INTEGRATING SPATIAL AUDIO WITH ACTIVE ACOUSTICS THROUGH THE LENS OF EGOCENTRIC AND ALLOCENTRIC FRAMES OF REFERENCE

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1 INTRODUCTION

Active acoustics systems, which adjust room acoustics through electro-acoustic means, have become a widely accepted and proven technology for meeting the increasing needs of aspirational multipurpose venues.[1] Meanwhile, awareness and adoption of spatial audio has grown, driven in part by its use in personal audio, commercial audio, and cinema over the past decade. Both technologies enable venues to expand their artistic and creative possibilities, helping to attract audiences who typically experience spatial audio and immersive acoustics in settings like cinemas and concert halls. Both technologies use multiple loudspeakers positioned around and above the audience. Can these loudspeakers be used for both acoustic and spatial audio activation?

To address this, we explore fundamental questions about the nature of both spatial audio and electronically adjustable room acoustics through the perspectives of egocentric and allocentric reference frames. We will demonstrate how these systems can be integrated and provide examples of successful integrations.

2 EGOCENTRIC AND ALLOCENTRIC FRAMES OF REFERENCE

Spatial memory enables us to encode, store, and recall information about locations and their spatial relationships. This has been extensively explored in cognitive science.[2,3] Two main frames of reference have been identified: egocentric and allocentric. Egocentric spatial memory represents locations relative to oneself, while allocentric spatial memory represents locations relative to external landmarks or the environment. These frames of reference can also be applied to spatial audio design and experience. Spatial audio systems enable directional control and movement of sound objects. The specific technology and panning techniques may vary. Still, fundamentally, creators of the spatial audio experience and the systems that produce them must consider a key question about the universality of the experience. Spatial sound can be configured using two distinct frameworks.

Egocentric approaches strive to create a consistent spatial experience for all audience members. This is the prevailing model in cinema, broadcast, and frontal concert formats. The goal is for everyone to perceive all sound objects and spatial audio beds from a similar orientation and at comparable audio levels.

Allocentric approaches are grounded in the environment. Sound objects are placed and moved in relation to architectural features or zones within the space. Audience members have unique spatial experiences depending on their position, orientation, and movement within the space.

These approaches are not tied to specific technologies. Instead, they reflect design intent and influence how both spatial audio and active acoustics systems are implemented. Egocentric systems emphasize uniform coverage and consistent imaging; allocentric systems embrace spatial variability and listener agency.

Fundamentally, physical reverberation is allocentric. The direct-to-reverberant level of a sound source, as perceived by a listener, varies with the distance from the source. Early reflection patterns are shaped by physical features and are experienced at different levels throughout a performance space.

One compelling example of allocentric sound design is HRA (1970), a sound installation by Polish artist Andrzej Łobodziński, currently on loan to The Museum of Contemporary Art in Los Angeles. Comprised of a seven-minute two-channel loop played through a pair of loudspeakers, the work is exhibited in a reverberant gallery space and, according to the artist's intention, "should fill the space with its clear, though not obtrusive sound."[4] The two audio channels are decorrelated. Visitors experience the installation from various locations as the sound reverberates throughout the space. A single chair, positioned 4.5 meters from the pair of loudspeakers, marks a preferred seated listening position. As listeners move around the room, the spatial impression and direct-to-reverberant balance shift, offering an allocentric experience shaped by the room's architectural acoustics and the listener's position with respect to the installation.

Another allocentric example is Icelandic artist Ragnar Kjartansson's "The Visitors," a nine-screen video installation created in 2012. It features a musical performance recorded at the historic Rokeby Farm in upstate New York. The piece, which lasts over an hour, shows Kjartansson and a group of musician friends performing a song simultaneously from different rooms and areas on individual screens. The audio is recorded with a single microphone in each room. This virtual reconstruction of the ensemble allows viewers to move freely within the exhibition space, effectively creating a personalized spatial mix.

