impact.

Choi stressed the importance of user-centered design, considering the functional context of tonality and the psychological factors of the end user.^[14] Soundscape interfaces could use these principles to tailor auditory experiences to individual user preferences or needs, enhancing user satisfaction and effectiveness. Customizing soundscapes based on user feedback or psychological profiles could make them more effective in settings such as personalized meditation apps or adaptive learning environments.

To integrate Choi's findings into soundscape interface design, one could develop a modular system where components of the soundscape are influenced by tonal music theories. For example, a module could dynamically adjust the soundscape based on the user's current activity or emotional state, using principles of musical progression and expectancy to predict and influence user behavior.

This integration not only improves the auditory experience by making it more intuitive and engaging but also makes the design process more clear and aligned with established musical theory, facilitating more effective and rapid development of new soundscape applications.

By integrating these advanced theoretical perspectives into soundscape interface design, the interfaces can be both more theoretically reliable and artistically fulfilling, meeting the dual needs of functionality and creativity in sound design.

1.5 Intersections of Two Areas

The development of soundscape interfaces often intersects with traditional user interface design, particularly in the application of tangible user interfaces (TUIs) and graphical user interfaces (GUIs). This section explores how blending these areas can lead to innovative solutions for sound interaction.

Jeon, Andreopoulou, and Katz (2020) discuss significant advancements in auditory displays and auditory user interfaces, which are highly relevant to the intersections we are discussing. They highlight that the field has evolved from simple sound mappings to more systematic and refined sonic information design. By integrating approaches from art, design, science, and research, these advancements have improved the precision of sound and data mappings, as well as enhanced user acceptance, aesthetics, and usability. The authors emphasize the application of multimodal and multisensory systems

in areas such as education, assistive technologies, auditory wayfinding, and virtual and augmented reality environments. These developments provide a robust theoretical and practical foundation for soundscape interface design, driving the field forward.^[15]

Case Study: Full-Body Interactions in "A Very Real Looper" (AVRL)

"A Very Real Looper" (AVRL) presents an innovative approach to musical interfaces in virtual reality, emphasizing full-body interactions without the need for visual input. This audio-only VR interface allows performers to engage with music through body movements, facilitated by the Unity game engine and VR technology. Unlike traditional VR musical interfaces that may alienate performers from their audience, AVRL integrates physical objects within the performance space to locate sounds, thereby augmenting the musical performance environment both spatially and acoustically.^[16]

AVRL's innovative use of VR technology for musical expression exemplifies the intersection between soundscape interfaces and traditional user interfaces, specifically in the context of enhancing user engagement and interaction within a performance setting. This case study highlights several key aspects relevant to the broader application of interface design principles in soundscapes.

AVRL merged physical interaction with virtual reality, allowing performers to physically interact with music through movement rather than traditional tactile interfaces. This model can be adapted to soundscape interfaces to allow users to interact with ambient sounds in an environment, such as a museum or an interactive installation, where movement through space could trigger and manipulate audio elements.

By overlaying virtual sounds onto physical objects in the environment, AVRL created a more intuitive mapping of sound to space, enhancing the performer's ability to navigate and interact with the sound elements. A similar spatial mapping can be utilized in educational and therapeutic soundscapes, where users can interact with and manipulate sounds that are spatially correlated with physical elements or activities, enhancing the learning or therapeutic outcomes.

The performance environment in AVRL is both expansive and reconfigurable, providing performers with a dynamic space that responds to their movements and interactions. This approach can be used to create flexible and

adaptive soundscape environments in areas such as interactive playgrounds or adaptive recreational areas, where the environment responds to the presence and activity of users, altering soundscapes accordingly.^[16]

AVRL focused on auditory feedback and physical interactions, reducing reliance on visual cues, which often dominate virtual and augmented reality experiences. This principle can be particularly valuable in designs intended for visually impaired users, where auditory and tactile feedback are crucial for interaction and navigation within the soundscape.

The AVRL case study underscored the potential for innovative user interface designs that bridge virtual reality and physical interactions in musical performance. By leveraging these principles, soundscape interfaces can foster more engaging and intuitive user experiences, allowing for more profound interaction with sound in various contexts. This integration not only enhances the practical applications of soundscapes but also pushes the boundaries of how we interact with and perceive sound in immersive environments.

1.6 Conclusion

TUIs bring a physical connection to digital interactions, enhancing the tangibility and direct manipulation of sound elements, while GUIs offer precision and detailed visual feedback that supports complex tasks. An optimal soundscape interface may blend TUI's intuitive physical engagement with GUI's detailed control, providing a balanced and effective user experience.

Leveraging advances in VR and AR technologies can bridge the gap between traditional interface paradigms and soundscape interfaces. For example, augmented reality can overlay graphical elements on physical TUI components, enriching the user interaction without sacrificing the intuitive nature of physical controls.

As sound technology continues to evolve, the integration points between different interface paradigms will likely expand. Future research could explore deeper integration of AI to automate some aspects of soundscape creation, providing users with even more powerful tools to manipulate audio environments effectively.

Chapter 2

Method:

Interface Design Logic and User Test

2.1 Research Methods and New Interface Design

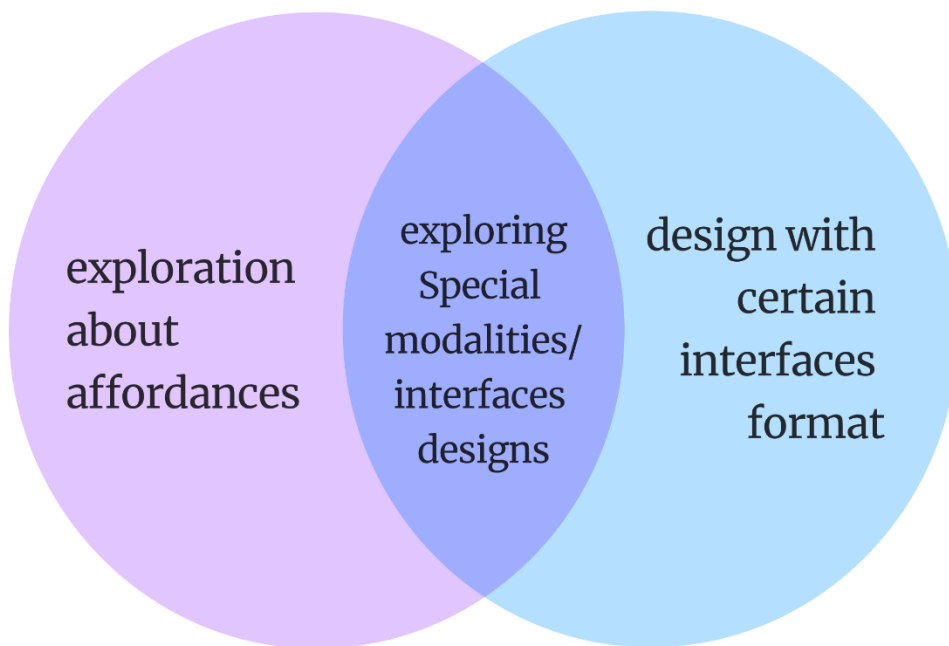


FIGURE 2.1: The research methods begin with explorations about affordances and identifications of certain interface formats, and then explore the special modalities and interface designs.

The design method was rooted in the analysis of design experiences and applications. Through assumptions about how users are using the platform, the main affordances are identified and defined. These capabilities include enhanced tangible interaction, visualization, and direct, real-time feedback.

The concluded affordances are then connected with specific interactive elements. The process involves determining how to take advantage of each affordance to improve user engagement and the effectiveness of interfaces. For example, the integration of real-world interactions with dynamic visualization can enrich user experiences and help users understand dynamic spatial audio directly.

Moreover, the connection between affordances and interactive methods is important since it provides the required information for design strategies, guiding the functionality and innovation of UI elements. This theoretical foundation supports creating a user-centered interface that can predict and respond to users' needs and behaviors.

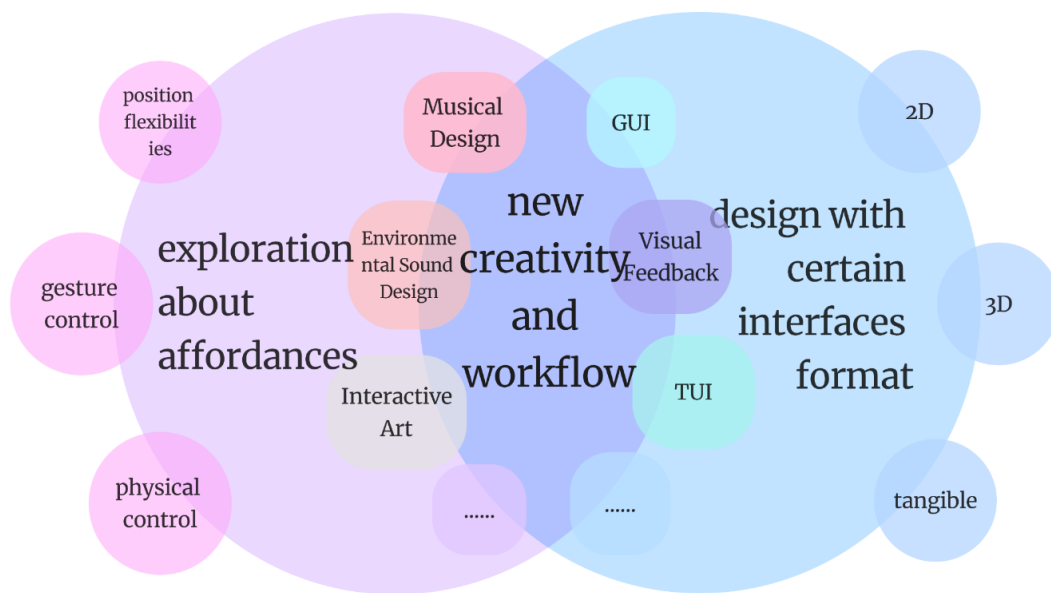


FIGURE 2.2: Exploring interaction modalities can inform certain interface formats, and new combinations can boost creative new workflows. The approach is to explore prototypes and user tests to couple interaction modalities with the unique affordances of spatial sound design.

Once the affordances and interface formats were defined, I broke down each category into detailed elements corresponding to specific design components

and integrated them with one another. I then used Figma to design mock-ups that incorporated Unity3D style logic and elements, intending to develop the entire design using scripts within Unity. This strategy is effective for implementing the consistent interface since Unity3D provides a wide range of flexible Application Programming Interfaces (APIs) and is widely used by designers. Moreover, Unity3D is very flexible in cooperating with scripts that enable users to write and define the functions they want.^[17] To gather insights for future interface design, these early-stage prototypes were created with Figma mock-ups and tested with master's students from the School of Architecture. With the feedback, future instructions and suggestions were concluded, identifying patterns and areas for improvement, ensuring that the final design is user-centric, functional, and design-oriented.

2.1.1 High-Level Design Based on User Scenarios

The conceptual framework of the new interface is built with the idea of enhancing user interaction and engagement through intuitive design elements. These UI elements handle the smooth integration with different design software, facilitating the connections between the user's actions and the system's feedback. Thus, the design is derived from the assumptions of the user's design.

The first step is to conclude the characteristics that Sound Hologram can provide and the affordances based on these characteristics. The results are shown in Table 2.1.

Characters	Affordance
Spatial Freedom • place sounds anywhere within a room • shared experience of spatial audio • regardless the traditional "sweet spot" of listening	3D visualization of sound positions 3D modification of sound positions
Interactivity and Physicality • Changing the sound's properties with gestures and movements • Track the sound in a visible way	Gesture recognition and interactions
Sound Autonomy • sounds can have behaviors • sounds can be positioned away from physical object	Cast characters on sound resources -movement, frequency, density

TABLE 2.1: Characters and affordances concluded.

In Tables 2.1 and 2.2, I described the characteristics and corresponding affordances of the original system "Sound Hologram" and the applications in different user scenarios. These scenarios are based on observations of students of Spatial Computing using either the motion-tracking system alone or the complete Sound Hologram platform. Additionally, insights were gathered from email interviews with one of the original designers of the system, Miles Scharff, and current developer John Kolar. Miles' initial idea was to create an immersive sound system and implement a virtual band playing in the lab. In this case, the platform is not primarily a design-oriented tool, but it does incorporate basic design tool elements, such as flexibility in sound resources.

John, a musician with a band and a current master's student in music and technology, is exploring applications for performances and creating chorus effects. After discussing their work, I summarized the scenarios. Figure 2.2 concludes basic characters and related user functions. 'Spatial Freedom' ensures that users can place and perceive sound in any place in the tracked space, freeing users from the constraints of traditional audio experiences. This character is complemented by affordances including 3D visualization of sound positions, enhancing the interactive spatial audio experience.

'Interactivity and Physicality' emphasizes the dynamic interactions between gestures and audio output to specify certain sounds. The corresponding affordance, especially gesture recognition, transfers body motions into audio changes, fostering a tangible connection with the sound.

The third is "Sound Autonomy," which acknowledges sound as an entity with its own behavior. This character allows sound motions and directions to be separated from the tracked object and users. Related affordances are helpful for dynamic attributes cast on sound resources, thus augmenting users' creative control over the auditory landscape.

Scenario	Features	Needs	Affordance
Musical Composition	-Creating an immersive audio environment/live performances. -Customizable performance effects	-Sound moving with users -Sound that has directions	-Visual indicators for sound movement and direction (projections in the room) -Shoot sound -Sound surround the objects
installations/exhibitions	-Interactive responsive to users	-Interactions trigger	-Motion-sensitive areas (triggered sound when users approach) -Visual feedback
Immersive/Mixed Reality Design	-Layered sensory experience within a virtual or augmented reality setting. -Adapt to visual elements	-Distance, randomized -Link with visual elements	-Visual feedbacks -GUI about randomized the sound Sound in a different space

TABLE 2.2: Scenario assumptions and the affordances required.

Table 2.2 illustrates specific scenarios, highlighting the features, needs, and affordances of the platform. These scenarios are primarily derived from interviews with Miles and John, as well as my classmates' projects on Spatial Computing. The main scenarios include Musical Composition, Installations/Exhibitions, and Immersive/Mixed Reality Design. In the context of Musical Composition, the system accommodates the need for sounds that move with the user and possess directionality through affordances like visual indicators and directional audio projection. For Installations/Exhibitions, the interface responds to user proximity with motion-sensitive areas and provides visual feedback, thereby elevating the interactive experience. Lastly, the Immersive/Mixed Reality Design scenario demands a multi-layered sensory experience, integrated with visual elements and supported by affordances including visual feedback and a GUI for the manipulation of randomized sound elements.

