

# Sonic Portal: Designing Interactive Soundscapes for Shared Memory and Community Connection

Alaa Algargoosh  
 Architecture  
 Virginia Polytechnic Institute and  
 State University  
 Blacksburg, Virginia, USA  
 MIT Media Lab  
 Massachusetts Institute of Technology  
 Cambridge, Massachusetts, USA  
 algargoosh@vt.edu

Hayoun Noh\*  
 Department of Computer Science  
 University of Oxford  
 Oxford, United Kingdom  
 Media Lab  
 Massachusetts Institute of Technology  
 Cambridge, Massachusetts, USA  
 hayoun.noh@cs.ox.ac.uk

Yuqing Lucy Li\*  
 MIT Media Lab  
 Massachusetts Institute of Technology  
 Cambridge, Massachusetts, USA  
 lucy\_li@media.mit.edu

Xiao Xiao  
 De Vinci Research Center  
 De Vinci Higher Education  
 Paris La Défense, France  
 MIT Media Lab  
 Massachusetts Institute of Technology  
 Cambridge, Massachusetts, USA  
 xiao.xiao@devinci.fr

Hiroshi Ishii  
 MIT Media Lab  
 Massachusetts Institute of Technology  
 Cambridge, Massachusetts, USA  
 ishii@mit.edu

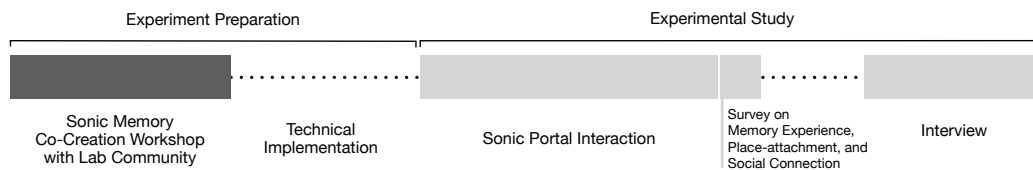


Figure 1: Schematic of Sonic Portal main study procedure.

\*Both authors contributed equally.



This work is licensed under a Creative Commons Attribution 4.0 International License.  
 DIS '26, Singapore, Singapore  
 © 2026 Copyright held by the owner/author(s).  
 ACM ISBN 979-8-4007-2563-0/26/06  
<https://doi.org/10.1145/3800645.3813032>

## Abstract

Many spatial interaction systems privilege visual representation, leaving other sensory modalities underexplored as design materials. This paper presents an interactive research prototype and its evaluation, examining how sound can support memory evocation, place attachment, and social connection within a virtual

representation of a shared space. The prototype combines a navigable three-dimensional environment with location-specific ambient sounds and spoken narratives through a two-stage process. First, participatory workshops were conducted with members of a lab community to collect meaningful sonic memories and associate sounds with the corresponding locations in the virtual environment. Second, the resulting audiovisual prototype was evaluated through a controlled study with two conditions: visual-only interaction and audiovisual interaction. The evaluation combined quantitative measures of the autobiographical memory experience, place attachment, and social connection with qualitative accounts of the user experience. The results show that audiovisual interaction was associated with stronger emotional engagement and perceived connection. Qualitative findings further illustrate how everyday sounds supported a sense of shared presence and continuity across non-overlapping occupants of the same space.

## CCS Concepts

• **Human-centered computing** → **Participatory design**; *User studies*.

## Keywords

Multisensory Interaction, Soundscapes, Memory, Place Attachment, Social Connection, Spatial Navigation, Virtual Reality.

### ACM Reference Format:

Alaa Algaroosh, Hayoun Noh, Yuqing Lucy Li, Xiao Xiao, and Hiroshi Ishii. 2026. Sonic Portal: Designing Interactive Soundscapes for Shared Memory and Community Connection. In *Designing Interactive Systems Conference (DIS '26)*, June 13–17, 2026, Singapore, Singapore. ACM, New York, NY, USA, 20 pages. <https://doi.org/10.1145/3800645.3813032>

## 1 Introduction

Visual and sonic memories carry temporal information differently. Visual memories—particularly of places and people—often provide contextual detail that situates experiences within specific historical moments [13, 49]. Sonic memories, by contrast, are less tightly bound to explicit temporal markers and instead tend to support affective and experiential continuity across time [31, 46]. Because acoustic qualities such as ambient sounds or familiar reverberations can persist across changing visual identities and generations of occupants, sound can support a sense of continuity through shared space [22].

Phenomenological and architectural accounts of dwelling have long emphasized this role of sound [3, 47]. Rather than treating sound as a secondary component of perception, phenomenologists and architectural theorists describe it as part of the atmospheric fabric through which places are lived and remembered. Bachelard emphasizes how reverberation and acoustic qualities awaken memory and imagination [3], while architectural theorists such as Robinson frame dwelling as a cognitive and affective condition shaped by sensory atmospheres [47]. From this perspective, sound is not simply something heard within a space, but a medium through which a place becomes inhabitable, meaningful, and capable of carrying memory across time.

These perspectives raise the question of whether sound's capacity to carry memory across time extends beyond individual

recollection to collective experience. In many communities, members do not overlap temporally: people arrive and depart, cohorts change, and direct encounters may never occur. Yet, they share a space whose sonic atmosphere may persist across such shifts. This suggests that ambient sounds, recurring acoustic signatures, or remembered voices could serve as a connective medium, potentially linking individuals to a broader community history they did not personally witness. Although soundscape and heritage research has empirically examined collective memory and place attachment, studies that highlight the role of sound in supporting cross-temporal social connection within lived communities remain limited [11, 16, 22, 33].

**This paper investigates the following research question: How does the addition of spatially anchored sounds to a navigable virtual reconstruction of place shape (1) memory evocation, (2) place attachment, and (3) social connection when revisiting a shared environment?** We address this question through Sonic Portal, an interactive research prototype based on a Matterport 3D reconstruction of a lab building interior, experienced either visually alone or augmented with sound. Using the MIT Media Lab community as a case study, we first conducted participatory workshops to co-construct sonic materials, including ambient soundscapes and spoken narratives. These materials were then associated with locations in the 3D environment and evaluated in a screen-based study in which participants explored the space under two conditions: visual-only and audiovisual. We assessed memory evocation, place attachment, and social connection using validated quantitative measures, complemented by semi-structured interviews (Fig. 1).

By examining the role of sound in a meaningful spatial reconstruction, Sonic Portal provides an empirical case through which to investigate claims previously articulated in phenomenology and architectural theory. Our findings indicate that sound supported the reactivation of embodied, temporally layered memories of place that were less accessible through visual representation alone. Compared to the visual-only condition, the audiovisual condition was associated with higher scores on specific dimensions of the Memory Experience Questionnaire (MEQ), particularly vividness and sensory detail, as well as higher perceived connection to the lab community and increased interest in future engagement. These results suggest that sound contributes to the perceptual richness of memory recall and supports a sense of social presence and continuity across non-overlapping cohorts.

This paper makes three contributions to research on multisensory interaction, memory, and spatial experience in HCI. First, we present Sonic Portal as an interactive research prototype that examines sound not as a supplementary layer, but as a spatially situated, community-authored medium for evoking memory, attachment, and social connection within a virtual reconstruction of shared space.

Second, we contribute a design approach for community-authored sonic interaction, combining participatory co-creation of ambient sounds and narratives with their spatial association in a navigable virtual environment. This approach illustrates how everyday sounds and voices can function as resources for collective memory rather than as isolated media artifacts.

Third, through a mixed-methods evaluation comparing visual-only and audiovisual interaction, we provide empirical results and design implications for how spatial sound shapes autobiographical memory experience, place attachment, and perceived social connection in virtual spaces. Our findings connect prior phenomenological and soundscape perspectives to the design of interactive systems that engage memory and social connection across time.