3 SPATIAL AUDIO SYSTEMS

System design practices have evolved as spatial audio has transitioned from specialized research to mainstream applications in performances, installations, and architecture. Spatial audio systems differ in their technical implementations, but all primarily allow for the placement and movement of audio channels, or "sound objects." A sound object is an audio signal combined with spatial metadata, such as level and position, that determines how the signal is distributed across the loudspeaker system.

These systems can support both egocentric and allocentric design objectives:

Egocentric spatial audio requires loudspeakers to deliver consistent coverage and imaging across a shared listening space from multiple angles. The loudspeakers should be aimed at the central listening area and each must produce enough SPL to reach throughout the room.[5]

Allocentric spatial audio requires loudspeakers to provide continuous coverage around a room's perimeter. It enables the precise placement and movement of sound objects that aren't experienced uniformly across a shared listening space. As a result, these may use lower-SPL loudspeakers that are consistently aligned with architectural surfaces.

Egocentric and allocentric approaches can be combined, provided the system is designed to support it.

4 ACTIVE ACOUSTICS SYSTEMS

Active acoustics systems offer electronically adjustable early reflections and reverberation. Reverberation can be tailored in terms of strength, length, and density through the use of microphones, signal processing, and a system of loudspeakers.[6] These systems modify the room's reverberant qualities to suit various types of content, from spoken word and amplified music to unamplified choral or orchestral works.[7] Physical reverberation is allocentric: listeners near sources experience a higher direct-to-reverberant ratio, while those farther away receive more reflected energy. Active acoustics systems reflect this behavior.[8] Additionally, reverberation is a global room property. Ideally, the active acoustic system will provide reverberation evenly (in contrast to the direct sound) and with a distribution pattern influenced by the configuration of the room's physical surfaces. As a result,

- Loudspeaker placement usually aligns with architectural surfaces.
- Loudspeakers are often oriented perpendicular to walls to uniformly energize the reverberation in the room.

5 SYSTEM INTEGRATION AND DESIGN CONSIDERATIONS

Integrating spatial audio and active acoustics systems requires careful architectural and electroacoustic planning. Depending on the application, loudspeakers may be:

- Shared between both systems
- Dedicated to spatial or active acoustic functions

Typical hybrid designs include:

- Perpendicular loudspeakers in the central area of each surface that support both spatial audio and reverberant field generation
- Corner-aimed, high-SPL loudspeakers for egocentric reinforcement
- Smaller, distributed units for localized environmental anchoring in allocentric designs

Designers must consider:

- SPL needs: egocentric systems require every individual loudspeaker to cover all seats; active acoustics systems send similar level signals to nearly all loudspeakers simultaneously (thus each individual loudspeaker can be smaller);[9] allocentric systems tolerate local variation
- Signal routing: spatial and reverberant content will need distinct paths through the processing infrastructure
- Tuning and calibration: alignment of timing, level, and dispersion across both systems

Design patterns such as the Go Zone[5] and Dolby's Atmos cinema specification[10] offer guidance for establishing loudspeaker placement in egocentric spatial audio systems.

6 CASE STUDIES

These venues demonstrate the effective integration of spatial audio and active acoustics systems:

- National Sawdust (Brooklyn, NY): A hybrid venue where the loudspeakers and processing provided by the Constellation active acoustics system supports allocentric spatial sound design, and incorporating the installed PA and grouping loudspeakers supports an egocentric approach
- Pearson Theater (Berkeley, CA): This system features both a Dolby ATMOS loudspeaker configuration and a Constellation active acoustics system. It supports both egocentric and allocentric approaches

6.1 National Sawdust

National Sawdust in Brooklyn, NY, is a versatile performance space designed to host a wide range of musical and interdisciplinary performances. In 2019, it was upgraded with an electroacoustic system that included a new PA and an active acoustics system supporting spatial mixing using Spacemaps and a touch interface. This system features 16 microphones suspended overhead, 93 compact full-range loudspeakers, and 16 subwoofers. Most loudspeakers are hidden behind acoustically transparent fabric panels that blend into the architecture, allowing adjustable reverberation and spatial sound mixing. The stage is configurable and usually raised. A flown line array system is often integrated with the spatial mix to support egocentric reinforcement and frontal

emphasis. Spacemaps are designed to provide both egocentric and allocentric approaches to mixing.