These figures collectively construct a comprehensive framework for a sound interface design that is inherently user-centric, addressing the distinct requisites of different scenarios through a coherent set of affordances, thus enabling robust and versatile user interaction with sound.

2.1.2 Interface Design Details

To create the interface prototypes, I used Figma to design a mock-up incorporating Unity3D elements. This involved scripting custom menus and interactions within Figma to simulate the functionality and appearance of the final design in Unity3D. The use of Unity3D style elements in Figma allowed for a more seamless transition to the final development stage, where the design will be implemented using Unity3D scripts.

We firstly divide the interface into attributes part and objects part. The objects part is divided into tracked objects and untracked objects.

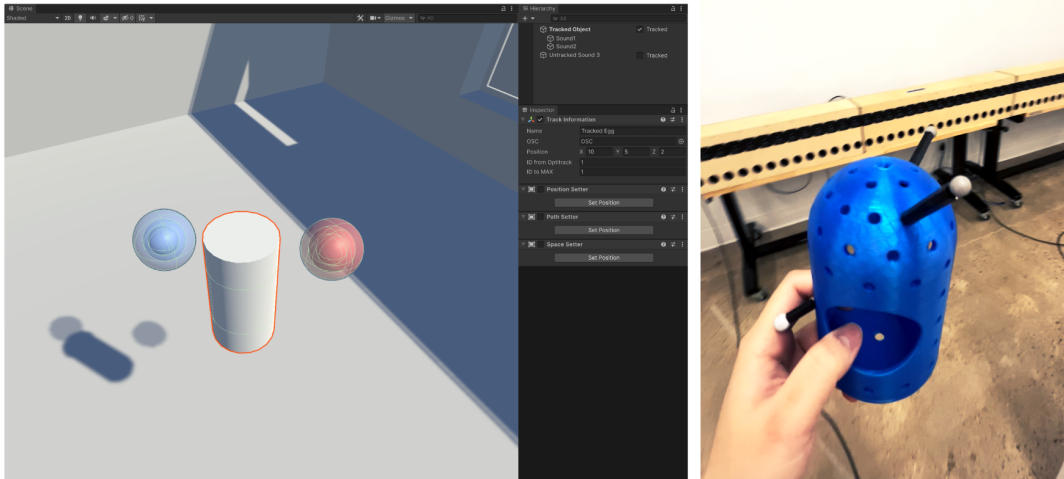


FIGURE 2.3: A tracked object with sounds has basic attributes such as tracking ID, MAX ID, positions, and resources. It can also function as a setter.

This interface allows users to apply tracked objects to multiple aims, such as setting coordinates toward space, setting paths, or demarcating specific spatial regions within the environment. In the 3D scene, the tracked object (the blue egg on the right in reality) is illustrated as a white cylinder to highlight it in the scene. The different kinds of objects are also highlighted in the object area at the right-top corner of the interface, improving the efficiency of choosing tracked objects, untracked objects, and sounds. This function also simplifies attributes in the Inspector panel, thus providing a more intuitive interaction for users seeking to identify and interact with specific objects in the system.

In the Inspector Panel, we can set the OSC script (already existing within the current workflow) to define the directions and space of the lab, and send existing spatial data from Unity3D to MAX. Additionally, we can observe the coordinates of the cylinder in the Position section. Using the ID from Optitrack, we can connect the cylinder with the blue eggs. By tracking the markers on the eggs with the camera, we can create a rigid object in Optitrack to track and send data with the same ID in Optitrack and Unity3D in real-time. Using the same ID in Unity3D and MAX, we can send this position data to MAX, connecting sound objects with the right audio manipulations. The reason we do not send the data directly to MAX is that we are creating virtual objects for sound in Unity3D and adding behaviors to them. By using

the corresponding ID to MAX, we can obtain the real-time position of the sound in the lab.

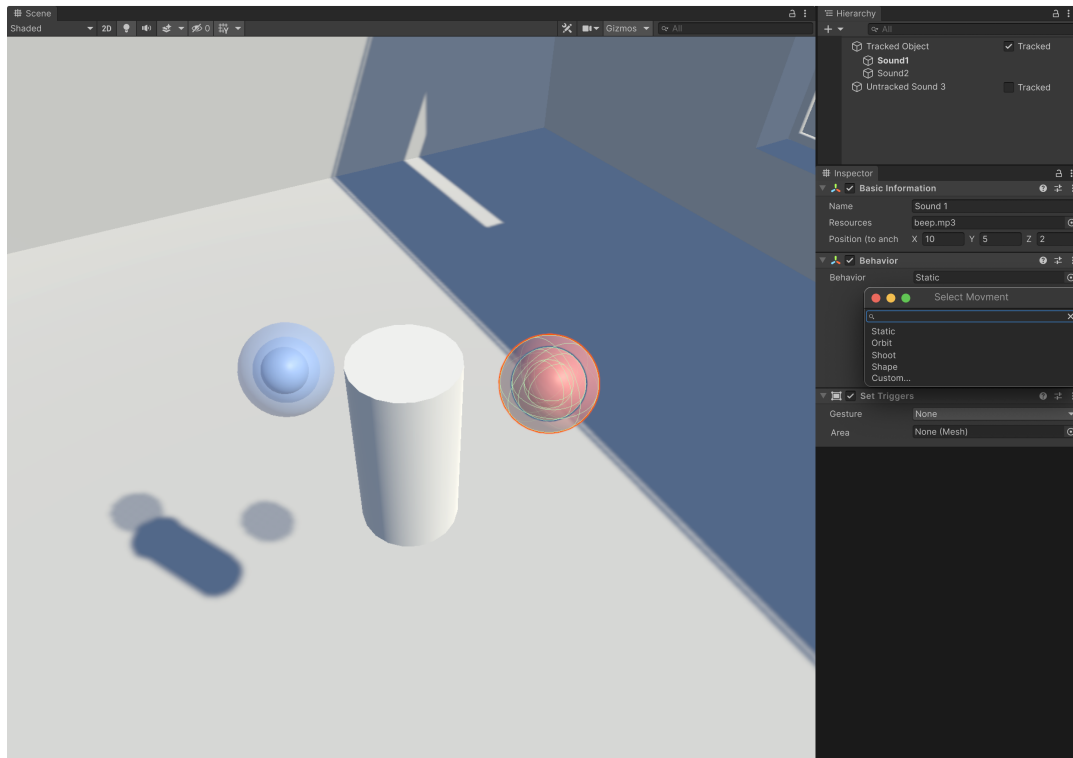


FIGURE 2.4: Sound can be linked with one tracked object, allowing real-time auditory mapping and customizing sound behaviors.

Figure 2.4 shows the interface of sounds linked with tracked objects. Within the Hierarchy window, "Sound 1" is listed as a tracked object, indicating its synchronization with a physical entity monitored by the OptiTrack system. This establishes a live auditory mapping; as the physical object maneuvers through the tangible world, "Sound 1" echoes its path in the virtual landscape, ensuring the sound's position is a true reflection of its physical counterpart's location.

The Inspector panel is the control hub where the sound's identity is forged—enabling the designation of its title, source file (beep.mp3), spatial coordinates, and a distinct ID which governs the maximum positional data transmitted. The behavior attribute can be tailored from a static state to dynamic forms such as shape-shifting, orbital, projectile, or bespoke patterns. Though tethered in relative position to the tracked object, these sounds maintain the autonomy to exhibit their individualistic behavior.

Semi-transparent markers delineate the ephemeral position of the sound in the scene, contrasting with the solid white geometry—spheres and cylinders—that signify the presence of tracked objects in motion.

The 'Set Triggers' feature empowers users to sculpt the auditory experience further, enabling them to conjure specific events that dictate the sound's response—whether it is to awaken or transform upon entering a designated spatial zone or in reaction to a predefined gesture.

By intertwining sound with the dynamic essence of physical objects, the platform endows creators with the means to orchestrate a symphony where audio elements adapt in harmony with the physical dance of objects, crafting an authentic and immersive spatial soundscape.

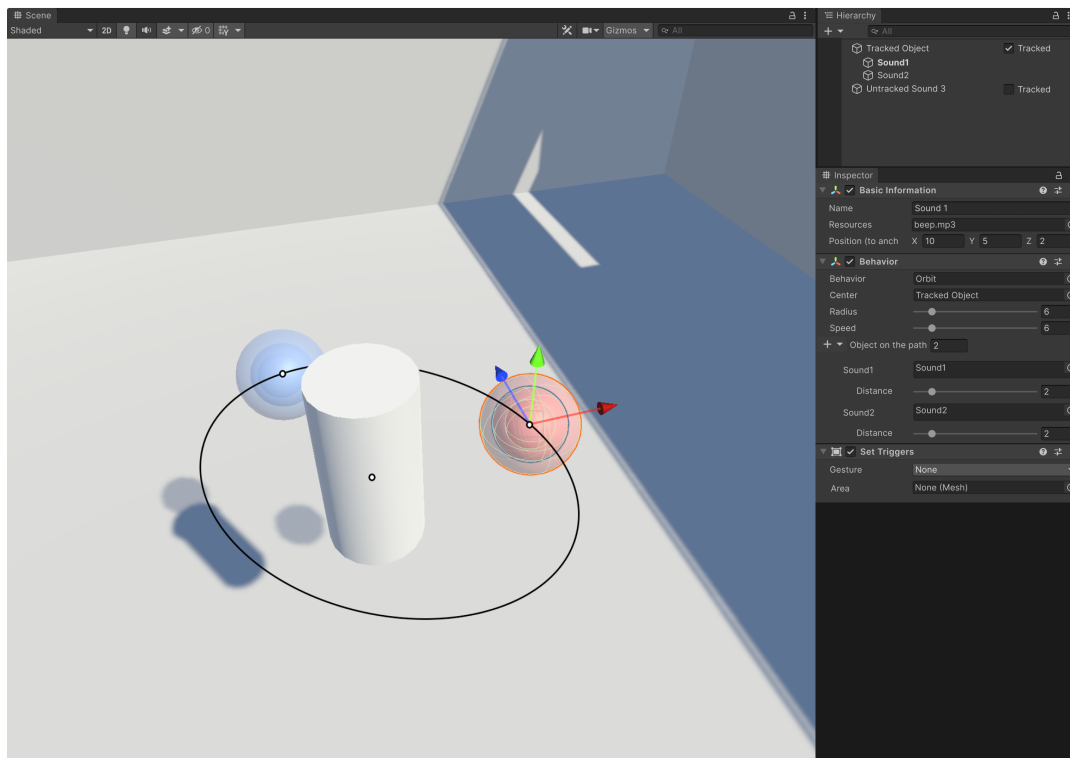


FIGURE 2.5: To orbit a sound, the radius and speed can be adjusted in the Inspector panel for precise movement paths.

As shown in Figure 2.5, the track behavior of the sound can be set to rotate around a selected center point—in this case, the Tracked Object. Through the Inspector panel, you can define the radius and speed of rotation, thereby creating a predictable path for the sound source to move.

The "Behavior" section details the parameters of the track behavior. The center point is set to a "Tracked Object," which means the sound will rotate around this tracked physics object. The values of radius and speed determine the range and rate of sound movement, allowing the sound to maintain a constant distance and rotate around the center point at a set rate. In addition, the "Object on the path" area allows users to add and configure trajectories for multiple sound sources, and the distance of each sound source can be set independently.

The black circle in the scene view represents the visual path of the sound trajectory, allowing users to intuitively understand the range of motion of the sound source. In this example, the white object in the center of the circle is the center point of the sound's trajectory—that is, the tracking object around which the sound will rotate. Users can configure specific interaction triggers for sounds. For example, different sound effects or behaviors can be triggered when the sound reaches a certain point in the trajectory or when a specific user gesture is detected. Such behavioral settings provide a dynamic spatial representation of sound objects, allowing them to move around objects in the physical world, thereby creating an enveloping and three-dimensional listening experience.

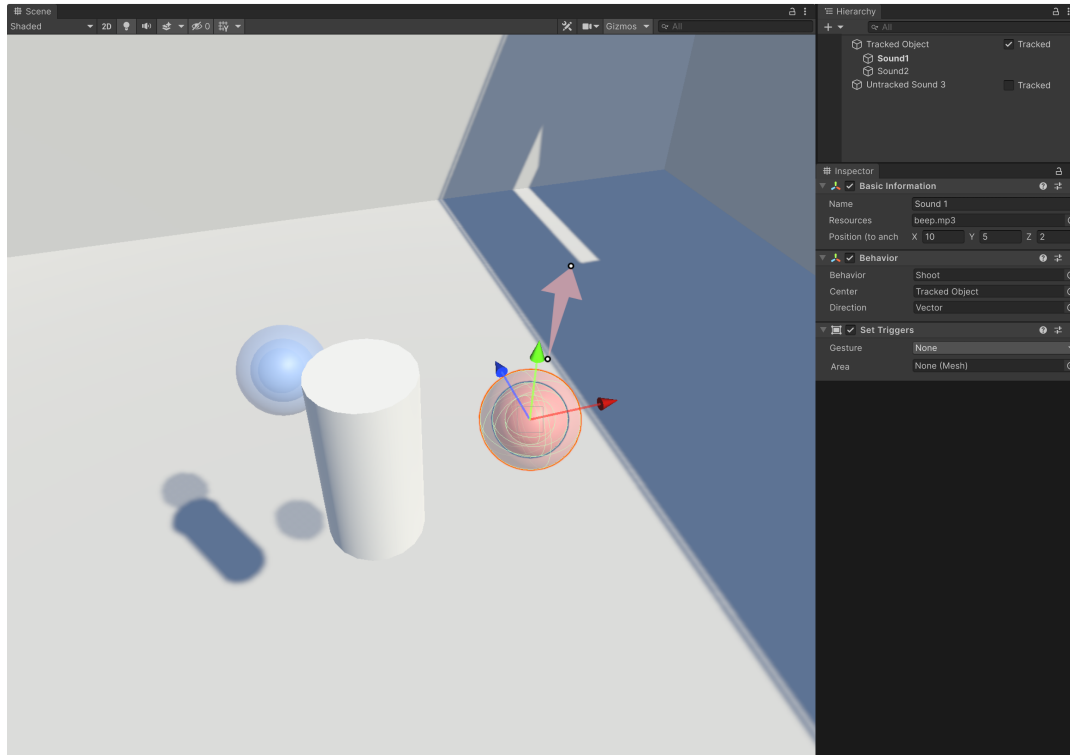


FIGURE 2.6: Sound objects can be set to "shoot" from a tracked object, maintaining relative movement and direction, configurable by setting a vector.