## 2 Related Work

This work engages multiple research areas that approach memory, space, and sound from different perspectives. We first review psychological accounts of sensory modalities in autobiographical memory, followed by phenomenological and architectural theories of sound and dwelling. We then examine empirical work on sound, place, and collective memory, and situate our contribution within HCI research on reminiscence, immersive environments, and sound-based interaction. We conclude with methodological precedents relevant to studying memory, place attachment, and social connection.

### 2.1 Sensory modalities and Memory

Memory is fundamentally multisensory, with different sensory modalities contributing distinct kinds of information to recollection [19, 35, 51]. Visual memory is often closely tied to spatial layout and temporal organization, providing a structured framework for episodic recall. Conway and Pleydell-Pearce's model of autobiographical memory describes how visual imagery supports the organization of memory across time, linking event-specific sensory details to broader lifetime periods within a coherent personal history [13]. Rubin similarly emphasizes visual imagery as a central representational component in episodic remembering, supporting the reconstruction of spatially coherent scenes with associated temporal and contextual details [49]. In this sense, visual memory often affords relatively explicit access to where and when an experience occurred. Compared to visual memory, auditory memory is less tightly coupled to explicit spatial layout or detailed temporal reconstruction. Instead, the processing of auditory cues tends to privilege affective salience, familiarity, and experiential continuity [12, 52]. Prior work shows that music can evoke autobiographical memories [4, 25–27, 30] through emotional and self-referential pathways without requiring detailed episodic reconstruction [26]. Related mechanisms extend beyond music: studies show that the human voice conveys rich affective and identity information and supports recognition of familiar individuals, functioning as a socially and emotionally meaningful cue [5], while work on everyday environmental sounds demonstrates that memorability depends less on acoustic complexity than on familiarity and emotional association [46]. Prior work using multimodal cues suggests that sensory modalities and their combinations contribute differently to autobiographical memory retrieval [20, 45], with visual and auditory information often exerting strong influences in controlled cueing paradigms [59]. Our work examines the combined role of visual and auditory cues within spatially navigable virtual environments that reconstruct places participants have previously inhabited.

### 2.2 Sound and Dwelling

Where psychological and neuroscientific accounts of memory emphasize visual imagery as a primary scaffold for spatial and temporal organization, phenomenological and architectural theories shift attention from representation to lived experience. In this approach, places are not primarily remembered as visually reconstructed scenes, but as multisensory atmospheres that are inhabited, felt, and emotionally attuned over time [3, 47]. Sound is central to this account of dwelling. Rather than specifying where or when an event occurred, sonic qualities—reverberation, rhythm, and ambient presence—shape how a space is experienced as inhabitable and meaningful [55, 58]. Studies in applied acoustics indicate that sound can influence perceived attachment to indoor environments, highlighting the role of acoustic experience in how people relate to places [11]. Bachelard describes reverberation as a catalyst for memory and imagination, through which past experiences surface via sensory immersion rather than deliberate recall [3]. Architectural critiques of visual dominance similarly foreground sound as anchoring perception in the body and sustaining a sense of presence beyond the visual field [41]. More recent phenomenological work on atmosphere extends this view by framing sound as a medium through which affect and meaning are shared across space, in ways not reducible to discrete events or representations [56]. By situating sound within an interactive system that layers memory, narration, and navigation, Sonic Portal explores how dwelling can be enacted through sound as a socially mediated, temporally layered experience of place.

### 2.3 Sound, Place and Collective Memory

Empirical research in soundscape studies and cultural heritage provides concrete support for phenomenological claims about sound's role in memory and dwelling [23]. Studies of reconstructed and curated soundscapes show that sonic environments can evoke emotional, autobiographical, and historical memories, supporting people's sense of connection to places across time [2, 22, 54]. In this literature, sound is treated as a form of intangible heritage that carries meaning beyond visual representation, shaping how places are collectively remembered. Acoustic Research further demonstrates that acoustic environments shape affective relationships to space [1]. Quantitative studies of residential and indoor soundscapes link perceived acoustic characteristics to place attachment, suggesting that sound contributes to how environments become emotionally and socially meaningful [11]. However, this work largely conceptualizes attachment as an individual–place relationship, leaving open how memory mediates social connection within shared spaces across non-overlapping cohorts and time periods. Complementary perspectives from sensory ethnography and memory research foreground the relational dimensions of sensory remembering. Work on sensobiographies shows how shared sensory atmospheres—sounds, smells, textures—become sites of collective remembering that extend across generations [31]. Psychological research on nostalgia similarly demonstrates that recalling personally meaningful past experiences can increase positive affect and feelings of social connectedness, even in the absence of direct social interaction [17]. Prior work has examined sound in relation to historical memory, place attachment, and emotionally meaningful recall. Building on

these perspectives, our work examines how sound attached to a reconstructed place can mediate memory recall and cross-temporal social connection.

## 2.4 HCI Perspectives on Sound, memory, and space

HCI research on reminiscence has historically privileged visual media—such as photos, videos, and physical objects—with sound typically treated as secondary or supportive [28, 37, 43, 63]. A smaller body of work focuses on sound as a memory cue, emphasizing its emotional, ambient, and sometimes involuntary qualities [15, 21, 28, 40, 42, 62]. These systems primarily focus on recording, replaying, or curating sounds as artifacts rather than exploring how sound operates within spatialized environments.

XR systems have explored reminiscence and social connection through immersive and navigable environments, showing how spatial immersion and narrative can support presence, emotional engagement, and place attachment across distance and time [57]. In this work, sound—typically voice or ambient audio—plays an instrumental role in supporting atmosphere and storytelling, but is rarely examined as a primary mechanism shaping memory recall or social connection. Recent works have explored sound as a medium for social connection across time, emphasizing affective presence rather than place-based memory [44, 61]. While sound is central to both systems, its specific role in shaping participants' spatial experiences was not explicitly examined. A third, adjacent strand of HCI research addresses sound in relation to space through soundscape-oriented approaches. A recent review characterizes soundscape research in HCI as spanning two main streams: soundscapes treated as acoustic environments to be analyzed or augmented, and soundscapes treated as compositional materials for design and artistic exploration [29]. Notably, the review calls for greater engagement with existing, lived environments, such as the work around sounds as carrier of meaning in everyday life [40]. Within sonic interaction design [18], researchers have also examined the role of sonic memories and soundscape through participatory workshop methods that help participants access and reinterpret everyday sound events as part of the design process [10, 32, 36]. Building on these strands, Sonic Portal examines how sound attached to a reconstructed, navigable place shapes memory recall and social connection across time, focusing on sound not as an artifact or backdrop but as an active mediator of spatial, affective, and collective remembering.

## 2.5 Methodological Precedents

Psychological research has developed validated instruments to quantify the phenomenology of autobiographical memory and related affective states. Measures such as the Memory Experience Questionnaire [53] and the Autobiographical Memory Characteristics Questionnaire [7] capture dimensions including vividness, sensory detail, emotional intensity, and temporal perspective. Additional scales assess nostalgia [48], place attachment [60], and sense of community or social identification [38, 39], and have been adopted in HCI and CSCW studies to evaluate social and spatial experience. Sonic Portal builds on these precedents by combining participatory sound curation with randomized controlled experiment and validated quantitative measures, complemented by

open-ended qualitative responses to provide more depth in understanding the participants' experiences. This integrated approach brings together methods that have largely been used separately, enabling the study of how sound shapes memory, place attachment, and social connection within a shared spatial context.

## 3 Sonic Portal Research Prototype

Sonic Portal is an interactive research prototype built on a Matterport-based three-dimensional reconstruction of the space. It augments a navigable virtual tour with community-authored sonic content: ambient sounds and spoken narratives grounded in personal experiences of specific locations.