The Constellation active acoustics system at National Sawdust allows the venue's reverberation time to be extended from 0.6 seconds to over 2 seconds. Constellation provides controls over key acoustic parameters: **Length**, **Strength**, **Warmth**, and **Brightness**. *Length* adjusts the reverberation time of Constellation's VRAS processor, while *Strength* governs the overall system gain, effectively determining the coupling between the physical room and the additional reverberation. Acoustic music performances typically use higher *Strength* settings than amplified events. *Warmth* adjusts the low-frequency content of the reverberant field. For reinforced performances, where subwoofers provide full-range support, *Warmth* is often reduced to preserve the impact of the low frequencies of the PA. *Brightness* shapes the high-frequency response of the system and can be tailored to match the tonal balance of the performance or ensemble. In addition, reverberation provided by the system may be delayed to lateral and overhead loudspeakers to inform the perceived volume of the space. The active acoustics system behaves analogously to physically coupled spaces; the resulting reverberation time is shaped by the room's inherent acoustics, the processor's *Length* setting, and the level of coupling established by the *Strength*, *Warmth*, and *Brightness* settings.

A GOD OF HER OWN MAKING, performed by JOJO ABOT and esperanza spalding in September 2022,[11] exemplifies a hybrid allocentric/egocentric spatial experience. The performance featured reinforced vocals by both artists, as well as reinforced acoustic bass, all of which were mixed through the PA system to provide uniform coverage across all listening areas. As shown in Figure 1, the stage was positioned at floor level, with some audience members seated within the performance area and others along the perimeter walls and in the balcony. Figure 2 shows the PA line arrays as well as the distribution of the hidden loudspeakers used for spatial audio and active acoustics. The music featured multiple pre-recorded vocal tracks, along with synths and digital percussion. Spacemaps were designed to distribute sound overhead and through lateral loudspeakers on two levels on the floor, as well as an additional layer in the balcony. Vocals were spatialized around both levels of the audience. The result echoed Ellen Reid's *a cappella* choral piece, performed on September 27, 2019, at National Sawdust by the Young People's Chorus of New York City during *A Night of Women Composers*.[12] In that performance, singers stood around the audience and sang without amplification, with extended reverberation provided by the active acoustic system. In both these cases, the spatial mix and perceived source location shifted with each listener's position, making individual perspective an integral and compelling part of the experience.