In Figure 2.6, we see a sound object configured with the "shoot" behavior in the 3D Sound Platform user interface. This behavior allows a sound object to move in a specified direction relative to the tracking physics object to which it is attached. This means that although the path of the sound source appears as a straight "shot," its actual position is closely tied to the movement of the tracked object. The sound's emission direction and speed are configured through the parameters of the Inspector panel, but its performance in space always maintains its relative position to the tracked object.

The "Behavior" section shows the details of the "shooting" behavior in the Inspector panel. The center point can be set to any object in the scene or a point. In this diagram, the center point is set to the "Tracked Object," meaning that the sound will be "emitted" from the position of this physical object. Even so, the relative position and direction of the sound changes as the tracked object moves and rotates. This design ensures that the movement of the sound reflects the dynamics of the tracked object in the physical world.

The arrow in the scene view indicates the initial direction of sound emission, while the black trajectory line depicts the sound's expected path of motion. Surrounding geometry—such as white spheres and cylinders—may represent other tracked objects or interactive features.

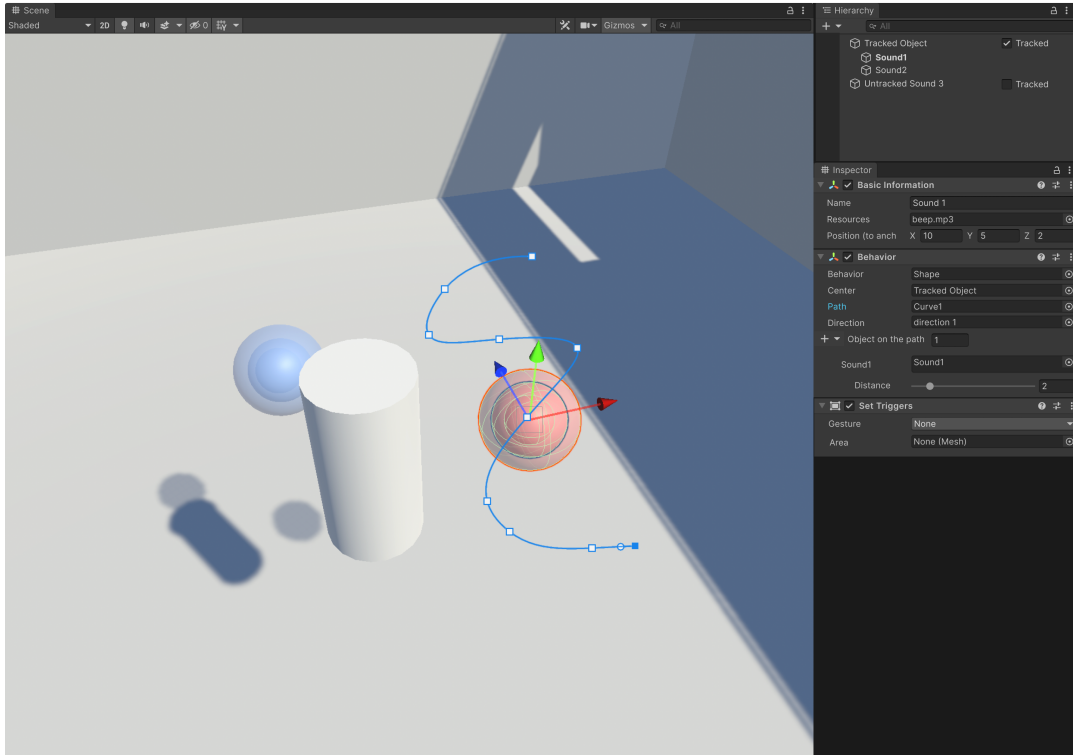


FIGURE 2.7: The sound moves along 'Curve 1', visualized as a blue line while dynamically linked to the 'Tracked Object'. Users can adjust speed, objects on the curve, or set a new path for the sound.

In Figure 2.7, the user interface shows the settings for the shape behavior. In this behavior mode, the sound object moves along a predefined path—in this case, "Curve 1". This path is represented by a blue line in the scene view, clearly depicting the movement of the sound. In the Inspector panel, the center point is set to "Tracked Object," which means that although the sound moves along the path, its movement is always related to the position of the tracked object. This association ensures that sounds move synchronously within the dynamic range of objects in the physical world, even along complex paths. Additionally, users can adjust the distance of sound objects along the path, providing further flexibility in the movement of sounds.

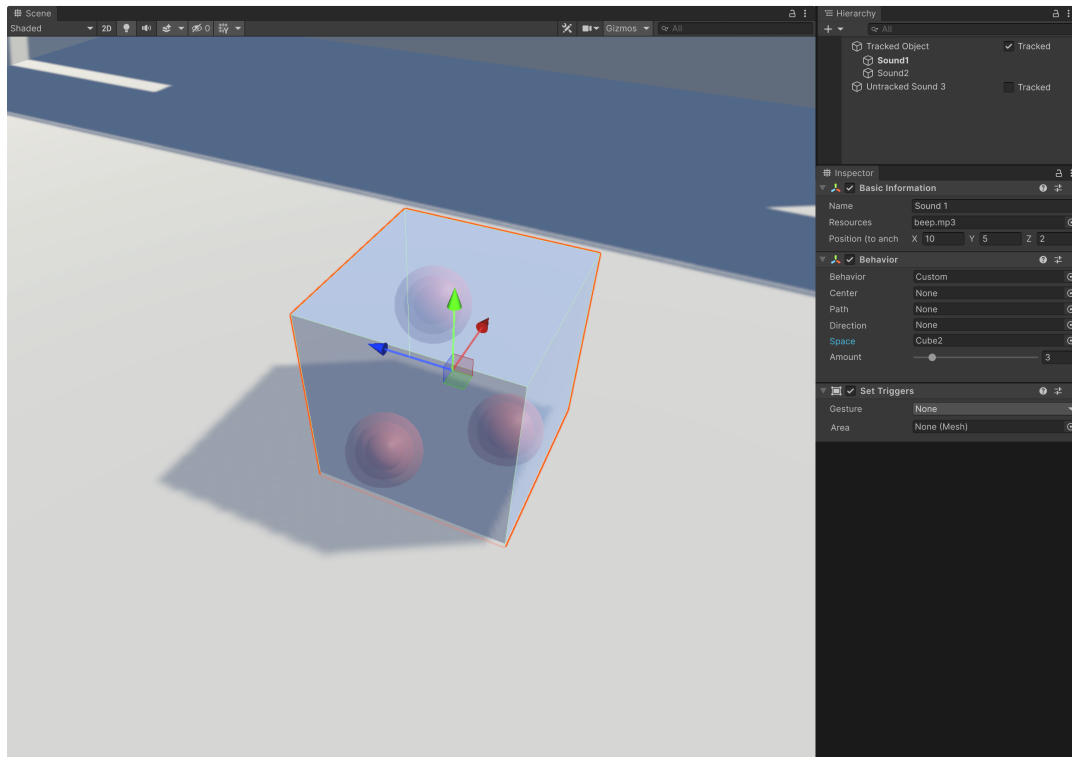


FIGURE 2.8: Custom setup allows for complex movements across multiple points, controlled by user-defined parameters for versatile sound positioning.

In Figure 2.8, we see the "custom" behavior settings for the sound object. This behavior allows sounds to move freely within a user-defined space—as designated "Cube 2". This space is marked by an orange outline box in the scene view. Within this box, the sound object can be moved between multiple points according to user-set parameters, the amount specified by the "Amount" property. In this behavior mode, the sound no longer relies on a fixed tracking object or path, but shows more freedom and complexity in a wider area.

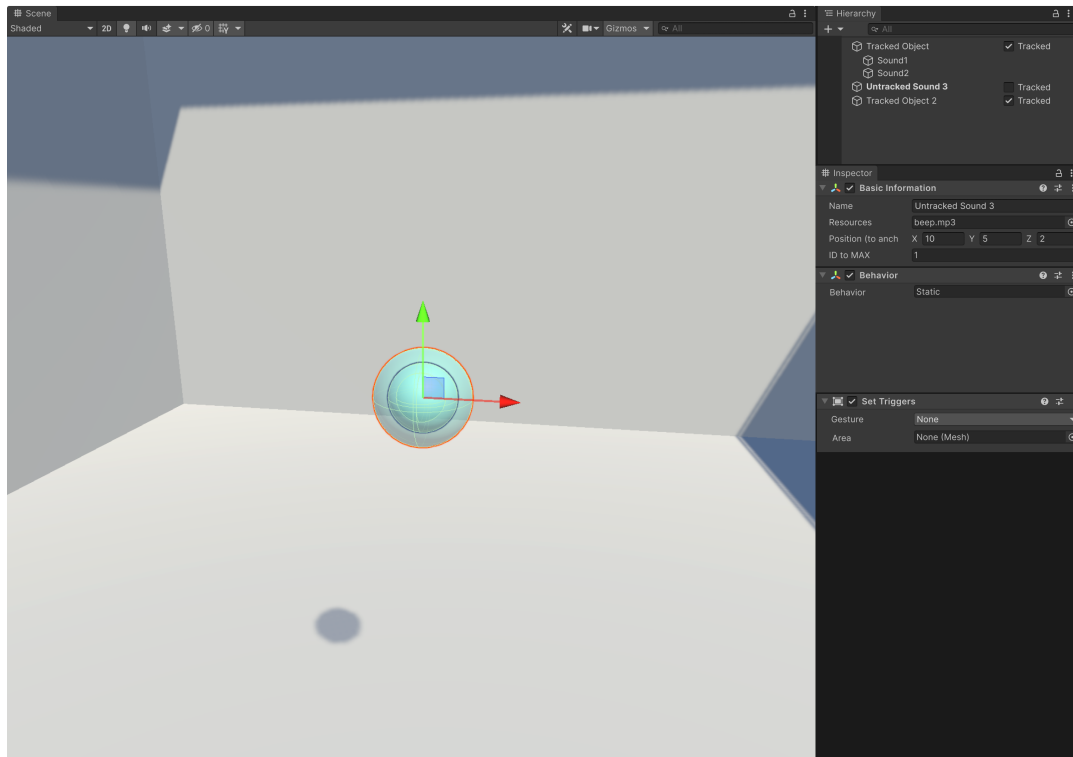


FIGURE 2.9: If a sound is not related to any tracked object, it will not move with any objects, but move around a certain area by itself.

Untracked objects are designed to play sounds around a fixed point in three-dimensional space without relying on a physical tracking system to update their position. Therefore, these sound elements can be considered static, creating a persistent and unchanging acoustic background for the user in the virtual environment.

In the Inspector panel of the interface, users can set detailed properties for each untracked object (such as "Untracked Sound 3"). This includes specifying the audio resource (such as beep.mp3), defining its specific location in three-dimensional space (in the form of X, Y, Z coordinates), and assigning a unique identifier (ID to MAX). Additionally, Behavior settings allow users to specify behavior patterns for sound objects. Although in this example the behavior is set to "Static," meaning that the sound object remains constant at runtime, the interface design supports specifying other complex behaviors, such as volume or pitch that changes over time.

Additionally, the 'Set Triggers' section provides an interface that allows the

user to define trigger conditions for sound objects. Although no trigger conditions are currently set ('Gesture' and 'Area' are both 'None'), the user can configure these parameters to respond to specific gestures or activate sounds when the user enters a specific area. This provides the possibility to create dynamic and interactive audio environments, further enriching the user's immersive experience.

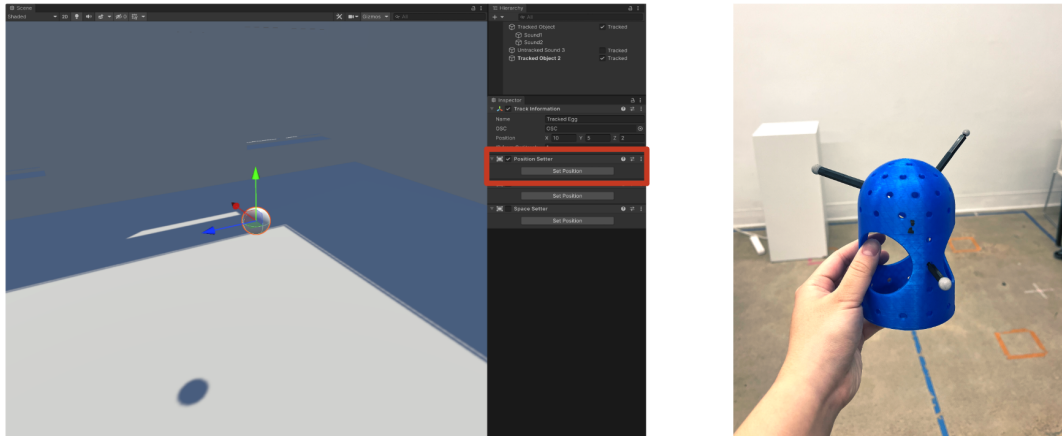


FIGURE 2.10: In this interface, users can interact with a physical object in real space to set the position of a point within the software. The Position Setter in the Inspector panel reflects the coordinates of the tracked object, allowing for precise alignment in the virtual soundscape.

Point Setter

A point-based approach allows designers to define a single precise location in a space where sound is generated or anchored. This is the basic unit of sound position in space. By using tracking objects as tools to set points, sound designers can easily position sources of energy in space. The method is to move the tracked object to the desired position and then press the set position button. This method is very intuitive and easy for designers to operate.