These materials are curated and associated with corresponding points in the Matterport environment, where they are encountered through spatial proximity and optional user interaction. As users move through the space, ambient soundscapes are triggered automatically on entry, while spoken narratives remain user-controlled, allowing participants to regulate the depth and pacing of engagement.

Sonic Portal does not aim to reproduce a single authoritative history of the space. Instead, it allows temporally and socially distinct memories to coexist within the same spatial framework. Voices from different cohorts are encountered without chronological ordering, so that the space appears as a composite of lived experiences rather than a linear narrative. In this way, sound functions not only as sensory input but as a medium through which traces of others remain present across time.

### 3.1 Sonic Memory Co-Creation Workshop

To prepare for the experiment, designing Sonic Portal involved a series of co-creation workshops exploring how sound conveys memory and emotion within a community. Participants reflected on personal sonic experiences at the selected building. These sounds, derived from narrative reflection and spatial recall, were later used in an interactive virtual sonic experiment.

**Participants:** A pilot and three Zoom-based workshops were held, each with two to five participants ( $N = 12$ ). Participants were current or former lab community affiliates, including students, faculty, and alumni—selected to represent diverse roles, disciplinary backgrounds, and time periods of affiliation (1995–2025), with age distribution (18–30,  $n = 4$ ; 31–40,  $n = 5$ ; 41–50,  $n = 2$ ; 61–70,  $n = 1$ ) (Gender: Female,  $n = 8$ ; Male,  $n = 3$ ; Non-binary = 1). A pre-session survey gathered demographic and contextual information, including age range, gender, research group affiliation, years at the lab, and current level of engagement with the lab community.

**Procedure:** Each 60 to 90-minute workshop followed a three-part structure. In the first segment, participants reflected on sonic memories without visual cues. Facilitators prompted discussion of voices, ambient sounds, machine noises, and emotionally resonant sound events, as well as how sound shaped daily routines at the lab. In the second segment, participants engaged with a 3D virtual tour of the lab building using a Matterport<sup>1</sup> interface. As they navigated familiar spaces, they recalled soundscapes associated with specific rooms and events. This spatial recall enriched earlier reflections,

<sup>1</sup><https://matterport.com>

allowing for embodied, location-specific memory. In the final segment, participants reflected on their recall process, see Appendix (section 8.1). Sessions were audio-recorded and transcribed. Personal narratives were used to inform the design of the ambient soundscape in addition to some selected to serve as part of the interactive experiment.

**Sound Selection:** We analyzed transcripts from recordings of three sonic memory co-creation workshop sessions. Analysis began with cleaning and anonymizing the transcripts, and all qualitative analysis was conducted using Atlas.ti. As the workshops aimed to inform the design of Sonic Portal's soundscapes, we employed a deductive thematic analysis focused on design-relevant aspects of the data [8, 9]. Specifically, the research team examined transcripts with attention to the types of sounds and narratives participants associated with particular locations, as well as participants' reflections on the co-creation process itself. This deductive analysis supported the systematic identification and organization of location-specific sounds and narratives, which directly informed the composition and spatial mapping of soundscapes within the 3D environment, laying the groundwork for the experiment.

**Ambient Sound and Narrative Curation:** In total, there were 126 sound cues mentioned during the co-creation workshop. First, we sorted out 14 cues for which we were unable to collect sounds e.g., retired machine shop keeper's voice. Then, we grouped the remaining 112 sound cues based on their locations in the building to get a better understanding of which route through the 360-degree virtual scene would cover the most memorable shared places. The most dominant places include Atrium (n=25), Multi-Purpose Room (n=15), Machine Shop (n=13), Stairwell (n=9), Group X Lab space (n=8), Lobby (n=7), and Group Y Lab space (n=5). From each location, we then selected a couple of the most frequently mentioned sound cues, such as, Atrium -> playing at ping pong table, community and public events, student conversations, see Table 1 for more details. The final curation of the ambient sounds included 12 sound cues across 7 locations. We collected the 12 ambient sounds through on-site recording, sound libraries, and lab archival video recordings. Lastly, for each of the 12 ambient sound cues one complementary spoken narrative drawn from interviews was selected. Most stories featured an explicit link to community members' memories evoked through the sound cue, e.g., "the echoey footsteps in the lobby gave a distinct feeling of arrival". Other narratives helped to illustrate emotions triggered by the absence of sound, which is difficult to capture through standalone audio cues e.g., the silence of the 6th floor during mornings and nights.

**Technical Implementation:** To create the multi-modal experience of 12 ambient sound cues and 12 spoken narratives (Table 1) embedded in a 360-degree virtual interior of the lab, we used a virtual tour software called CAPTUR3D<sup>2</sup>. The participants experienced the interaction through a first-person perspective and navigated by clicking on the spot in the virtual model they wanted to go to. The ambient sound cues were incorporated as immersive background track that automatically plays when a participant enters a specific area of a tour. The spoken narratives were added as multimedia tags at the corresponding audio zones. The multimedia

<sup>2</sup><https://captur3d.io>

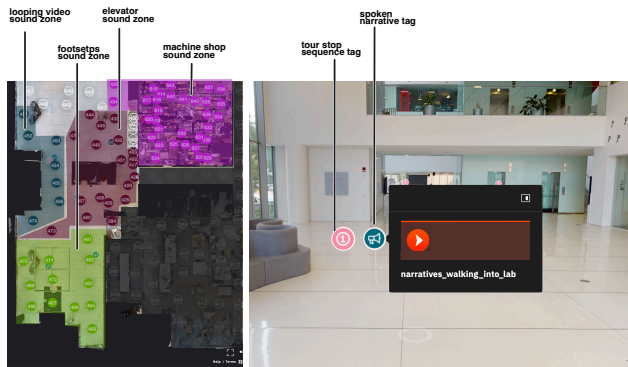
1st floor			
<b>Lobby</b>	echoey footsteps	looping video with professor voice	elevator
<b>Machine Shop</b>	machine hum		
3rd floor			
<b>Atrium</b>	ping pong table	community and public events	student conversations
<b>Stairwell</b>	resonance of that specific stairwell		
<b>group X lab space</b>	(project 1 installation) melody	(project 2 installation) pins	Prof. A voice
<b>group Y lab space</b>	looping demo video	project melodies	Prof. B voice
6th floor			
<b>Event Space</b>	reoccurring exhibition event	quietness at morning/night	
<b>Multi-Purpose Room</b>	professors voices	transitioning music during a reoccurring exhibition event	student organized parties
<b>Balcony</b>	fireworks		

**Table 1: List of Ambient Sound Cues used in the Experimental Study based on thematic analysis of Sonic Memory co-creation workshop.**

tags appeared as audio player interface with a play/pause button, visualization of the sound wave and audio length. When participants clicked on the tag, they were able to play and pause the narrative at their own pace. Additionally, as participants were allowed to roam freely within the system, number tags and floating arrows were put in place to indicate the sequence of the tour and guide participant to all 12 ambient sound cues or narrative, see Fig. 2.

## 4 Methods

The project involved a between-subjects randomized controlled experimental study designed to examine how multimodal conditions influence memory evocation, place attachment, and social connection to the lab. Participants experienced one of two 360-degree virtual scenes of the lab interior, presented either visually only or paired with ambient sounds and spoken narratives drawn from interviews conducted in the co-creation workshops. These stimuli were developed to test whether sound and narrative strengthen



**Figure 2: Technical Implementation and Setup of Sonic Portal.** On the left, is a screenshot of sound zones in one location that automatically played when participants entered. On the right is a first-person perspective showing the pink-colored tour stop sequence tag, which helped with navigation, and the teal-colored spoken narrative tag, which played narratives collected during experiment preparation when participants clicked on it.

emotional recall and activate deeper senses of attachment to the lab community, see Fig. 3.