Figure 1 Floor seating for A GOD OF HER OWN MAKING

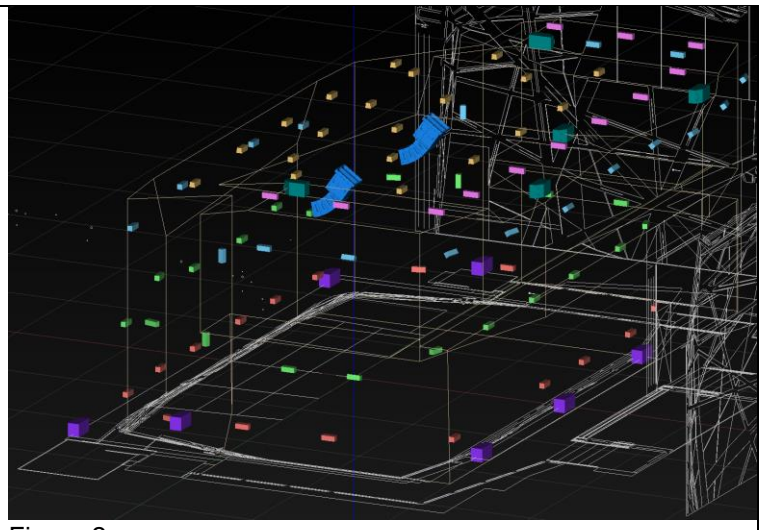

Figure 2
National Sawdust Loudspeaker Positions

Another example of allocentric spatial sound design is "*Spatial, No Problem*," a performance by electronic music producers Mouse on Mars and the late Lee Scratch Perry at National Sawdust on March 12 and 19, 2022.[13] The piece used only multi-channel audio playback and did not include the flown PA. Imagery was projected onto the venue's surfaces, the room was configured with a flat floor, and bar tables were set inside. Sound objects were placed around the room and overhead, anchored by vocals fixed in the upstage wall. This social engineering, visual production, and sound design implicitly encouraged the mobile audience to explore the space. Although the audience experienced the work allocentrically, hearing different perspectives depending on their location, the mix was created using both egocentric and allocentric methods. Spacemaps provided the mixer with a top-down, front-facing view of the venue for traditional panning, as well as others referencing specific architectural features, such as the upstage wall with multiple levels of loudspeakers. This hybrid approach enabled precise authoring while fostering an open and exploratory experience for the audience.

6.2 Pearson Theater

The Pearson Theatre, located on Meyer Sound's Berkeley campus, is a dedicated demonstration and research venue originally built in 2004 to showcase immersive audio technologies. In early 2025, the theater underwent a significant upgrade that integrated three key systems: a 33-channel Dolby Atmos theatrical playback system, ASTRYA-140 cinema screen channels, and an updated Constellation active acoustics system. The Constellation system includes 34 compact loudspeakers and 24 cardioid microphones distributed throughout the room. The room is frequently used for acoustic music performances and recordings that benefit from the adjustable acoustics provided by Constellation. Live spatial audio mixes may be created using the Spacemap Go application, which provides access to all system loudspeakers for spatial positioning and movement.

The Pearson Theatre exemplifies a hybrid configuration in which loudspeakers are either shared across multiple systems (Atmos and Constellation) or dedicated to specific functions; for instance, ASTRYA cinema screen channels serve ATMOS and Spacemap, but not Constellation. Four compact loudspeakers are installed just above floor level on the upstage, stage right, and stage left walls. Constellation uses these to provide early reflection support for musicians, while Spacemap accesses them for ground-level sound object positioning. In one environmental installation, they are used to convey water features and footsteps. Audience members seated in the front row hear these sound elements with clarity and natural volume; those farther back may not hear them at all, prompting movement toward the source for a deeper immersive experience. This hybrid configuration enables both the egocentric approach of traditional front-focused cinema mixes and allocentric spatial sound design.

The Pearson Theatre has loudspeakers positioned and aimed to support several standard cinema formats. Cinema loudspeakers only need to cover the seated audience, not the space between the screen and the first row of seats. In contrast, the active acoustic system must serve critical listeners – namely, the performers - positioned between the screen and the first row of seats. Therefore, the theatre has additional loudspeakers aimed perpendicular to the wall to supplement the active acoustic system. These loudspeakers can also be used for non-cinema allocentric spatial presentations. They are typically lower in elevation and also smaller because the energy of the active acoustic system is distributed much more evenly throughout all the loudspeakers than in spatial audio. Figure 3 and Figure 4 show the first lateral cinema loudspeaker versus the first lateral allocentric loudspeaker. Coverage is shown in color gradients that indicate 3 dB increments.