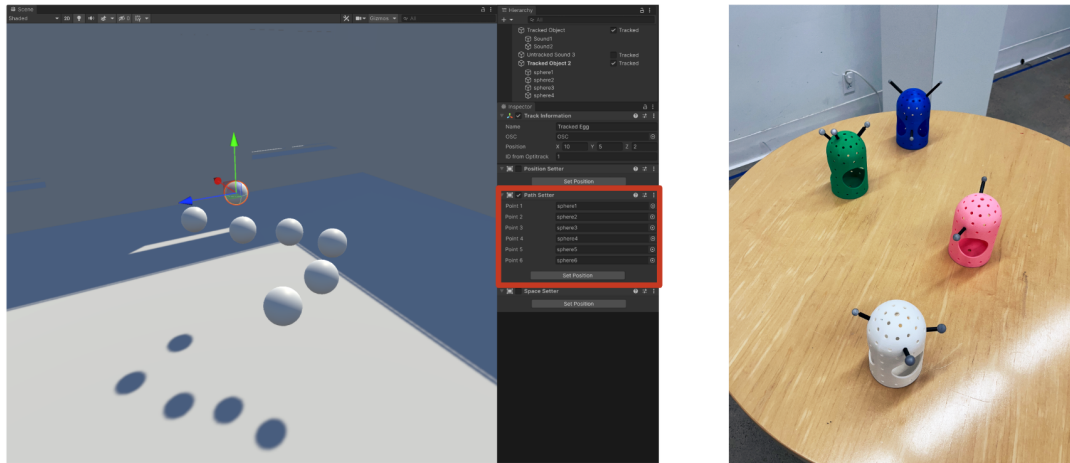


FIGURE 2.11: In this interface, users can interact with a physical object in real space to set the position of a point within the software. The Position Setter in the Inspector panel reflects the coordinates of the tracked object, allowing for precise alignment in the virtual soundscape.

Path Setter

In the interface of the path setter, we can create a curve by setting several points in the space and input the points into the corresponding input of the inspector panel. The result can be a sound's path, which creates a dynamic experience that the sound moves based on a certain path. By setting the path using tracked objects, designers can move the tracked objects to the required points on the desired path. By clicking on the set position button, the mapped position will be added to the interface as a key point on the path. After setting all the key points, one curve will be created. The design applications include going across a road or birds flying across the sky. This interface provides a user-friendly and precise way to map complicated sound movements.

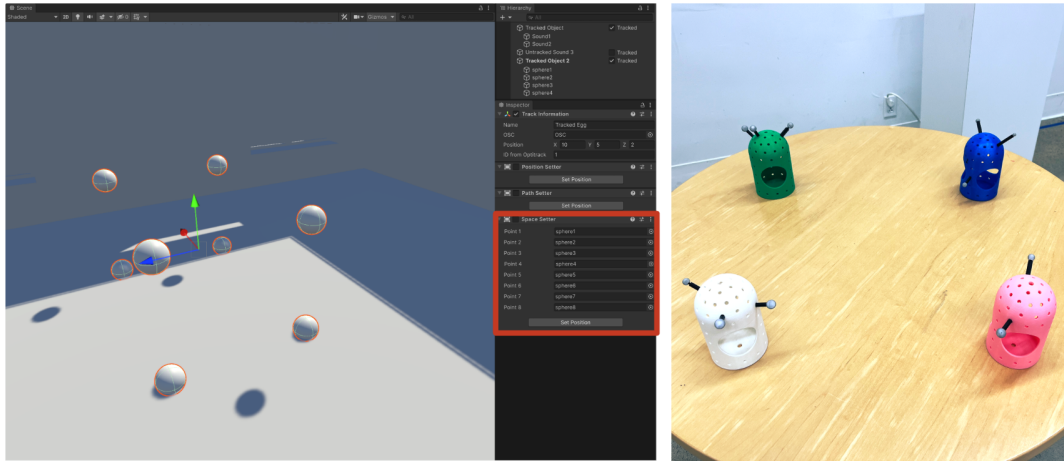


FIGURE 2.12: The volume-based approach enables designers to define a three-dimensional space with tracked objects to mark the boundaries.

Space Setter

The space setter provides designers with the capability to specify a three-dimensional area within

which sounds can be freely placed and moved. This method involves using tracked objects to mark the corners or boundaries of a 3D space, in this example, a cube. Designers can navigate the tracked object to different locations that represent the vertices or limits of the desired area and set these positions to define the volume. Once the bounds are set, sound can operate within this predefined space, offering a heightened level of immersion as the audio can envelop the listener from all directions. The space setter is especially beneficial for creating ambient soundscapes or environments where the listener is at the center, such as in virtual reality or interactive installations. It's an efficient and interactive way to craft complex spatial audio environments that react to the listener's movements within the defined zone.

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2.2 Workshop and Survey Design

For the workshop, the target is to test and examine the interplay between the two different user interfaces. Specifically, the focus is on the advantages of using TUI elements. This exploration aimed at uncovering how the distinct modalities of TUI and also the collaborations with GUI can create a

more intuitive user experience. By analyzing participants' interactions and requested design strategies within scenarios and the use of interface types, the patterns of use and preferences could be concluded. These conclusions can contribute to future design decisions toward interfaces design of Sound Holograms.

The surveys are crafted with several renowned evaluated frameworks to provide a holistic view of user experience. They use the design principles in Customer Effort Score Surveys (CES), Customer Satisfaction Surveys (CSAT), and Net Promoter Score Surveys (NPS). CES is used to explore the effort that users must spend to get issues resolved, use a service, or achieve an outcome from a certain system. This criterion provided insights toward systems' efficiency from the user's perspective. For the CSAT, it was utilized to measure users' satisfaction levels with the service provided, reflecting immediate user attitudes toward the interfaces. Additionally, the NPS is included as a tool to assess customer loyalty on their likelihood to recommend the platform to others. This is commonly used in assessing business growth. In this research, it is used to see the potentials for future use of designers.

To enhance the depth of our analysis, both surveys incorporate a blend of closed-ended questions for quantitative analysis and open-ended questions aimed at uncovering deeper insights related to the research. The open-ended questions are crafted to discover innovative thoughts that extend beyond the initial conceptions of the designers, which may reveal unique design ideas and offer detailed feedback. The closed-ended questions are specifically designed to give an objective view of the interfaces. This dual-method approach contributed to an overall understanding of the user interface.

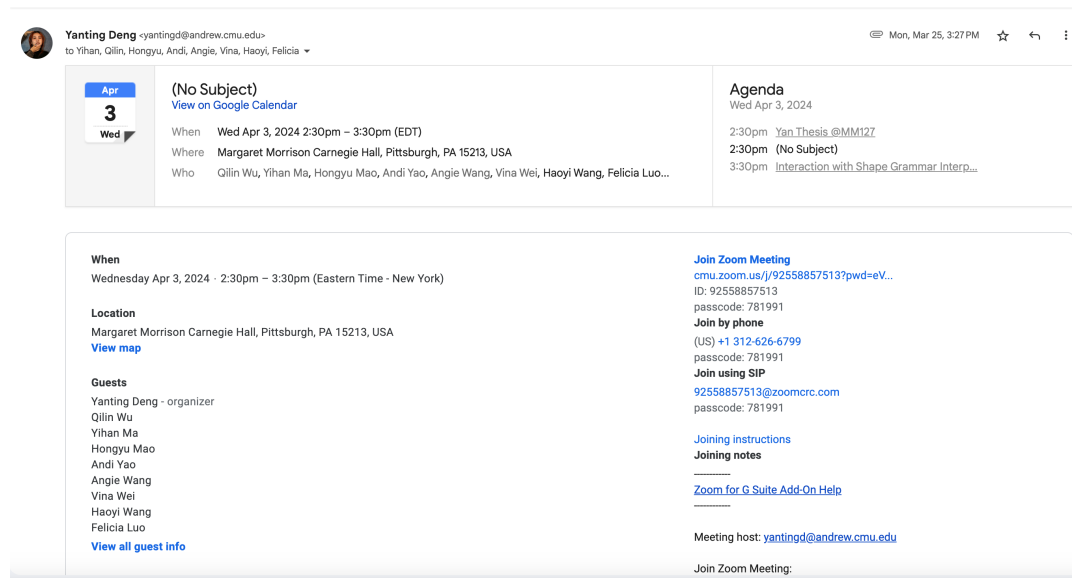


FIGURE 2.13: I invited participants to MMH127 to view the system.

To gather comments and feedback, I invited people to MMH127 to introduce the system and demonstrate its functionality. At the lab, I walked them through the original interface process, explaining how OptiTrack was used to transmit positional data to Unity, and how sound position data was sent to Max. After that, I demonstrated my Figma mockup for the new integrated interface. Due to the participants' tight schedules, I asked them to complete the survey at their convenience and sent them the questions with Google Forms. I included a demonstration video and flowchart in the Google Form to help them understand the new interface and provide informed feedback.

2.2.1 Participants' Background

The participants consisted of 10 graduate students from the College of Fine Arts (CFA). Among them were one Master of Design (MDes) student, five Master of Science in Computational Design (MSCD) students, one PhD candidate in Computational Design, one Master of Science in Sustainable Design (MSSD) student, and three Master of Science in Building Performance and Diagnostics (MSBPD) students. Two user tests were conducted with the same group of participants, ensuring consistency and reliability in the feedback collected across both iterations. This continuity allowed for a more accurate evaluation and comparison of user interactions between traditional

and newly developed interface modalities for sound design. The evaluative phase invited participants to engage deeply with both the original and updated interfaces, providing valuable insights through direct comparison. Their feedback was sought not only for its affirmative qualities but also for its constructive criticism, which is integral to refining the effectiveness and usability of the interface.

The MDes student has an advanced understanding of user interface design and a general sense of soundscape design, but not extensive knowledge.

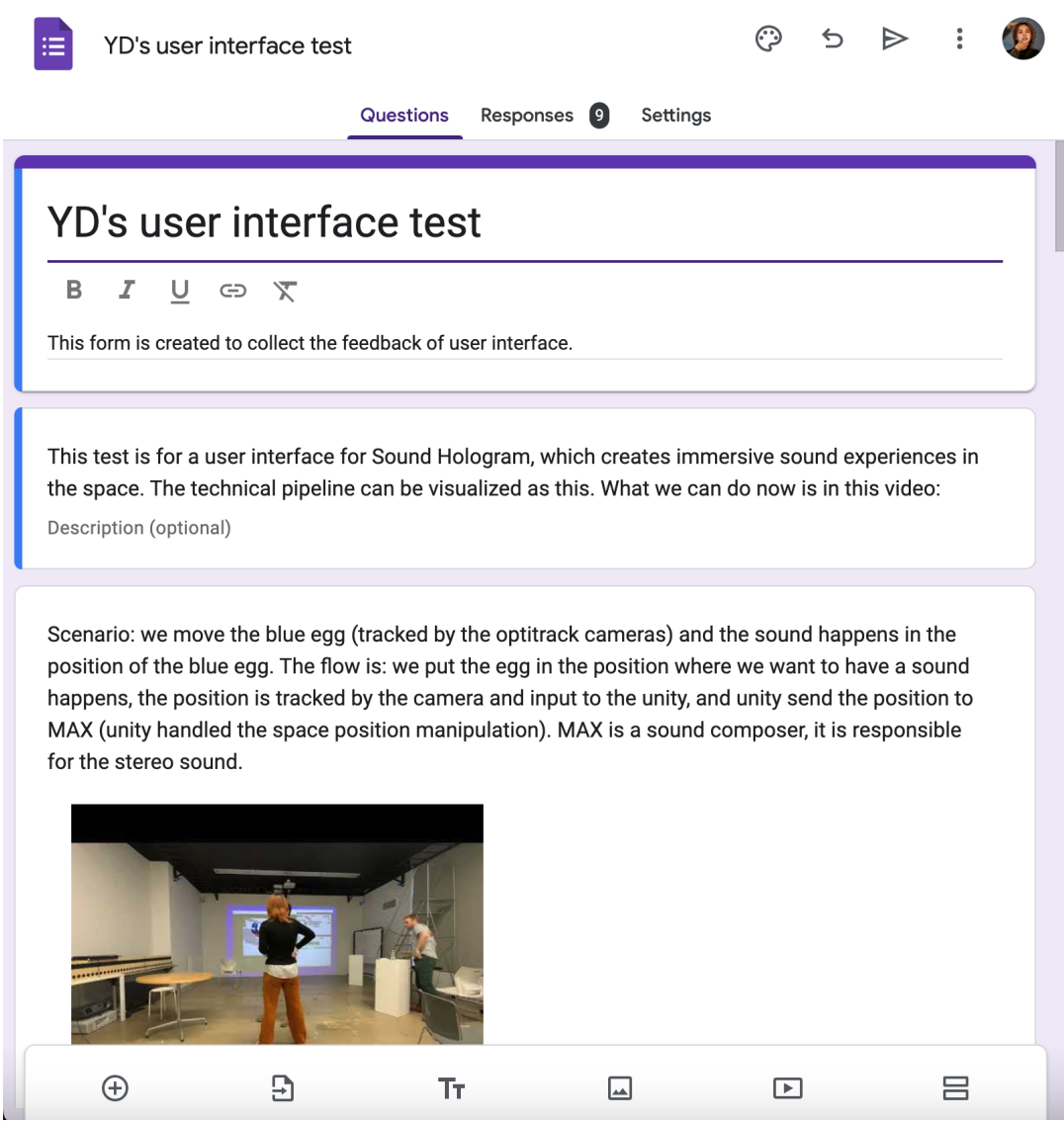
The Computational Design students all hold five-year bachelor's degrees in architecture, giving them advanced knowledge in space design. They have a general understanding of interface and soundscape design, primarily from their broad design training.

The MSBPD students come from a background in building performance and energy applications, with bachelor's degrees in engineering. As a result, they have limited knowledge in soundscape, interface, or space design.

The MSSD student has a background in creative computation and studio art, providing her with knowledge in interactive digital art, though not specifically in interface or soundscape design.

Overall, the diverse backgrounds of these participants underline that my user test targets individuals with general design knowledge. Although their expertise spans different areas—such as user interface design, space design, and interactive digital art—they all possess foundational design skills. This makes them ideal candidates for testing the interface of a soundscape design platform. The insights gathered from this group demonstrate that the platform can be effectively used by general designers who wish to prototype soundscapes, regardless of their specific design focus.

2.2.2 The first workshop and survey



The screenshot shows a Google Form titled "YD's user interface test". At the top, there are tabs for "Questions", "Responses" (with a count of 9), and "Settings". The form content includes a title "YD's user interface test", a text area with the description "This form is created to collect the feedback of user interface.", and a video player showing a person in a room with a large screen displaying a 3D interface. The video player has standard controls like play, pause, and volume.

YD's user interface test

Questions Responses 9 Settings

YD's user interface test

B *I* U [Link](#) [Image](#)

This form is created to collect the feedback of user interface.