**Participants:** A total of 28 members of the lab community (mainly past members) participated representing various roles, disciplinary backgrounds, and time periods of affiliation (1985–2025), with age distribution (18–30,  $n=5$ ; 31–40,  $n=10$ ; 41–50,  $n=4$ ; 51–60,  $n=6$ ; 61–70,  $n=3$ ) (Gender: Female,  $n=8$ ; Male,  $n=20$ ; both are equally distributed between the two groups), see Table 2. Participants were recruited through the lab’s alumni newsletter supplemented by snowball sampling. This study was reviewed and approved by the authors’ institutional review board, and all participants provided informed consent prior to participation.

**Experimental Conditions:** Participants were randomly assigned to one of two conditions:

a) Visual-only: A 360-degree visual scene of the lab interior with no audio, serving as a control.

b) Audiovisual: The same 360-degree visual scene accompanied by an ambient sounds composed of sounds selected based on the co-creation workshops, as well as spoken personal reflections contributed by the lab community members about their sonic memories of the lab recorded during the workshops.

**Procedure:** Each participation began with informed consent, followed by the collection of demographic data and information about participants’ lab affiliation. Participants reported the frequency and nature of their current engagement with the lab community. They then navigated the virtual lab building using floor-specific links to Matterport 360-degree scenes, each containing a numbered route through the space, after which they were free to explore before returning to the survey. In the audiovisual condition, each numbered location included sounds and spoken narratives describing a sonic memory associated with that point in the space.

After completing the virtual experience, participants completed a set of questionnaires that included both open-ended responses

and standardized measures. Participants were first asked whether the experience evoked a specific memory and, if so, to describe it. When multiple memories emerged, they were instructed to select one focal memory and explain their choice. Participants then completed the Memory Experiences Questionnaire (MEQ) [53], which assesses dimensions such as vividness, coherence, accessibility, time perspective, sensory detail, visual perspective, emotional intensity, emotional distancing, sharing, and valence. This was followed by a brief place attachment scale [60] and a set of items assessing social connection at different levels of engagement [38, 39], including interest in future involvement such as participating in community events or mentoring a current student. Finally, the questionnaire included reflective prompts asking whether the memory had previously been salient or was re-activated by the experience, whether the experience was surprising, and whether it altered how participants thought about the memory. The full questionnaire is provided in Appendix (Section 8.2).

**Follow-up Interviews.** Among participants who indicated willingness to be contacted for an interview in the questionnaire, we selected a subset of six participants (three from each experimental condition) for follow-up interviews. Participants were purposively sampled to capture diverse perspectives, including variation in the length of time since they had been affiliated with the lab (e.g., those who left the lab several years ago versus more recent members). The goal of the interviews was to deepen our understanding of how the virtual experience shaped participants’ memory recall and sense of connection to the lab community.

All interviews were conducted via Zoom and lasted approximately 35–40 minutes. Interview questions focused on participants’ experiences with the system in both the visual-only and audiovisual conditions (see Appendix, Section 8.2). We reviewed participants’ questionnaire responses in advance to tailor interview questions and probe more deeply into specific aspects of their reported experiences. For participants in the visual-only condition, after discussing their experience with the visual-only system, they were shown the audiovisual version of Sonic Portal and invited to experience it during the interview. This enabled us to elicit comparative reflections across both conditions and to examine whether and how participants’ perceptions and interpretations changed after encountering the audiovisual version.

**Quantitative Analysis:** Quantitative analysis were conducted to examine how interaction condition (visual-only vs. audiovisual) as independent variables influenced participants’ memory experience, place attachment, and perceived social connection to a shared community space, as the dependent variables. All analyses were performed using standard statistical software (R-Studio)<sup>3</sup>. Memory experience was assessed using the Memory Experiences Questionnaire (MEQ), which measures multiple dimensions of autobiographical memory, each measure included different effect levels which have been assigned with numerical values during the analysis. Place attachment was measured using a brief scale assessing participants’ emotional connection to and sense of belonging within the space (Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree)). Social connection was assessed through a set of items capturing perceived

<sup>3</sup><https://posit.co/download/rstudio-desktop/>

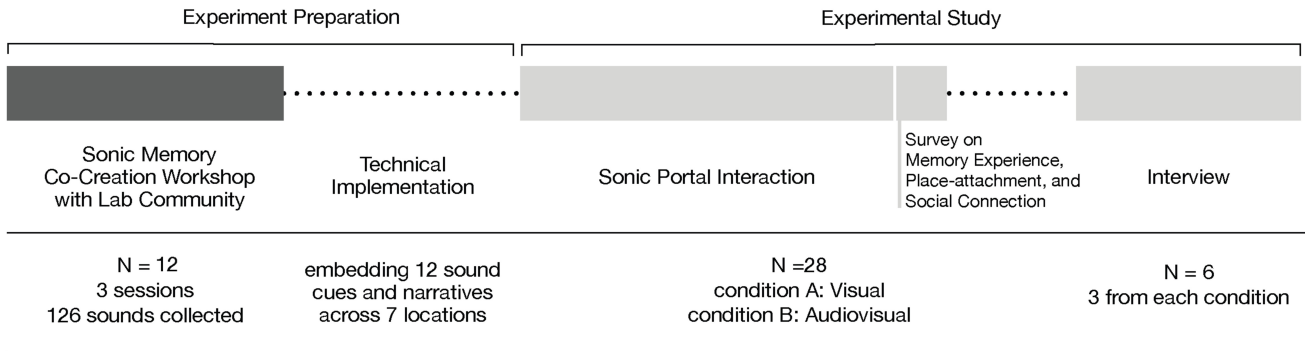


Figure 3: Schematic of Sonic Portal experiment preparation and experimental study.

Visual-Only (VO)			Audiovisual (AV)		
Participant ID	Gender	Time Spent at Lab	Participant ID	Gender	Time Spent at Lab
P1VO	M	2014–2021	P1AV	M	2010–2018
P2VO	M	2012–2019	P2AV	M	2023–2023
P3VO	M	2007–2014	P3AV*	M	2015–2017
P4VO*	F	2014–2022	P4AV*	M	1986–1991
P5VO*	M	2010–2013	P5AV	M	2013–2020
P6VO	F	2023–2025	P6AV	M	2005–2025
P7VO	F	2023–2025	P7AV	F	2012–2018
P8VO	M	2022–2025	P8AV	F	2006–2013
P9VO	M	1993–1995	P9AV	M	1987–1992
P10VO	M	2008–2010	P10AV	M	2016–2025
P11VO	F	1987–1988	P11AV	F	2024–2024
P12VO*	M	1985–1997	P12AV	F	1997–2001
P13VO	F	2000–2025	P13AV*	M	2024–2024
P14VO	M	2021–2022	P14AV	M	1987–1990

Table 2: Participant demographics and time spent at the lab for visual-only (VO) and audiovisual (AV) conditions. Asterisks indicate participants selected for the interview.

companionship, perceived specialness of the space, changes in participants’ perceptions of the space and of the people associated with it, and intentions for future engagement, such as participating in community activities or engaging in more intensive forms of involvement (e.g., mentoring), through reporting the number of times per year between 0 to 4).

In addition, participants reported their level of engagement with the community space prior to the experiment, including frequency of engagement and overall level of connection.

Prior to hypothesis testing, data were screened for completeness and outliers. Normality of outcome variables within each experimental condition was assessed using Shapiro–Wilk tests and visual inspection of distributions (Q–Q plots). To compare outcomes between the visual-only and audiovisual conditions, two-tailed independent-samples t-tests were conducted for each dependent variable. results are interpreted as exploratory and are complemented with effect size estimates (Cohen’s d) to assess the magnitude and consistency of observed differences. This approach was selected to evaluate whether the inclusion of sound as a primary

design material systematically altered participants’ reported memory experience, place attachment, and social connection relative to visual interaction alone.