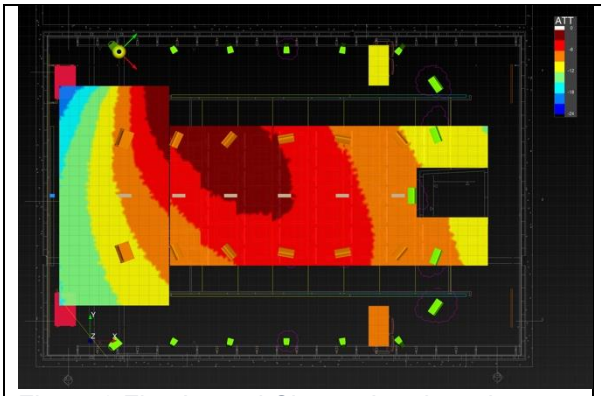

Figure 3 First Lateral Cinema Loudspeaker

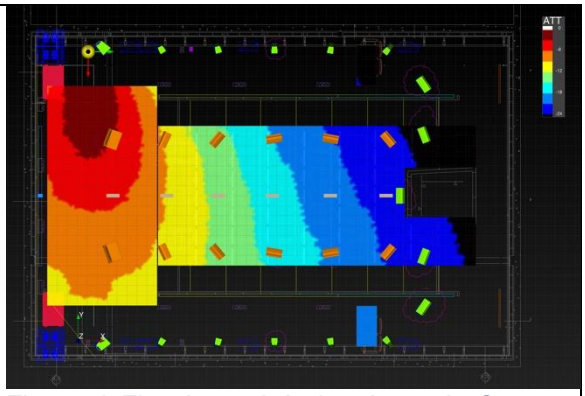

Figure 4 First Lateral Active Acoustic System Loudspeaker

Similarly, the first overhead cinema loudspeakers are heavily panned into the audience, and the theatre includes smaller supplemental loudspeakers for active acoustics and allocentric-spatial audio for listeners on stage.

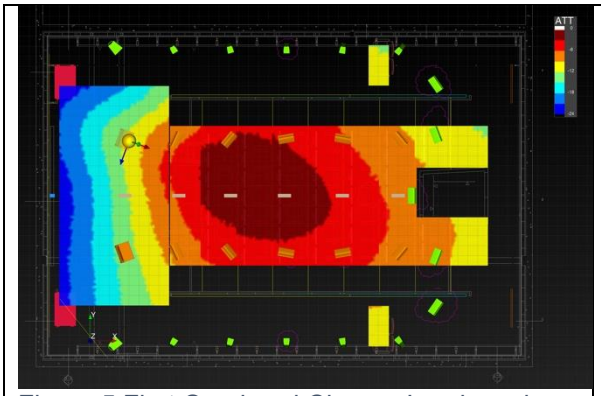

Figure 5 First Overhead Cinema Loudspeaker

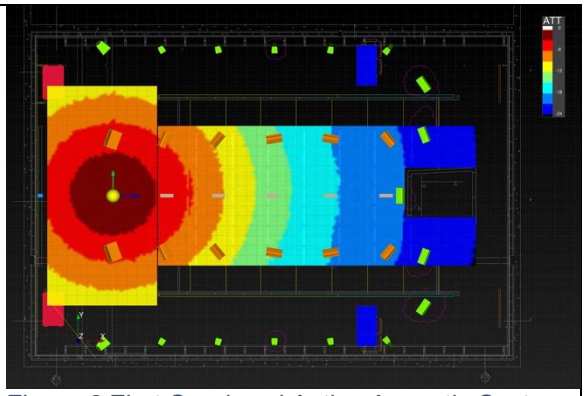

Figure 6 First Overhead Active Acoustic System Loudspeaker

In contrast, loudspeakers near the center of the wall are nearly perpendicular and can be used for both Cinema and Active Acoustics (and allocentric spatial).