This test is for a user interface for Sound Hologram, which creates immersive sound experiences in the space. The technical pipeline can be visualized as this. What we can do now is in this video:

Description (optional)

Scenario: we move the blue egg (tracked by the optitrack cameras) and the sound happens in the position of the blue egg. The flow is: we put the egg in the position where we want to have a sound happens, the position is tracked by the camera and input to the unity, and unity send the position to MAX (unity handled the space position manipulation). MAX is a sound composer, it is responsible for the stereo sound.



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FIGURE 2.14: The Google form collecting feedback from participants of Round 1.

The first user test has a main aim to define the usability and effectiveness of the newly designed interface in boosting users' creativity and controlling desired sound environments. Several design scenarios are provided to explore the tracked object and sound system, and users can use the system's interface to adjust the sounds positions dynamically. The test was designed to collect qualitative feedback on the intuitiveness, functionality, and overall user satisfaction of the user interface.

This test is important to recognize potential aspects to modify and make sure the interface satisfies the requirements of users who want to create complex soundscapes with our system. Collected feedback is helpful for improvements in future interface developments, increasing accessibility to users with varying levels of technical expertise.

Here's how the workshop was structured:

Workshop Agenda

15 minutes - System Introduction: In this phase, the original system is introduced. Participants are provided with access to the interface for familiarization, ensuring they are comfortable with the system's features.

30 Minutes - Scenario-Based Design Activity: Participants are tasked with creating sound design solutions for specific scenarios. Following this, they will fill out a form to capture their design choices and rationales.

15 Minutes - Feedback Session: This session is dedicated to gathering participant insights and reactions, particularly regarding the Graphical User Interface (GUI).

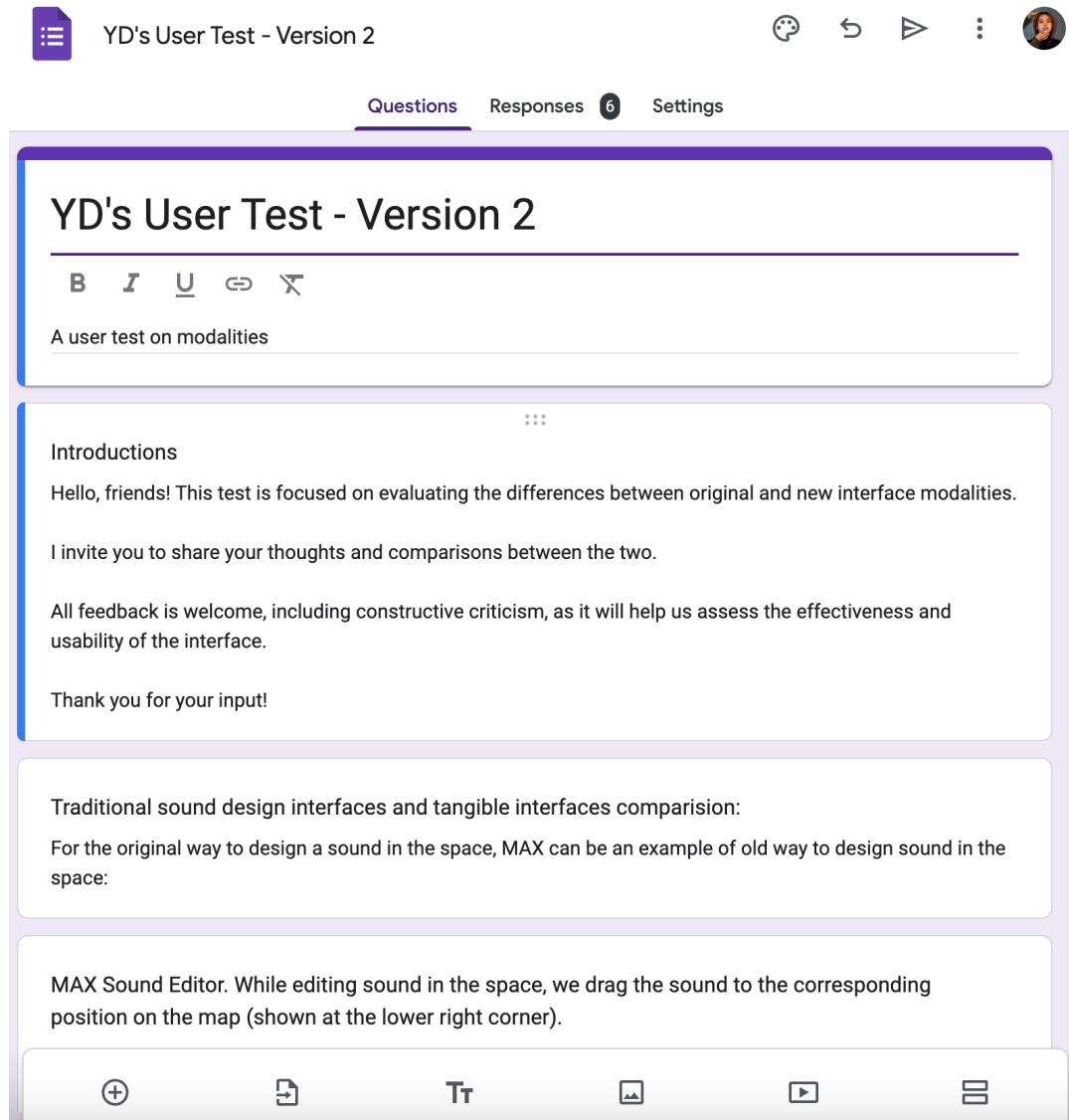
Survey Composition: The survey comprises 4 design-centric questions to gauge creative usage of the sound design platform, followed by 6 evaluative inquiries to assess the platform's functionality and user experience.

1. What activities would you create using our sound design platform?
2. Given the assignment of "creating an environmental sound design," what would you design with this system? (e.g., design sound for office or studio)
3. Given the assignment of "creating an interactive sound art," what would you design with this system?
4. Given the assignment of "creating a musical performance," what would you design with this system?
5. Rate the ease of understanding the features and tools on the sound design platform on a scale from 1 (easy) to 10 (difficult).

6. Rate the ease of navigation through the sound design platform on a scale from 1 (easy) to 10 (difficult).
7. Compare the ease of use of the design tool with the original interface on a scale from 1 (easy) to 10 (difficult).
8. Express your satisfaction with the activities you were able to create using the platform on a scale from 1 (unsatisfied) to 10 (satisfied).
9. Would you recommend this system to other designers? Please explain your reason.
10. Is there anything else you would like to share about your experience with the platform?

Given the structured method with both qualitative and quantitative questions, it was aimed to gain an overall and comprehensive understanding and evaluation of the interface. Collectively, these responses are expected to reveal general perceptions of the design possibilities of the new interfaces.

2.2.3 The second survey



The screenshot shows a Google Form titled "YD's User Test - Version 2". At the top, there are navigation tabs: "Questions" (selected), "Responses" (with a count of 6), and "Settings". Below the title, there is a rich text editor with icons for bold (B), italic (I), underline (U), link, and unlink. The text in the editor reads: "A user test on modalities".

The main content of the form is divided into sections:

- Introductions**: A section with a vertical ellipsis icon at the top. The text includes: "Hello, friends! This test is focused on evaluating the differences between original and new interface modalities.", "I invite you to share your thoughts and comparisons between the two.", "All feedback is welcome, including constructive criticism, as it will help us assess the effectiveness and usability of the interface.", and "Thank you for your input!".
- Traditional sound design interfaces and tangible interfaces comparison:**: A section with the text: "For the original way to design a sound in the space, MAX can be an example of old way to design sound in the space:".
- MAX Sound Editor**: A section with the text: "While editing sound in the space, we drag the sound to the corresponding position on the map (shown at the lower right corner)."

At the bottom of the form, there is a toolbar with icons for adding new questions, inserting a section, text, image, video, and a list.

FIGURE 2.15: The Google form collecting feedback from participants of Round 2.

The second iteration of the user test was devised with the primary goal of evaluating and contrasting user interactions between traditional and newly developed interface modalities for sound design. This evaluative phase invited participants to engage deeply with both the original and updated interfaces, providing valuable insights through direct comparison. The participants' feedback was sought not only for its affirmative qualities but also for its constructive criticism, which is integral to refining the effectiveness and usability of the interface. It is important to note that the participants in the

second user test were the same as those in the first, ensuring consistency and reliability in the feedback collected across both iterations.

In the realm of traditional sound design interfaces, MAX serves as an exemplar of the conventional method, wherein sound is positioned within a space by dragging it to a corresponding location on a digital map. Contrastingly, the new modalities introduce a physical component to the sound design process. Through the integration of technologies such as Optitrack, Unity, and MAX, sound is emitted from a speaker array at the exact position of a tracked physical object, thus fostering an immersive auditory experience.

Participants were enabled to physically set positions using tangible objects. These objects could be manipulated to set points on a curve or to define the vertices of a cube in the sound space, illustrating the blend of the physical with the digital in sound spatialization.

The crux of the user test lies in its emphasis on physical interaction. This novel approach allows users not only to design sound within a 3D scene via drag-and-drop but also to interact with physical objects in tangible reality. Key questions were posed to dissect users' experiences with these innovations, focusing on how the tangible interface compares with the traditional graphical user interface in terms of ease of use, precision in sound placement, and overall design capability. The feedback collected aimed to illuminate the significant improvements or potential drawbacks of these interaction

methods, and how they compare with purely graphical interfaces in terms of intuitive use.

The culmination of this user test was to gather exhaustive user feedback that would inform the future steps in interface design, with an eye towards integrating user-led improvements and aligning with the evolving needs of sound designers

User Test 2: Evaluating Interface Modalities

The user test aimed to compare traditional and innovative interface modalities for sound design. Participants were provided with the following key questions to guide their evaluation:

1. How does the new tangible interface compare to the traditional graphical user interface in terms of setting sound in space?

2. Employing a position tracker, the new interface allows the use of physical objects to set the sound's position. How does this compare to the traditional method of setting sound positions by dragging in Unity3D?
3. What is your detailed experience with the curve setting function?
4. How does the cube setting function enhance your design process?
5. Compared with the original interface, what are the significant improvements or shortcomings of the new interface in these interaction methods?
6. How easy is it to use compared to the pure graphical interface?
7. Which interface did you find significantly easier or harder to use compared to the original non-tangible, drag-and-drop interface?
8. Based on these improvements and shortcomings, what kind of interface should be designed in further steps?

Feedback from these questions will inform further development and refinement of the interface design.

Chapter 3

Results

In this chapter, we discuss the outcomes of user tests and conclude suggestions for future interface designs.

3.1 Survey 1: General Design Test Outcome and Analysis

3.1.1 Question 1: What activities would you create using our sound design platform?

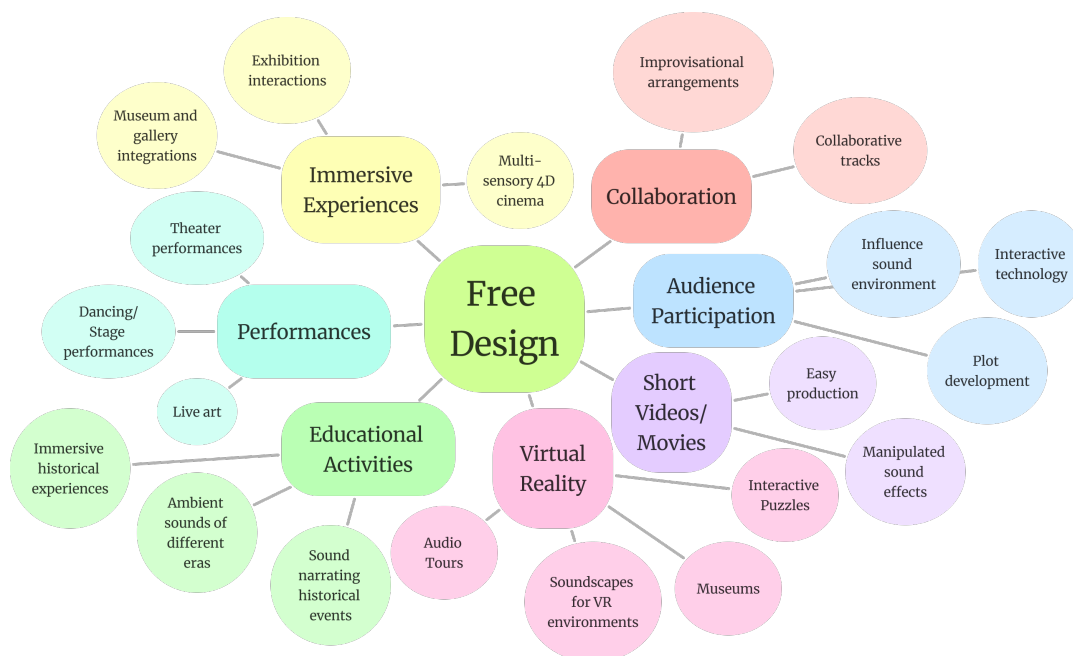


FIGURE 3.1: The Bubble Diagram of the First User Test Outcome - Free Design Ideas

Regarding the responses, when asked about free designs users may perform, participants answered in many categories, showing the system's versatility. As shown in Figure 3.1, the answers showed interest in:

Immersive Experiences: *Exhibition Interactions, Multi-sensory 4D Cinema*

Performances: *Theater Performances, Dancing/Stage Performances*

Educational Activities: *Immersive Historical Experiences, Ambient Sounds of Different Eras, Sound Narrating Historical Events*

Virtual Reality: *Audio Tours, Soundscapes for VR Environments*

Audience Participation: *Improvisational Arrangements, Short Videos/Movies*

Collaboration: *Collaborative Tracks, Influence Sound Environment*

Interactive Technology: *Interactive Technology, Plot Development*

The aim of this question is to explore the interaction affordances from designers' perspectives. The participants showed an obvious preference for features that could offer immediate feedback, such as interactive engagement with live audiences to create an immersive experience and the environment's reactive feedback to the user's input. Furthermore, testers are also interested in the platform's ease of use and tangible, intuitive characters. They appreciated the utilities in quick and early prototyping. This emphasized the potential of the platform in dynamic and collaborative sound design and the ability to create an iterative creative process.

3.1.2 Question 2: Creating an Environmental Sound Design

The answers about design in environmental sound focus on the displacement of time and space and the responsive environment. The bubble diagram in Figure 3.2 shows how testers design in different categories in environmental sound experiences.