**Qualitative Analysis:** We conducted a reflexive thematic analysis using Atlas.ti on six interview transcripts from a follow-up study and on open-ended qualitative responses from the questionnaire, see section 8.3 in the Appendix. Following standard qualitative analysis protocol [50], we began by familiarizing ourselves with the data through repeated close readings while cleaning and anonymizing transcripts for analysis. We then performed line-by-line coding using a combination of open and axial coding to iteratively develop and refine themes from participants’ accounts [14, 34]. We also analyzed open-ended qualitative responses from the questionnaire using the same thematic analysis approach. Throughout the coding process, the research team met regularly to compare interpretations, refine code definitions, and iteratively organize subthemes into higher-level themes.

Importantly, in our analysis, we use the term sound to refer to the combined sonic layer presented in the audiovisual condition, which included both ambient sounds (e.g., footsteps) and spoken

narratives (e.g., community members' recorded stories). As the goal of this study was not to compare their individual effects, but to examine how spatially anchored sonic experiences as a whole evoke memory, place attachment, and social connection, our qualitative analysis did not systematically separate the effects of ambient sounds and spoken narratives. Instead, we focused on participants' holistic experiential accounts of sound as an integrated, spatially situated memory cue. That said, participants occasionally referred explicitly to different types of sonic elements (e.g., voices vs. ambient sounds), and we preserved these distinctions in our coding where they emerged naturally in the data. Accordingly, where relevant, we reflect on differences between these sonic elements in the Results and Discussion.

Moreover, because participants experienced different versions of the system (visual-only vs. Audio-visual) and the interview protocols differed slightly by condition, we initially organized coding by condition to capture experience-specific nuances. During the grouping and theme development phase, however, we consolidated codes into a single integrated codebook rather than maintaining separate codebooks by condition. Specifically, condition-tagged codes that captured overlapping phenomena were merged into broader subthemes. For example, codes such as "(Visual-only) collective reminiscence strengthening a sense of belonging" and "(Audio-visual) strengthening connection to past memories" were integrated under a shared subtheme (e.g., Strengthening community connection), which was subsequently situated within a higher-level theme aligned with the research questions (e.g., Social connection and collective identity). This consolidation enabled us to represent both shared and condition-specific patterns within a coherent thematic structure while keeping the analysis grounded in participants' accounts. The final codebook consisted of 80 codes, organized into 28 subthemes and 9 overarching themes, which informed the analysis presented in the Results section.

**Researcher Context and Positionality.** All authors are affiliated with the lab that served as the context for this study, and bring diverse relationships to the space, including varying durations of affiliation (ranging from approximately 2 to over 30 years), roles (e.g., student, alumni, affiliate, faculty), and levels of current engagement (from active, on-site involvement to more occasional or limited engagement). This diversity reflects the range of experiences represented in our participant sample and informed both the study design and interpretation of findings by incorporating multiple perspectives rather than a single shared viewpoint. Throughout the research process, we remained attentive to how our own experiences with the lab might shape interpretation, holding regular team discussions to examine emerging interpretations.

## 5 Results

### 5.1 Quantitative results

Participant previous engagement with the lab community spanned a continuum from frequent in-person involvement to distant but enduring intellectual and social connections. Engagement took multiple forms, including research collaboration, teaching, event participation, alumni networking, remote interaction.

Normality of outcome variables was assessed within each experimental condition using Shapiro–Wilk tests and visual inspection of

distributions. All variables met assumptions of normality, allowing for the use of parametric statistical tests. Results from the two-tailed independent-samples t-tests of the standardized Memory Experience Questionnaire (MEQ) in Fig. 4 indicate that the audiovisual condition was associated with higher levels scores across multiple dimensions of memory experience, including vividness, coherence, accessibility, time perspective, sensory details, visual perspective, sharing, and valence, compared to the visual-only condition, while distancing was higher in visual-only.

Significant differences were observed for vividness ( $p = .036$ ,  $|d| = 0.53$ ) and sensory detail ( $p = .039$ ,  $|d| = 0.60$ ), indicating that participants in the audiovisual condition reported richer and more detailed memory experiences compared to the visual-only condition. Effect size analysis revealed moderate effects for both vividness and sensory detail, suggesting meaningful differences between conditions despite limited statistical power. Time perspective ( $p = .055$ ,  $|d| = 0.59$ ), showed a moderate effect sizes. No statistically significant differences were observed for coherence ( $p = .125$ ,  $|d| = 0.45$ ), accessibility ( $p = .165$ ,  $|d| = 0.39$ ), visual perspective ( $p = .805$ ,  $|d| = 0.06$ ), emotional intensity ( $p = 1.000$ ,  $|d| = 0.00$ ), sharing ( $p = .395$ ,  $|d| = 0.31$ ), distancing ( $p = .643$ ,  $|d| = 0.12$ ), and valence ( $p = .559$ ,  $|d| = 0.15$ ). To account for multiple comparisons, we applied a Holm correction to the p-values; no effects remained statistically significant after correction. However, consistent small-to-moderate effect sizes and directional patterns across memory-related measures suggest that sound contributes to enhancing key aspects of autobiographical memory experience.

Analysis of place attachment revealed that participants' perception of the lab building as a special place was comparable across the visual and audiovisual conditions, indicating no difference between conditions on this dimension ( $p = .764$ ,  $|d| = 0.10$ ).

Regarding the social connection aspects, there was also no difference between the visual and audiovisual conditions in terms of participants' reported intention to contact someone after the experience ( $p = 1.000$ ,  $|d| = 0.00$ ). With respect to changes in participants' perceptions following the experience, results showed that participants reported a greater change in their perception of the lab after the visual condition compared to the audiovisual condition ( $p = .132$ ,  $|d| = 0.42$ ), but there was no difference in their perception of the people of the lab ( $p = .770$ ,  $|d| = 0.12$ ). Lastly, participants in the audiovisual reported higher levels of connection increase after the engagement with Sonic Portal connection; however, this difference was not statistically significant ( $p = .552$ ,  $|d| = 0.15$ ), see Fig. 5.

Results also addressed participants' engagement with the lab community. Prior to the experiment, participants reported their current engagement with the lab, including the approximate number of engagements per year and their overall level of connection. After completing the experimental condition, participants were asked how many times per year they would be interested in engaging with the lab community through events, allowing us to assess whether intended engagement increased following the experience. A second item assessed a more intensive form of engagement by asking whether participants would be interested in mentoring a current student. Across these engagement-related questions, the audiovisual condition showed a higher level of post-experience interest in future engagement relative to the visual-only condition Event Engagement ( $p = .351$ ,  $|d| = .19$ ), Mentoring Engagement;

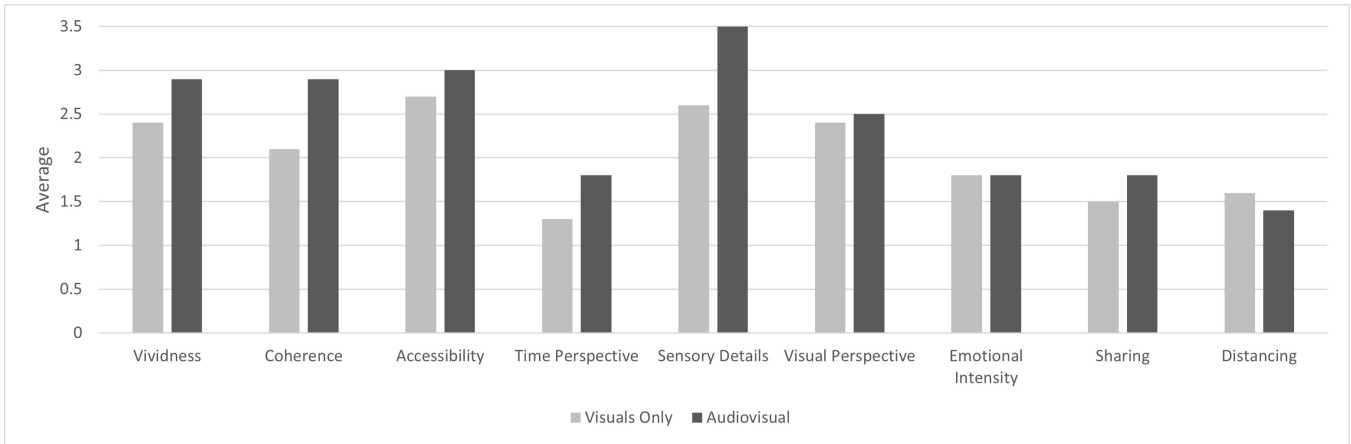


Figure 4: Standardized Memory Experience Questionnaire (MEQ) average scores for the visual and audiovisual conditions.