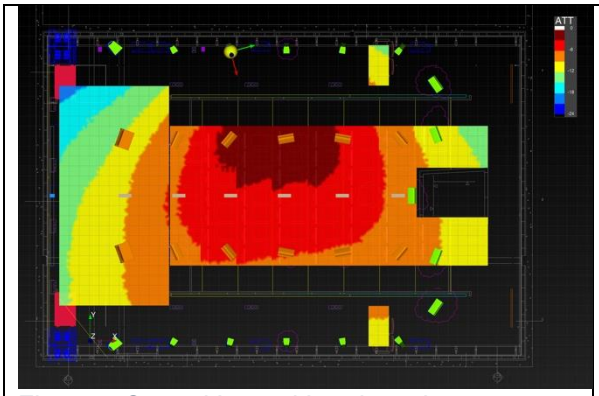

Figure 7 Central Lateral Loudspeaker

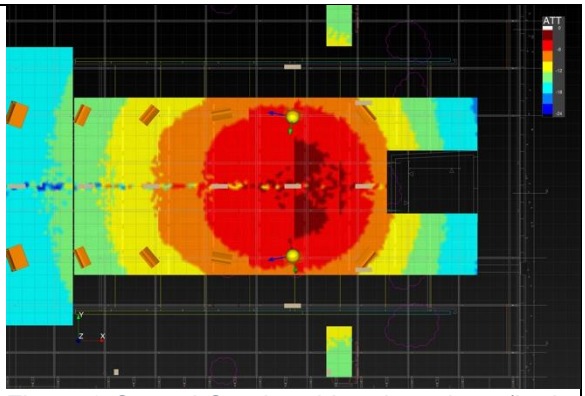

Figure 8 Central Overhead Loudspeakers (both sides)

There are also loudspeakers near the floor around the stage so that the active acoustics system can provide additional envelopment for small ensembles, and allocentric spatial presentations can include content like foot-falls and running water.

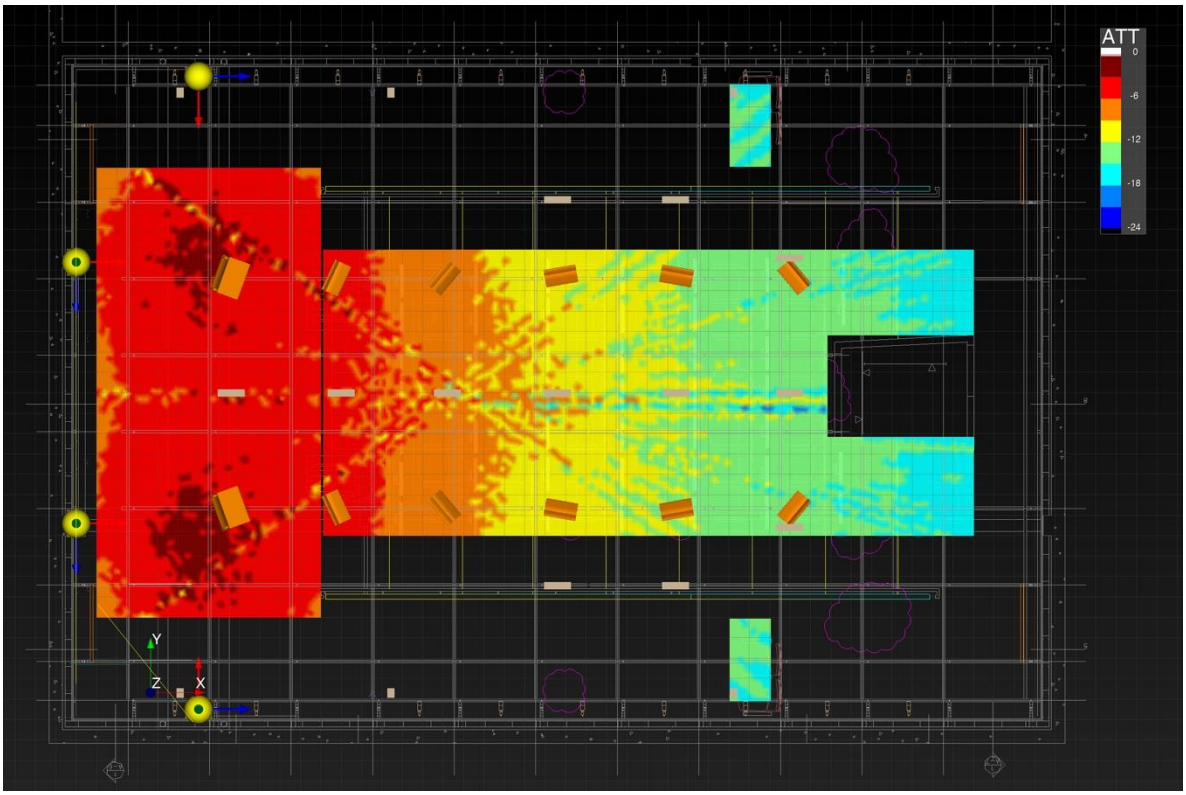

Figure 9 Loudspeakers near floor level around stage (positions shown with yellow circles)