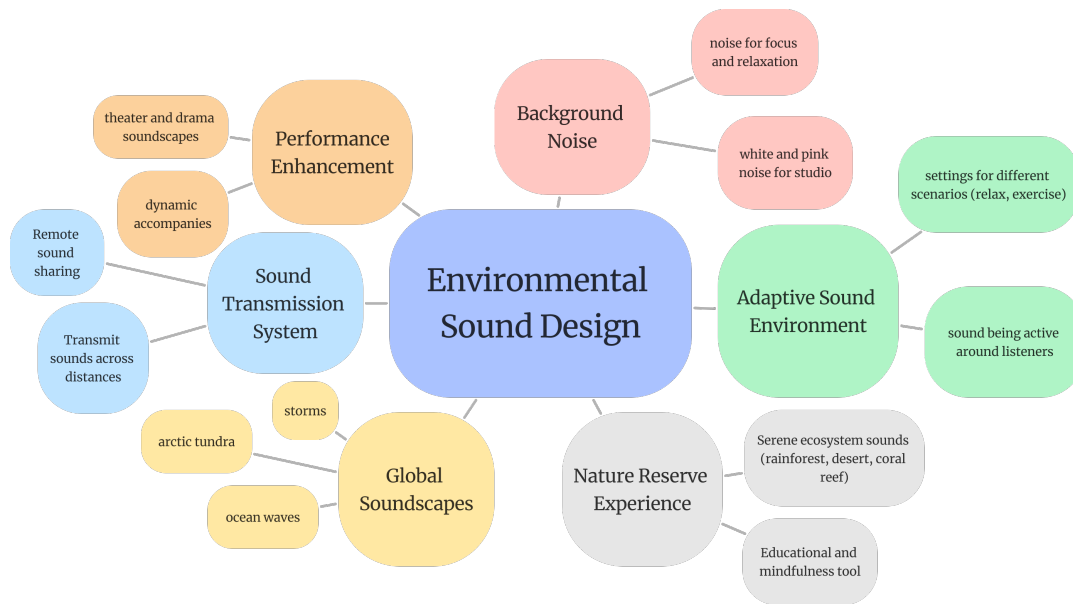


FIGURE 3.2: The Bubble Diagram of the First User Test Outcome - Environmental Sound Design

Immersive Experiences: *Exhibition Interactions, Multi-sensory 4D Cinema*

Performances: *Theater Performances, Dancing/Stage Performances*

Educational Activities: *Immersive Historical Experiences, Ambient Sounds of Different Eras, Sound Narrating Historical Events*

Virtual Reality: *Audio Tours, Soundscapes for VR Environments*

Audience Participation: *Improvisational Arrangements, Short Videos/Movies*

Collaboration: *Collaborative Tracks, Influence Sound Environment*

Interactive Technology: *Interactive Technology, Plot Development*

As shown in the results, the tested designers tend to use the platform as an environmental enhancement tool, believing that sound displacement regarding time and space is important for providing dynamic accompanying sound. Additionally, the results highlight the flexibility of adaptive sound environments in providing focused and relaxing noises (such as white noise and pink noise), as well as setting sound for different scenarios (such as relaxation and exercise).

Specifically, designers showed their interest in global natural soundscapes, from the sound of severe Arctic tundra storms to calming ocean waves. This

kind of application of space replacement can create tools for education and mindfulness.

3.1.3 Question 3: Creating an Interactive Art Design

Given the design assignment of interactive art, the results are shown in Figure 3.3.

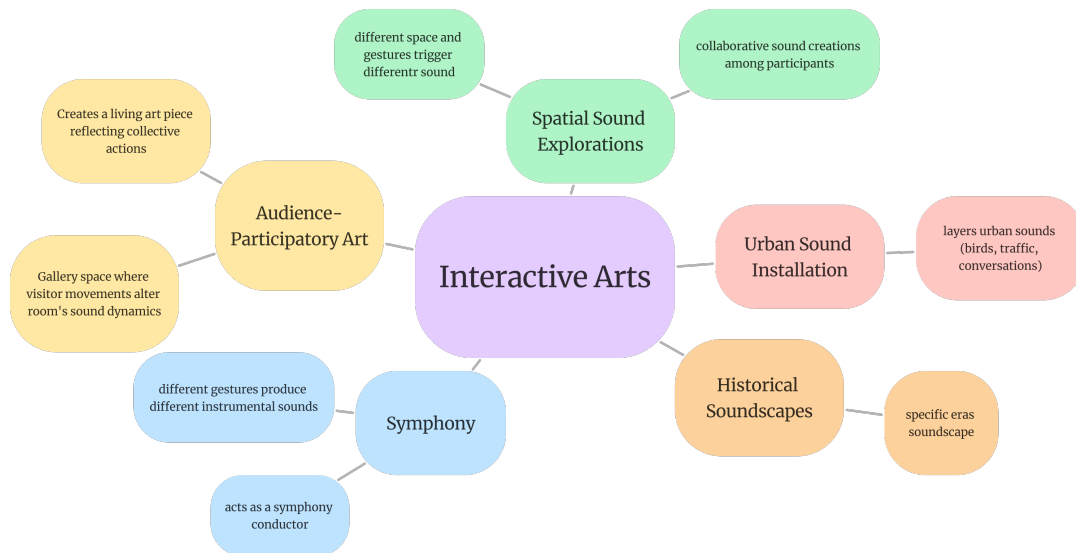


FIGURE 3.3: The Bubble Diagram of the First User Test Outcome - Interactive Art Design

Audience-Participatory Art: *Creates a living art piece reflecting collective actions, Gallery space where visitor movements alter room's sound dynamics.*

Symphony: *Different gestures produce different instrumental sounds, Acts as a symphony conductor.*

Spatial Sound Explorations: *Different space and gestures trigger different sound, Collaborative sound creations among participants.*

Urban Sound Installation: *Layers urban sounds (birds, traffic, conversations).*

Historical Soundscapes: *Specific eras soundscape.*

While exploring the components of interactive art and our platform, test participants showed a clear preference for elements allowing direct and active participation, such as spatial sound exploration and interactive symphonies shaped by the conductor's movements (and potentially, audiences' reactions). For most designers, they showed interest in applications where

individual movements within the gallery space change the acoustic dynamics of the room, creating living artworks reflecting collective actions.

The answers also showed a strong interest in the adaptability of layered and interactive installations. The urban sound installation was designed with layers of everyday sounds such as birds, traffic, and conversations into subtle aural landscapes. On the other hand, in design involving historical soundscapes, the designers explored the ability to create a sense of time travel. They also valued the ability to evoke the atmosphere of specific eras through sound. These preferences highlighted the potential of our platform to develop sound in dynamic, collaborative, and real-time ways, pointing to the importance of immediate feedback and intuitive interaction in creating immersive listening environments.

““latex

3.1.4 Question 4: Creating a Musical Performance Design

Given the design assignment of musical performance, the results are shown in Figure 3.4.

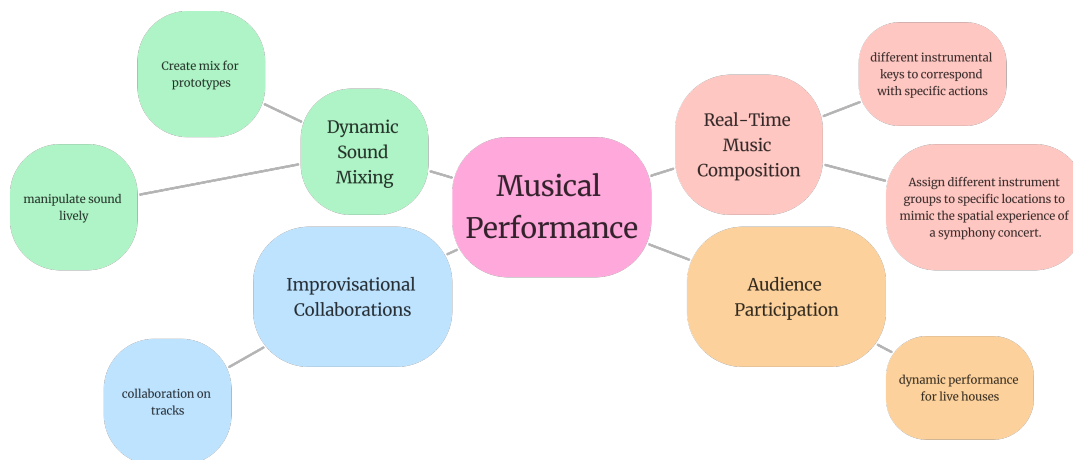


FIGURE 3.4: The Bubble Diagram of the First User Test Outcome - Musical Performance Design

Dynamic Sound Mixing: *Manipulate sound live, create mix for prototypes.*

Improvisational Collaborations: *Collaboration on tracks.*

Real-Time Music Composition: *Assign different instrument groups to specific locations to mimic the spatial experience of a symphony concert, different instrumental keys to correspond with specific actions.*

Audience Participation: *Dynamic performance for live houses.*

As shown in the results, there is a strong preference for dynamic mixing while designing with the platform. This affordance is featured by the tangible object provided by our platform, which is used in applications such as live performances, discussions on musical prototypes, and improvisational collaborations.

To explain in detail, among the various designs provided by testers, real-time music creation showed an innovative method to link instrument sounds with gestures, thus simplifying performance requirements. As mentioned in previous questions, the ability to engage audiences in performances is preferred by designers.

In sum, the testers' answers reflected an emphasis on simplifying performance equipment and enhancing the live performance experience.

3.1.5 Quantitative Questions about User Satisfaction

In the quantitative part of the survey, participants were asked to provide direct feedback regarding the platform's effectiveness.

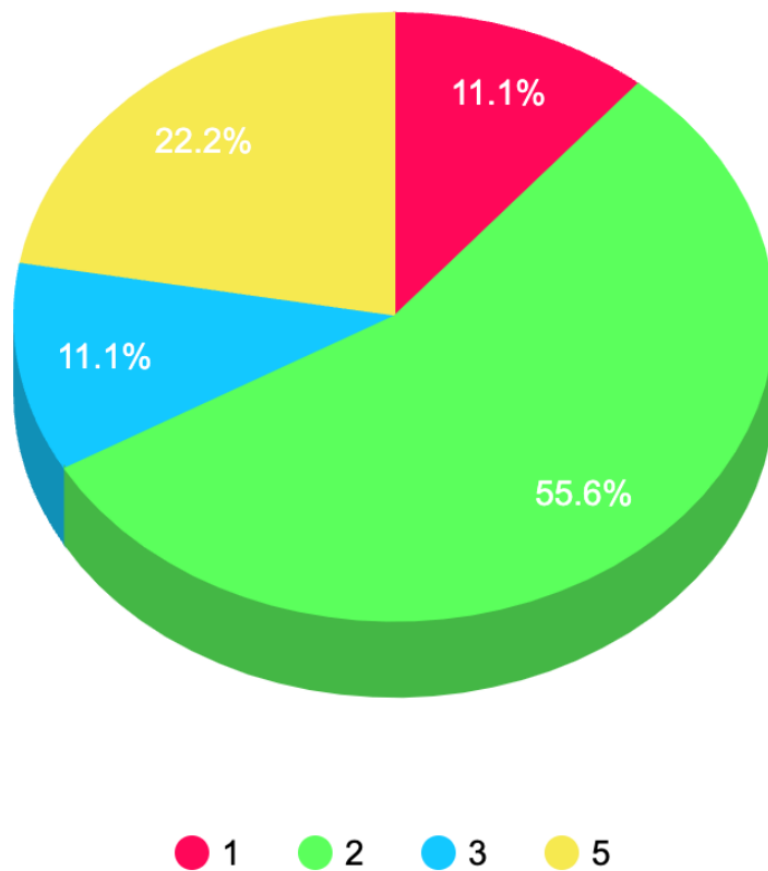
How easy was it to navigate through our sound design platform?

FIGURE 3.5: User Navigation Ease on Sound Design Platform

The first pie chart shows user feedback on the ease of navigation of the sound design platform. The majority (55.6%) found navigation easy (rating 5), indicating that the interface is user-friendly. However, a minority (22.2%) found navigation difficult (rating 1), suggesting that the interface could be improved for a better user experience. The remaining 22.2% of users were split evenly between finding navigation relatively easy (a rating of 3) and finding it a little bit difficult (a rating of 2).

How easy was it to understand the features and tools available on our sound design platform?

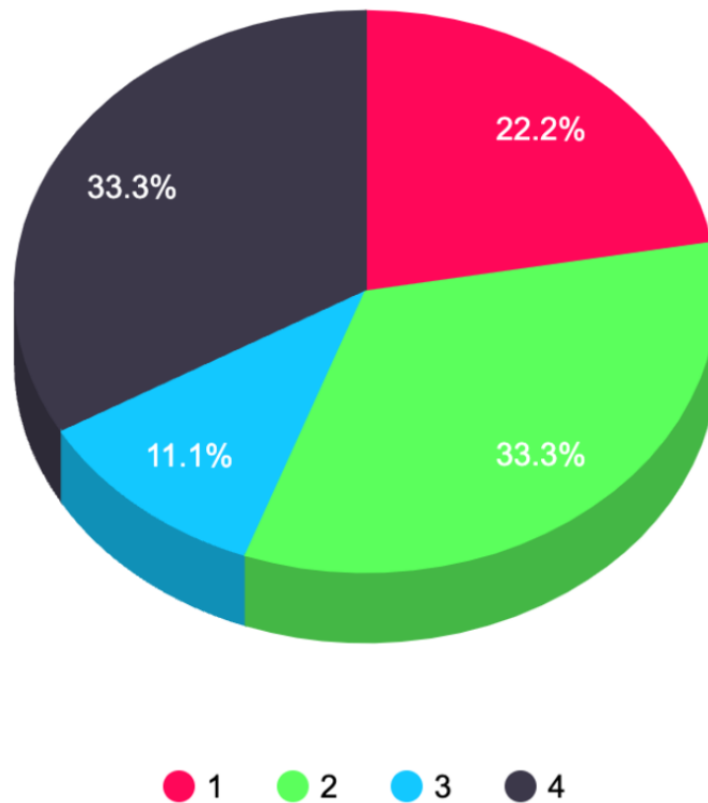


FIGURE 3.6: Understanding of Features and Tools on Sound Design Platform

The second chart is almost evenly split between users who find it easy to understand the available features and tools (33.3% rated it 4) and those who find it somewhat difficult (33.3% rated it 1). The rest of the responses were evenly distributed between ratings 2, 3, and 5, indicating varying user experiences when it comes to understanding how to use the platform. This may reflect a need for a more intuitive design or better explanations while teaching the participants.