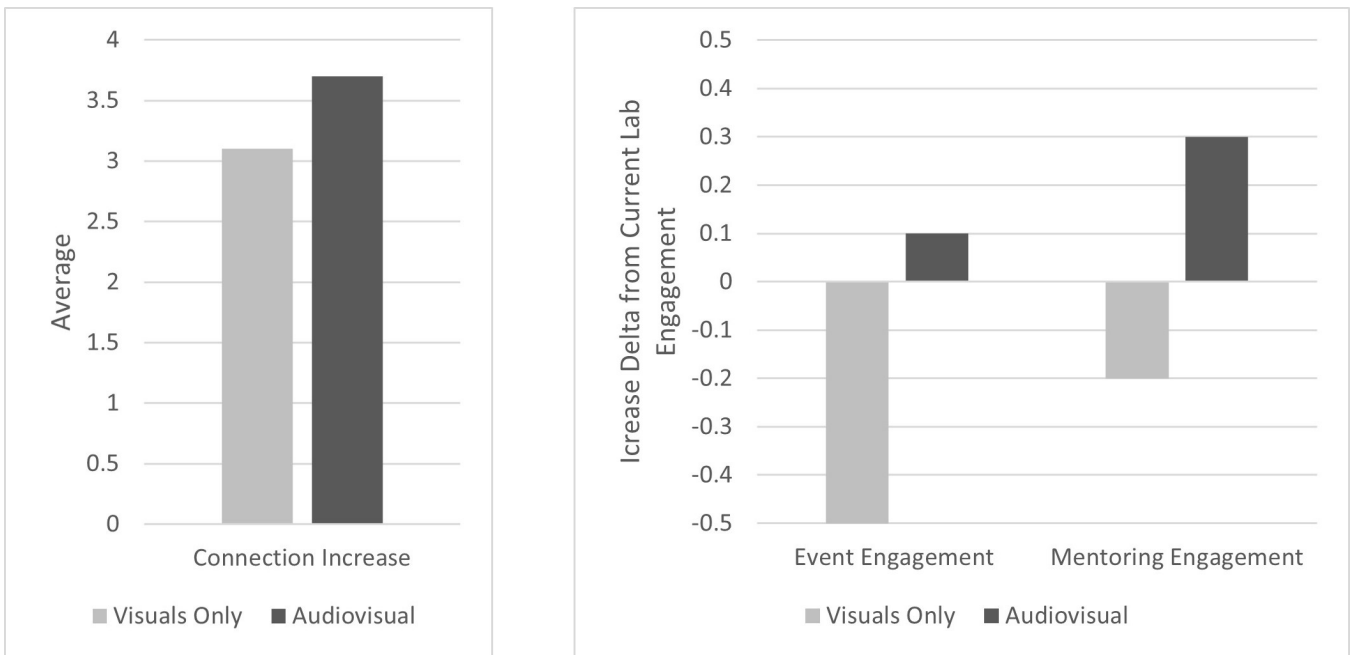


Figure 5: Left: Average connection increase scores for the visual-only and audiovisual conditions. Right: the increase in the participants’ interest level in engagement with the lab community through an event and mentoring current student for the visual-only and audiovisual conditions.

however, this difference was not statistically significant ( $p = .528$ ,  $|d| = .27$ ), see Fig. 5.

Overall, given the limited sample size, the quantitative results are interpreted as exploratory, supporting and directionally consistent, complementing, and triangulating the qualitative findings, which remain the primary source of insight, by demonstrating coherent patterns across key constructs such as memory experience and social connection.

### 5.2 Qualitative Results

To examine how sound shapes memory and presence in reconstructed spaces, we present themes from a qualitative analysis comparing visual-only and audiovisual interactions. We begin by outlining experiential commonalities across conditions, showing how the system supported exploration, autobiographical return, and renewed desire for connection, Fig. 6. We then analyze key phenomenological differences between the visual-only and audiovisual conditions, focusing on how sound reconfigured presence,

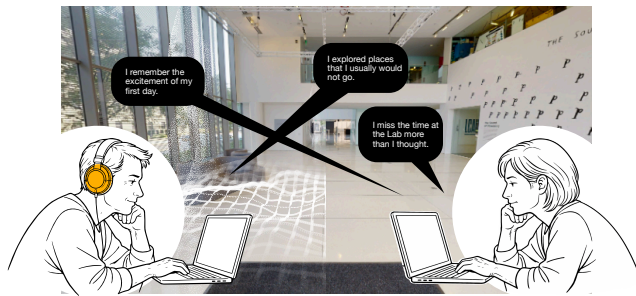


Figure 6: Visual summary of commonalities across conditions

emotional intensity, embodiment, and the social orientation of memory, Fig. 7, and Fig. 8. Finally, drawing on participants' reflections and design proposals, we discuss implications for designing sonic memory systems that support collective memory, continuity, and belonging across time, Fig. 9.

**5.2.1 Commonalities Across Conditions. Rediscovering spaces beyond everyday constraints across both conditions:** participants valued the opportunity to explore and rediscover areas of the building that were difficult to access or attend to in everyday lab life due to architectural or social constraints. The system was described as highly engaging, with many participants spending more time than expected in open-ended exploration beyond the intended paths. For instance, P3VO noted the “novelty” of “wandering around the model,” especially in parts of the building he “wouldn’t take when [he is] actually there,” while P3AV similarly reported spending “about half an hour just exploring the lab,” revisiting forgotten spaces and entering areas he had never physically visited.

**Traveling to early and formative periods of lab life:** In both conditions, moving through the reconstructed space prompted autobiographical return, with early memories frequently surfacing. P6VO described the experience as bringing back the “excitement and uncertainty” of her first months at the lab, along with thoughts of people she no longer sees, while P13AV reported that the virtual atrium evoked an early arrival memory, with “little noises” contributing to its vividness.

**3. Sense of Connection reinstating a desire for engagement:** Across conditions, the experience also reinstated a desire for reconnection with the community. P1VO realized she “miss[ed] [her] time in the lab more than [she] thought,” and P3AV expressed a wish to share the experience with others to see whether they remembered the same places and moments. Despite these shared patterns, participants' accounts revealed clear phenomenological differences between the visual-only and audiovisual conditions, which we detail in the sections that follow.

**5.2.2 Visual-Only. Feeling present without fully “being there”:** Several participants characterized the visual-only experience as “somewhere in between observing and being there” (P4VO). For P4VO, before the sounds came on, the system was “very much present” but “clearly not alive.” For P13VO, the absence of sound as well as the model being empty of people contributed to a sense



Figure 7: Visual summary of the visual-only condition.

of distance. Spaces appeared as a kind of “blank state,” which supported recognition of locations and past projects but did not evoke specific interactions or social moments.