Spacemaps were created for both egocentric and allocentric sound design strategies. Figure 10 shows a Spacemap for the for the loudspeakers used by ATMOS as shown in Figure 8. Figure 11 shows a Spacemap floor area as shown in Figure 9. The Spacemap panning ‘puck’ sets the object position and results in gains calculated for the matrix of inputs to buses. The buses are matrixed to loudspeakers that include bass management using nearby subwoofers.

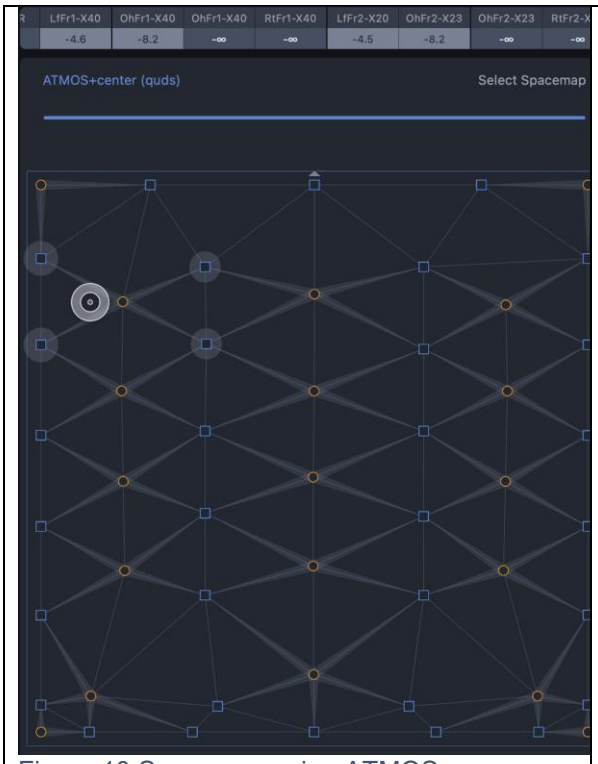

Figure 10 Spacemap using ATMOS loudspeakers

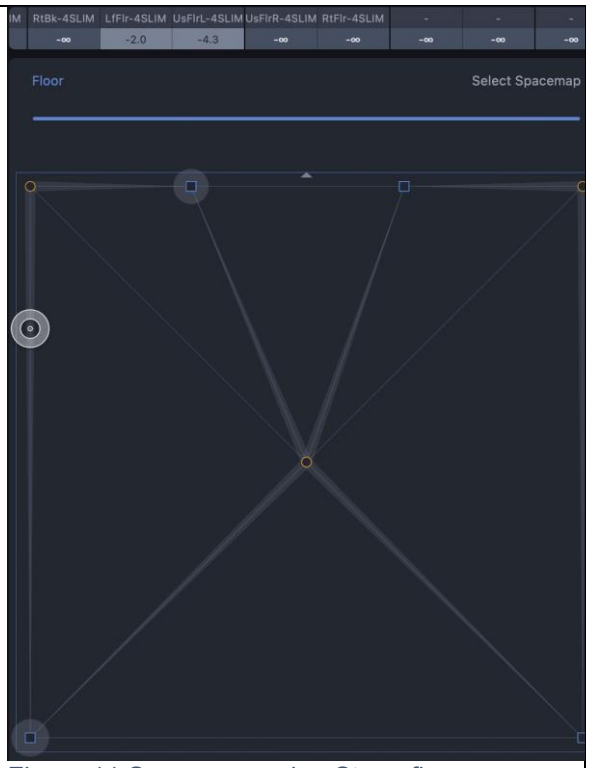

Figure 11 Spacemap using Stage floor loudspeakers

7 CREATIVE AUTHORING AND LISTENER EXPERIENCE

Integrated systems open up new possibilities for authorship, particularly in situations where spatiality and acoustic response are crucial. Artists and designers can:

- Anchor content to architectural elements (allocentric)
- Provide consistent coverage and localization (egocentric)
- Combine both in hybrid works

Authoring tools that can reflect room geometry (e.g., Spacemap, MIAP, DBAP) offer intuitive control for allocentric strategies. These, along with directional spatial control algorithms such as VBAP and VBIP, and other methods integrated with DAW-based panners, support egocentric workflows familiar to studio engineers.