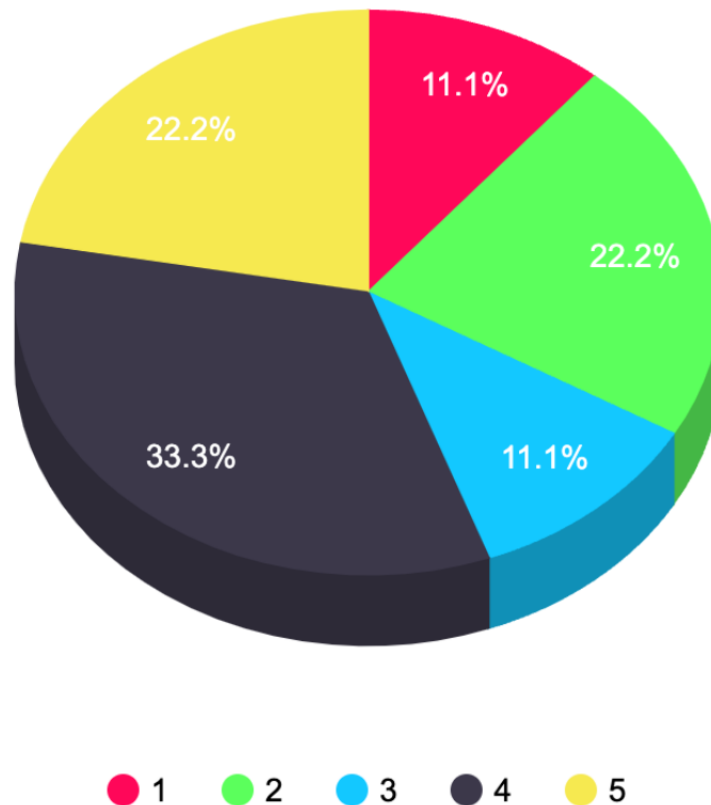
How satisfied are you with the activities you were able to create using our sound design platform?

FIGURE 3.7: User Satisfaction with Created Activities on Sound Design Platform

The third pie chart reflects user satisfaction with the designs they were able to create using the sound design platform. 22.2% of users reported the highest level of satisfaction (a rating of 5), which is a positive indication. However, the majority, at 33.3%, gave a rating of 4, suggesting that while most users are satisfied, there is room to reach that top level of satisfaction. A smaller segment, 11.1%, gave a neutral satisfaction rating of 3. Additionally, 22.2% of users reported a low level of satisfaction (a rating of 2). Notably, 11.1% of users expressed the lowest satisfaction (a rating of 1), indicating areas of the platform that may require attention and improvement to meet user expectations more effectively.

How easy is it to use the design tool compared to the original interface?

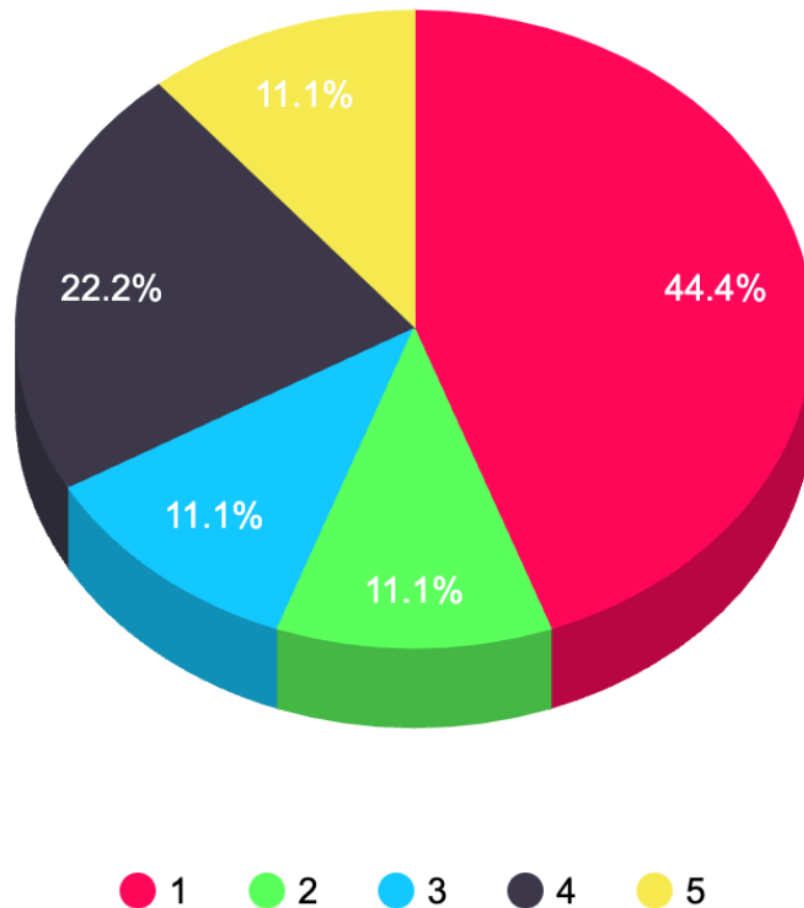


FIGURE 3.8: Ease of Use: Design Tool vs. Original Interface Comparison

In the final pie chart, users rated the ease of use of the design tool compared to the original interface. The majority of users (44.4%) found the design tool easier to use (a rating of 1), indicating that the update to the original interface was successful. However, each of the other ratings (2, 3, 5) received an equal share of 11.1% and rating 4 is 22%, suggesting that for some users the improvements may not be obvious and there may be a learning curve associated with the new tool.

In summary, while there is a trend toward positive reception, especially in terms of ease of use compared to the original interface, the results also highlight areas for improvement. If there is a new interface to develop in the

future, platform interface designers may need to investigate the specific difficulties users face while navigating and learn about tools that enhance the overall user experience.

3.2 Survey 2: Tangible Modality Comparisons Outcome and Analysis

In this section, the user comments toward tangible modality comparisons are concluded as separate points.

3.2.1 Tangible vs. Traditional Interface

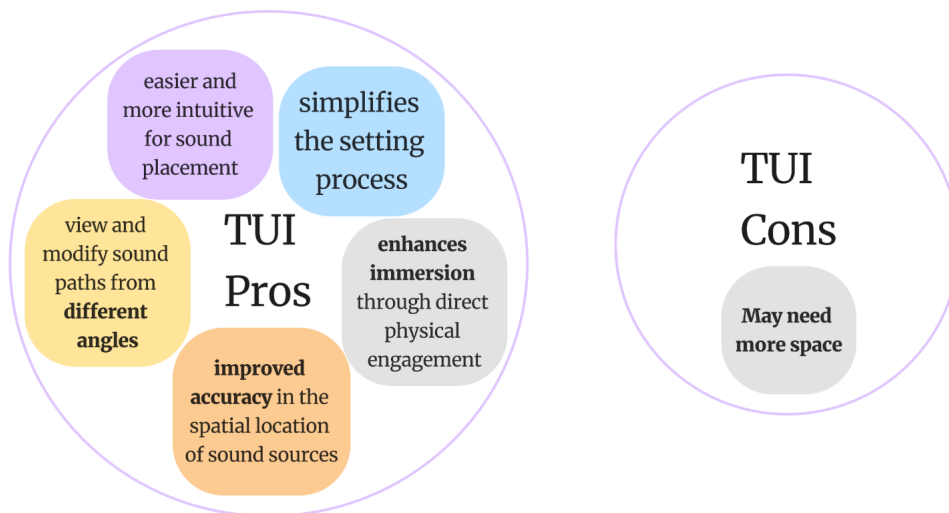


FIGURE 3.9: The prospects and considerations of TUI compared to the traditional interfaces by user test participants.

Intuitive Sound Placement: Compared to traditional GUI, most users preferred TUI since it is easier to control and more intuitive while setting sounds in the space.

Immersive Interaction: TUI is complimented because of its immersive characters, allowing users to physically interact with sound paths and modify them from different angles.

Spatial Accuracy: Users reported that TUI improves the precision of locating sound resources, but also indicated that more physical space and devices, such as the tracked objects, are required.

3.2.2 Point Setter - Position Tracker Integration

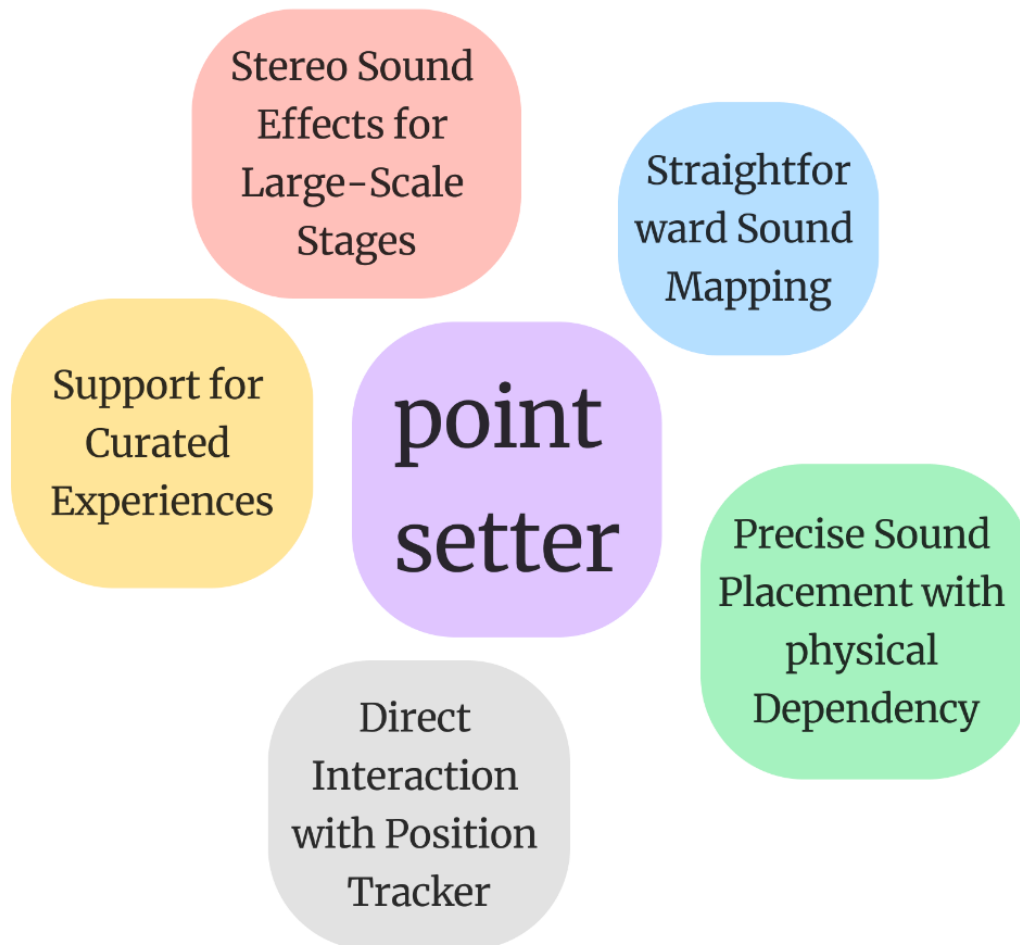


FIGURE 3.10: The thoughts about point setter by user test participants.

“Enhanced Sound Effects: The use of tracked objects is claimed to be efficient in creating stereo sounds for large-scale designs such as stage and dancing performances.

Sound Mapping for Exhibitions: The tracker facilitated a seamless transition from digital sound mapping to physical space settings, which is beneficial for exhibition and installation setups.

Targeted Sound Design: The integration of tracked objects as setters provided flexibility and adjustment for the design in the real world.

3.2.3 Curve Setter - Simulating Dynamic Sounds

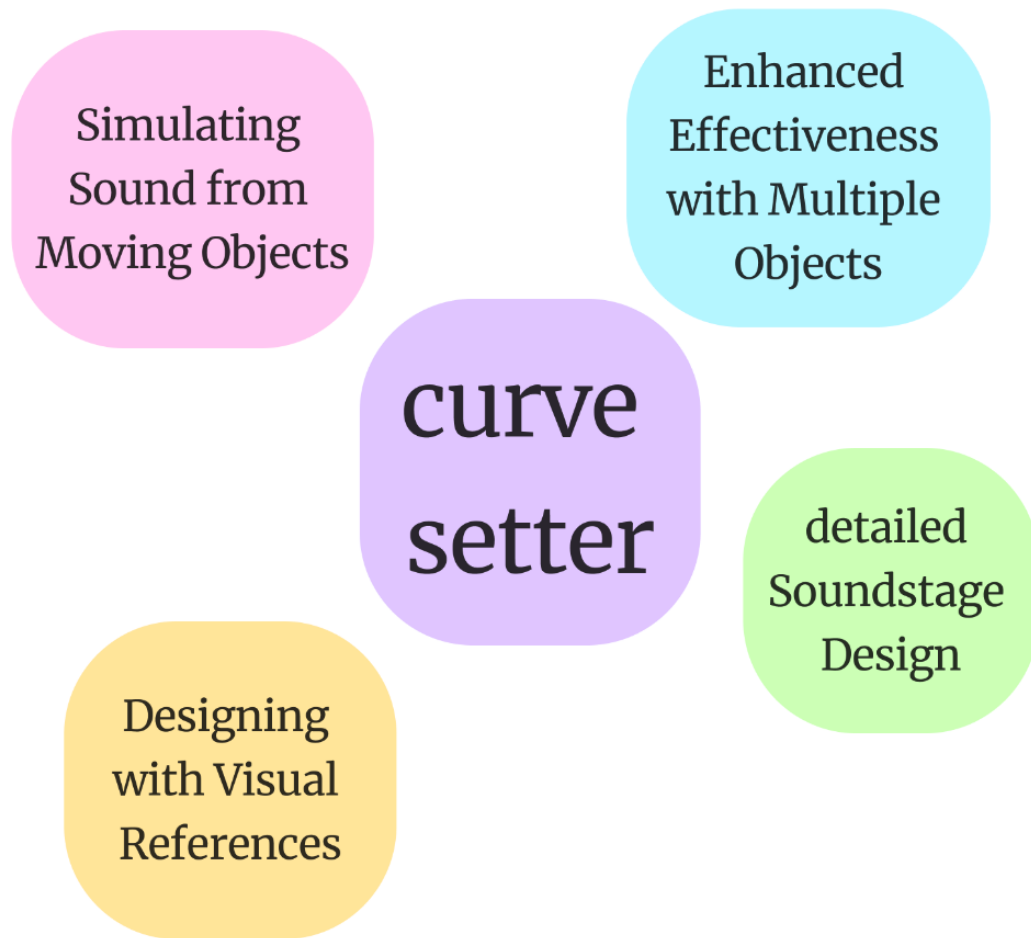


FIGURE 3.11: The thoughts about curve setter by user test participants.