**Cognitive recall skewed toward positive memories:** Memories that surfaced in the visual-only condition were often disproportionately positive, despite participants noting that their actual experiences were not only positive. For example, P3VO describes an “element of delight” in “seeing the space in this virtual model.” For others, like P6VO, the experience prompted a reappraisal of the past from a distance, encouraging them to “think about that time more positively” and to “appreciate how much has changed since then.”

**Noting what “should” be there:** Participants were acutely aware of sound as a meaningful absence. Rather than experiencing silence as neutral, they described sound as something missing. For instance, P3VO reflected on how he would “appreciate having the sound” and wondered what kinds of sounds might belong in the space and whether those sounds would “resonate” with him emotionally. The absence of sound also heightened the perceived emptiness of the virtual space without people. P23VO noted that when passing the space of a particular professor, “what he contributed over time is very much an auditory experience,” explaining that sound would immediately link the space to the person and their presence.

**Imagined and reconstructed sound in the absence of sound:** Interestingly, participants frequently reported imagining familiar sounds as part of their spatial memories. Some, like P5VO described “hearing” everyday sounds like doors and elevators as well as “the acoustics of entering the building”, while others, like P4VO reported “hearing” “the sound of my best friend’s voice” around an iconic pingpong table in a public space. These imagined sounds were tightly coupled to autobiographical memories. For P5VO, the imagined click of a door lock was tied to memories of being locked out due to a malfunctioning access card. For P4VO, the ping-pong table and the voice of her friend brought back associations with her “happiest, freshest days” at the lab. Imagined sounds from this study closely matched those recalled in the participatory design workshops, suggesting that they function as shared sonic anchors within the community.

**5.2.3 Audiovisual. Sound and narrative amplifying presence:** The addition of sound and narrative substantially intensified participants' sense of presence. Everyday acoustic cues such as footsteps, echoes, and elevator sounds made the space feel inhabited rather than observed. P7AV described how “the echo of footsteps and the



**Figure 8: Visual summary of audiovisual condition.**

elevator sound” immediately reactivated memories tied to transitions of arriving and leaving the Media Lab, recalling projects in the entrance “as if they were there.” P4AV similarly reported that when sound began, “the whole spectrum of things came back to me.” Even participants who first experienced the visual-only condition described a marked shift when sound was shown in the interview, such as P4VO characterizing the audiovisual experience as “more rich and more intense than I expected.”

**Re-experiencing past emotions in the body:** A defining feature of the AV condition was the somatic re-embodiment of past affective states. Participants frequently described bodily sensations—stress, tension, urgency, or comfort—triggered by familiar sounds. P3AV spoke of “instincts that kick in” upon hearing machine shop sounds, explaining “that means I need to be working on my laser cutter and getting this project done, because it’s probably late at night, and I’m probably hungry.” Similarly, after hearing sound during the interview, P4VO noted a bodily stress response that contrasted with the predominantly positive memories recalled in the visual-only condition “I feel, somatically, in the body, a stress... not because I can easily tell you the exact memory but because I feel the kind of nervous system activation”. Somatic recall was not exclusively negative. P3AV described iconic music from a demonstration project as “comforting in stressful times at the lab,” noting that hearing it again had “exactly the same effect as it did years ago.” Compared to visual-only recall—which often gravitated toward early, formative, and positive memories—sound tended to return participants to their most emotionally intense states, whether recent or repeatedly experienced across time. These embodied responses were frequently detached from specific temporally anchored events, operating through bodily familiarity rather than explicit narrative recall.

**Resurfacing dormant and unexpected memories:** In the visual-only condition, the absence of sound—particularly the absence of people-related sounds—often drew attention to the sounds and people that they would expect to be there. In the audiovisual condition, both ambient building sounds and voices actively triggered dormant, people-centered memories that were affectively charged and loosely anchored in time rather than anchored in specific episodes, differing from the more scene-based autobiographical memories that tended to surface during visual exploration alone.

For P4AV, hearing the “echoey” acoustics of the lobby immediately resurfaced memories of a former labmate who had passed

away, centered on his enthusiasm and presence rather than a specific encounter. The memory was emotional and atemporal: “I didn’t have a specific memory of any particular encounter... it’s just that I didn’t think about it as being a Media Lab experience until I was kind of in that space again.” Voices were particularly powerful in evoking people-centered memories. P3AV noted that background conversations were “almost as evocative” as known sounds, despite never having heard those specific voices before. He described recognizing the space through its soundscape and feeling nostalgic for conversations he had “never heard before,” producing a fuzzy, almost false sense of remembering. For participants who had initially experienced the visual-only condition, the introduction of voices during the interview immediately shifted attention from space to people. P3VO described becoming curious about who the speakers were and “where they were in time,” especially when the voices were unfamiliar.

**Sonic memory enabling continuity across generations:** Sound also fostered a sense of shared experience across non-overlapping cohorts. Recognizable, iconic sounds acted as anchors of continuity. P4AV described “a sense of camaraderie and continuity,” explaining that people from different eras would still recognize the ping pong table or [project] because “those things are static fixtures in the lab.” Other participants recalled shared social events triggered by voices and crowd sounds, such as P11AV remembering a large event upon hearing “Please welcome,” and P10AV recalling informal moments around the kitchen and ping pong table. These experiences often extended beyond the study itself. P4AV continued to reflect on memories of his friend after the session, sharing them with his wife. P3AV similarly described recounting the experience to his wife—whom he met at the lab—creating a moment of shared recollection: “Oh yeah, I remember that.” For several participants, the audiovisual condition not only reactivated memories but also prompted renewed social connection and reflection in everyday life.

**5.2.4 Envisioning Future Systems for Collective Sonic Memory. Participatory sonic memory-building:** Participants consistently expressed a desire to contribute additional memories beyond those already present, emphasizing that collective memory emerges through the accumulation of personal stories rather than iconic sounds alone. For example, P3VO suggested recording memories “in or adjacent to those spaces” during alumni events so they could be “stored in that location,” allowing the archive to grow “continuously, indefinitely.” He also imagined simple access mechanisms such as QR codes linking places to recorded memories.

**Temporal layering of space:** Participants emphasized that collective memory systems should preserve how spaces evolve over time. P3VO described wanting to “move through time in the model,” combining changing spatial scans with memories from different eras. P3AV similarly noted that while some sounds remain stable, others evolve gradually through recurring events and practices. Seasonal and annual rescanning, paired with a temporal slider, was repeatedly proposed by multiple participants as a way to situate memory within a living, changing space.

**Centering people as the source of meaning:** Participants consistently framed people—not architecture or equipment—as the

source of meaning. They envisioned sonic memory systems as alternatives to object-centered archives, foregrounding lived histories and social relationships. P4AV noted that the lab “should really be more about the people and less about the equipment,” while P3VO emphasized connecting documentation with “the stories and the memories and the people” to cultivate solidarity and shared experience.

## 6 Discussion

Here, we revisit each research question examining how the introduction of spatially anchored sound within a navigable visual reconstruction of place shapes memory evocation, place attachment, and social connection when revisiting a shared environment virtually. For each, we situate our findings in relation to existing literature and articulate the open questions and future directions that emerge from this work.

### 6.1 Influence on Memory Evocation

Our findings suggest that adding spatially anchored sound to a navigable visual reconstruction of place shapes how autobiographical memories are evoked when revisiting a shared environment. Note that our findings reflect not a comparison between auditory and visual memory, but rather how sound, when integrated with visual representation, modulates the experience of remembering by enriching affective engagement, sensory detail, and perceived connection.

In both conditions, participants were able to recognize locations and orient themselves within the building; however, the visual-only condition was often experienced as incomplete. Participants anticipated or mentally supplied sounds tied to specific locations, suggesting that silence in reconstructed environments is not neutral and that sound contributes to an experientially coherent sense of place.