From a pedagogical standpoint, framing spatial audio design in terms of egocentric and allocentric strategies promotes critical thinking about listener perspective, mobility, and intent.

8 DISCUSSION

Active acoustics and spatial audio systems are not inherently incompatible - they can, and increasingly do, coexist in high-performance venues. A hybrid design approach supports both a uniform audience experience and spatial diversity.

In some spaces, shared loudspeakers serve both functions; in others, dedicated systems support unique needs. The decision depends on room layout, performance objectives, and integration strategies.

By designing with flexibility and spatial strategy in mind, venues can remain adaptable to changing artistic practices and technological advances. Hybrid systems, driven by both egocentric and allocentric intent, will increasingly shape the future of immersive sound design, performance, and experience.

9 REFERENCES

1. S. Ellison and M. Parker, “Active Acoustics in Multi-purpose Venues: A Ten-year Retrospective,” presented at the 173rd Meeting of the Acoustical Society of America, New Orleans, LA, May 2017.
2. J. Paillard, “Motor and Representational Framing of Space,” in *Brain and Space*, J. Paillard, Ed., Oxford University Press, Oxford, pp. 163–182 (1991).
3. Iachini, T., Ruggiero, G. Egocentric and allocentric spatial frames of reference: a direct measure. *Cogn Process* **7** (Suppl 1), 126–127 (2006). https://doi.org/10.1007/s10339-006-0100-8
4. A. Łobodziński, HRA (1970), in The 1982 Cultural Exchange Between Łódź and Los Angeles, Paweł Polit, ed., Museum of Contemporary Art, Los Angeles (2024).
5. B. McCarthy and S. Ellison, “Designing Systems to Deliver Successful Immersive Audio Experiences,” Proceedings of the Institute of Acoustics, Vol. 43, Pt. 2 (2021).
6. M. A. Poletti, “Active Acoustic Systems for the Control of Room Acoustics,” Keynote, Proceedings of the 10th International Symposium on Room Acoustics (ISRA), Melbourne, Australia, August 29–31, 2010.
7. S. Ellison and R. Schwenke, “The Case for Widely Variable Acoustics,” Proceedings of the 10th International Symposium on Room Acoustics (ISRA), Melbourne, Australia, Aug. 29–31, 2010.
8. Schwenke, R., Ellison, S., "Objective Assessment of Active Acoustic System Performance" Proceedings of the International Symposium on Room Acoustics, 29-31 August 2010.
9. Poletti, M. A, Schwenke, R. W., "Prediction and Verification of Powered Loudspeaker Requirements for an Assisted Reverberation System", presented at 121st Audio Engineering Society Convention (San Francisco), October 2006.
10. Dolby Laboratories, San Francisco, CA. Dolby Atmos Specifications for IMS3000 and CP850. https://professional.dolby.com/siteassets/cinema-products-documents/dolby-atmos-specifications.pdf.
11. D. L. Davidson, “JOJO ABOT and esperanza spalding Immerse Audiences in A GOD OF HER OWN MAKING,” *I Care If You Listen*, American Composers Forum, Sep. 29, 2022.
12. Vivien Schweitzer, “In Review: A Night of Women Composers,” *National Sawdust Log*, September 27, 2019.
13. C. Young, “Unheard Lee ‘Scratch’ Perry / Mouse on Mars Immersive Collaboration Debuts,” *MixOnline.com*, Live Sound Venues section, Mar. 18, 2022.