Moving Sound Simulation: The interface can simulate moving sounds such as birdsong, providing a vivid auditory experience.

Curve Setting Functionality: Using physical objects to set points on the sound moving path to create the curve is considered to improve the efficiency of sound design.

3.2.4 Cube Setter - Defining Sound Areas

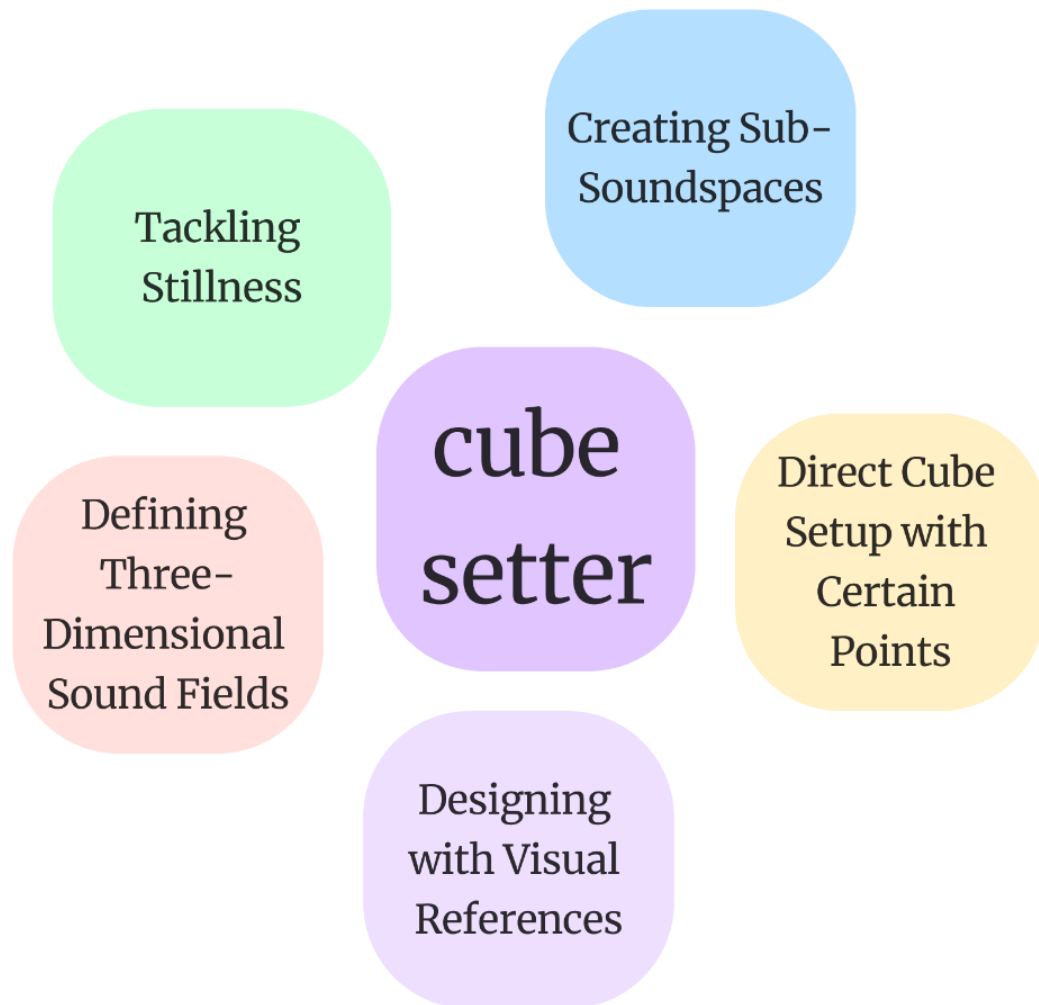


FIGURE 3.12: The thoughts about cube setter by user test participants.

Cube Setting Utility: The space setting function (which is a cube in this scenario) to define the sound space is essential for creating isolated audio environments, functioning as a microclimate in a larger space.

3.2.5 Interface Improvements and Limitations

Accessibility and Stability: TUIs are recognized for their enhanced stability and improved accessibility, especially for disabled users.

Natural Interaction: Manipulating the physical sound is recognized as a way to provide a more natural and understandable approach to sound placement.

Visualization Challenges: Though providing direct spatial interactions, there are claims about the need for more space and potential visual clutter, which were considered limitations.

3.3 Conclusions Toward Interfaces and User Feedback

To address the research questions regarding the modalities and how interface design influences user creativity and workflows, we can draw the following conclusions from previous feedback:

Enhanced Immersion and Interactive Experience

The Sound Hologram, based on its tangible affordances, has significant differences from traditional user interface principles. It utilizes WFS and MI to create immersive 3D audio environments. User feedback emphasized the immersive affordances of this platform. The real-time spatial feedback is not only beneficial for individual user experiences but also good for cooperation and user-inclusive performances. This interactive nature helps to create a powerful dialogue between users and the soundscape of the space where they position.

Given the feedback from participants, it is clear that they highly favor collaborations involving creative activities. Users are particularly interested in the system's ability to easily visualize sound within a physical space, which significantly enhances the ease of discussing and reviewing design concepts together. This feature allows for more effective communication and collaboration among team members, leading to more innovative and refined design outcomes.

Moreover, the potential for audience-participated performance design is frequently highlighted as a significant advantage of the system. Users see immense value in performances that can adapt and respond to audience reactions in real-time. This capability opens up new possibilities for interactive and immersive experiences, where the dynamics of the space can change fluidly based on audience engagement. Such responsive design not only enhances the overall experience but also fosters a deeper connection between the audience and the performance, making each event unique and memorable.

Participants also expressed a keen interest in the topic of immersive environments created by the character of 'displacement of time and space,' encompassing historical exhibitions and natural phenomenon experiences. Users noted that this soundscape design tool has the unique capability to link sound with specific historical artifacts, creating immersive experiences that evoke particular eras. Furthermore, users believe the tool can recreate immersive natural environments, enhancing educational experiences or generating white/pink noise for various applications. By linking sounds with gestures or objects, historical exhibitions can become more vivid and engaging. Similarly, the tool can be utilized to produce noise that better adapts to user needs, providing a versatile solution for both educational and ambient soundscapes.

Another notable feature is the 'replacement of object' capability, which allows sounds to be linked to objects. For example, our 3D-printed plastic egg can be used as a drum by associating drum sounds with it. This feature simplifies the requirements for symphonies or performances by enabling simple objects to serve as instruments. This innovative approach not only broadens the range of creative possibilities but also makes complex performances more accessible and manageable.

The combination of these features—facilitating collaborative design discussions and enabling dynamic, audience-responsive performances—positions the system as a powerful tool for creative professionals. It not only streamlines the design process but also pushes the boundaries of traditional performance art, offering new ways to engage and inspire audiences.

Tangible Interface Advantages

While using the current system, one notable issue is the inconvenience of dragging positions in Unity3D. This observation led to the idea in new interfaces of integrating the tangible interface with the graphical interface—utilizing the tangible interface for the setting process. Combining the original GUI with the tangible interface can enhance accuracy, such as by providing more precise position data. This integration aims to streamline the user experience and improve the efficiency of the design process.

In the user tests, I also found that due to the ease of use and intuitive engagement, TUIs are claimed to be significantly better than traditional GUI. Users conveyed a strong preference toward the physical interactions with TUI, which simplified the process of setting and manipulating sounds in the

space. The ability to interact with sound in different good directions is valued since it can provide detailed controls toward audio experiences.

The visual aspect of the tangible interface design offers significant advantages, as consistently mentioned by users. They emphasize that this feature eases the design process, particularly when it comes to reviewing and discussing ideas. This visual capability not only simplifies communication but also enhances the collaborative aspect of design projects.

Specifically, the tangible interface excels in scenarios that require creating mixes and collaborating on improvisations. It is especially beneficial in design fields closely related to spatial elements, such as theater and stage design. In these contexts, the ability to visualize sound and movement within a physical space allows designers to experiment more freely and effectively, leading to more innovative, dynamic, and accurate prototypes in the early stage of design. This interface transforms abstract concepts into tangible experiences, making it a controllable tool for designers working in creative and performance-related fields.

Challenges and Opportunities

Despite the advantages, TUI also brings challenges. There are users concerned about the need for extra physical space and devices, which could add limitations for confined environments. It is also difficult to create an accurate shape in the space, indicating an area for improvement in future interface design.

Additionally, users have reported difficulties in understanding the interfaces. The original interfaces in the three software platforms are often unstable and challenging to explain, and even the new interfaces required multiple explanations. Since I designed the new interfaces based on the original software, certain concepts were used directly from those platforms (for example, the concept of "ID" in OptiTrack and MAX). However, users who lack the relevant context find these concepts difficult to grasp. Therefore, it is crucial to develop user-friendly interfaces that convey these ideas intuitively. This will involve rethinking how to present these concepts in a way that is accessible and easy to understand for all users, regardless of their familiarity with the underlying software.

Another challenge lies in implementing the real interfaces. Writing scripts in Unity3D requires proficiency in C#, and its documentation can be difficult

to navigate. Additionally, integration with OptiTrack and MAX is necessary, which involves calling APIs from all three platforms. This demands a relatively high level of expertise in the APIs of these three software tools.

Furthermore, the current method of placing the tracked object and editing relevant information on the screen is somewhat unintuitive. With VR glasses, there are thoughts about integrating a VR layer on the object. This would allow users to manipulate physical objects and edit digital information seamlessly using VR glasses, enhancing both usability and interaction.

3.4 Future Possible Development

Overall, to better understand our new interfaces, clients requested more interactive tutorials and examples to create a better user instruction. Although users favor TUIs, they thought a hybrid interface would be helpful to create precise spatial mapping and adjustments. They also believed it important to design the physical tracked object in delicate ways. Detailed advice can be concluded into the following sections.

Integrating Tangible and Graphical Elements

As previously mentioned, while tangible interfaces offer several advantages, they also come with certain considerations. These include challenges with precision in adjustments, the requirement for additional physical space, and potential instability in tracking. For instance, while it's relatively easy to set general positions using tangible interfaces (such as the plastic eggs in our current setup), achieving precise positioning or adjusting distances can be difficult. Additionally, making accurate adjustments to curves or cubes can be cumbersome. In these scenarios, using Unity to drag objects within 3D scenes and input specific values in the inspector panel proves to be a more effective solution.

To address the challenges and opportunities highlighted by user feedback, the future development of the Sound Hologram interface can be guided by a hybrid solution. This would involve synergistically combining GUI and TUI, thereby maintaining the intuitiveness of physical interactions while ensuring the precision offered by graphic interfaces. The GUI can extend beyond traditional screen interfaces to include virtual interfaces accessible through VR glasses, enabling direct user interaction.

Implementing such integration in Unity3D is straightforward, leveraging APIs for VR glasses such as the new Apple glasses, which offer convenient APIs. Utilizing VR not only enhances immersive experiences but also allows users to connect digital information seamlessly with reality. Introducing interactive tutorials and examples would further aid users in effectively utilizing all the interface's functions.

Enhanced Responsiveness and Reduced Space Dependence

Emphasizing the improvement of responsiveness and handling the complexity of physical objects is crucial. This can be achieved through more sophisticated virtual integration of the interface as mentioned earlier.

Additionally, to enhance responsiveness, we can incorporate sound feedback and physical feedback such as vibration and lights. For instance, the tracked objects can be designed with blinking lights that activate when new attributes are added. Similarly, audio feedback can be integrated to inform users about the successful setting of attributes.

To further improve usability, the surface of tracked objects could be prefabricated with reflective materials that are easily tracked by high-speed motion tracking cameras, eliminating the inconvenience of attaching markers to physical objects and reducing the space required to attach the marker dots slightly.

In summary, the tracked objects, as the main components of tangible interfaces, should be fabricated with greater precision and include additional features such as integrated interfaces and responsive elements like lights. This would result in better-tracked objects that enhance the user experience. This type of integration would also alleviate many limitations associated with physical space manipulations, thereby expanding the creative potential of sound designers and performers.

Precise Positioning and Visualization in GUI

To fulfill the requirements of precision, especially for creating sound paths and defining specific trigger spaces, we should rely more on GUI for detailed visualizations. The GUI should offer improved visual representations of sounds, as many users have found the current sound visualizations using layered balls to be unclear. We need to conduct more visualization research

on how sound propagates throughout a space, helping users in understanding how audio functions as an integrated whole within the environment.

Moreover, real-time rendering of sound behaviors is essential. This would provide immediate visual feedback during the design process and on the overall activities occurring in the space. Such enhancements in visualization and real-time feedback will significantly improve user comprehension and interaction with the sound hologram interface.

In conclusion, participants highly favor collaborative activities and appreciate the system's ability to easily visualize sound within a physical space, which significantly enhances the ease of discussing and reviewing design concepts together. The system's potential for audience-participated performance design is frequently highlighted as a significant advantage, opening new possibilities for interactive and immersive experiences that adapt and respond to audience reactions in real-time.

The development of the Sound Hologram interface must focus on a hybrid approach that integrates both tangible and graphical elements. By combining the intuitive physical interactions of TUIs with the precision and flexibility of GUIs, particularly through the use of VR technology, we can create a more effective and user-friendly interface. Enhanced responsiveness through sound and physical feedback, along with the prefabrication of tracked objects with reflective materials, will improve usability and reduce the spatial limitations currently faced.

In summary, these enhancements in visualization, real-time feedback, and tangible interface design not only address the challenges identified through user feedback but also expand the creative potential of sound designers and performers. By implementing interactive tutorials and examples, users will be better equipped to utilize all functions of the interface, leading to a more seamless and immersive experience. Through these advancements, the Sound Hologram interface can achieve its goal of blending digital and physical realms in innovative and practical ways, pushing the boundaries of traditional performance art and offering new ways to engage and inspire audiences.

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