In the presence of the visual model, participants recalled spatially and temporally situated memories, such as early phases of participants’ time at the lab, consistent with models of autobiographical memory in which visual imagery scaffolds episodic recall [13, 49]. Notably, memories recalled in the visual-only condition were predominantly positive, even when participants explicitly acknowledged that their experiences in the space had not been uniformly happy.

In contrast, the addition of spatially anchored sound elicited affective and embodied responses, such as the machine shop sounds prompting P3AV to feel a bodily sense of urgency to work, without recalling a specific episode. This aligns with prior work showing that auditory processing prioritizes affective salience and experiential continuity, and that familiar everyday sounds can serve as potent memory triggers [12, 46, 52].

Beyond these immediate affective and bodily responses, the audiovisual condition also gave rise to affectively charged memories described as emerging involuntarily [6]. In a particularly moving case, echoes and footsteps at the building entrance reactivated a dormant memory of a close friend who had passed away, experienced not as a discrete episode but as temporally diffuse—“ignited” by the sound and lingering for weeks afterward.

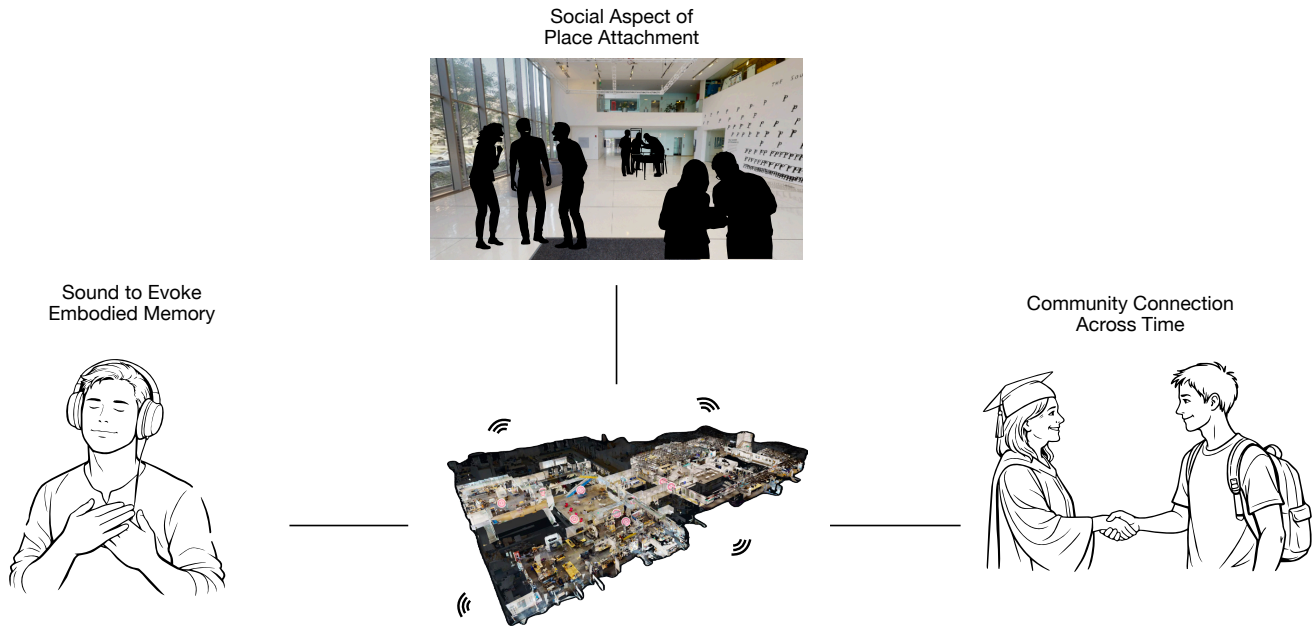
Taken together, these findings suggest that audiovisually reconstructed environments may function as a liminal space for reminiscence—neither a simple representation of the past nor a purely internal act of remembering. Instead, they constitute an intermediate experiential setting in which spatial structure supports orientation and recognition, while sound reintroduces affective, embodied, and temporally diffuse dimensions of memory, consistent with phenomenological and architectural accounts of sound as central to dwelling and atmosphere.

**Open Questions and Future Directions** Several considerations follow from these findings. First, the affective potency of sonic recall emerged within a tightly coupled audiovisual reconstruction, where sounds were explicitly anchored to locations participants had previously inhabited. This raises questions about the role of correspondence between sound and spatial context: to what extent do such effects depend on a faithful spatial anchor, and how might memory evocation differ if sounds were presented without a visual scaffold or intentionally misaligned with space? Second, revisiting reconstructed environments may itself shape memory over time. While repeated engagement with sonic cues may reinforce certain recollections, it may also transform or attenuate others, consistent with constructive accounts of autobiographical memory. Longitudinal work would be needed to examine how repeated audiovisual re-experience influences memory stability, salience, and affect. Finally, these effects were observed in a screen-based virtual environment with limited bodily immersion. That participants nonetheless reported strong somatic and emotional responses suggests that spatially anchored sound carries substantial experiential weight even under constrained conditions, while inviting further examination of how increased bodily engagement—through immersive virtual reality, spatial audio, or hybrid physical–virtual installations—might alter memory evocation.

### 6.2 Influence on Place Attachment

Interestingly, although this study set out to examine attachment to place, participants’ accounts indicated that attachment was primarily oriented toward people and shared emotional experiences rather than the physical environment alone. Our findings suggest a shift away from attachment to the place as such toward attachment to the people and relationships enacted there, with the space serving primarily as a setting that grounded those interpersonal bonds. Being in the reconstructed space frequently prompted references to specific colleagues and friends, including individuals with whom participants no longer interacted regularly and whom they missed. Sound played a central role in reactivating these attachments. Participants described how everyday and atmospheric sounds triggered memories of specific people, how hearing voices—both narratives and background conversations—evoked memories of shared social activities, and how imagined sounds associated with particular locations surfaced, such as P6VO imagining her best friend’s voice near the ping-pong table. Across these cases, sound appeared to carry traces of social presence and co-experience that were not visually specified, allowing interpersonal memories to be re-anchored within the space.

**Open Questions and Future Directions** Several considerations follow from these findings. First, the prominence of relational



**Figure 9: Open questions and future directions for designing sound in virtual spaces for shared memory and community connection.**

attachment raises questions about community specificity. To what extent is this pattern shaped by the characteristics of this community—highly creative, tightly knit, and organized around intense collaboration—and how might place attachment manifest differently in communities with more routine, hierarchical, or transient social ties? Second, the role of sound in mediating relational attachment invites further investigation into agency and authorship. How might place attachment evolve if participants could contribute new sonic memories over time, layer multiple voices within the same location, or navigate different temporal strata of a space’s social history? Exploring such dynamics could help clarify how authorship and control shape multisensory experiences of belonging. Finally, it is notable that the reconstructed space was largely empty of people, yet participants nonetheless recalled specific individuals and relationships. This raises questions about how the absence or presence of visual representations of people might shape place attachment. Would introducing visual depictions of others foreground particular individuals and constrain recall, or would the absence of people—as in this study—better support the emergence of participants’ own relational memories? Examining how populated versus unpopulated reconstructions influence attachment may further illuminate the role of imagination and projection in place-based remembering.

### 6.3 Social Connections Across Time

Our findings suggest that spatially anchored sound supported social connection not only with people participants had known while at the lab, but also across time with others who had inhabited the

space before or after them. Participants described a sense of connection grounded in shared experience of place, even in the absence of direct interaction or overlapping presence. This extends prior work showing that soundscapes can support collective meaning and historical continuity by embedding social memory within place [22, 31]. Ordinary, repetitive sounds—such as footsteps, echoes, and ambient activity—played a particularly important role in this process. Participants described these sounds as validating their memories as collective rather than personal, fostering a sense of belonging and continuity through the knowledge that others had heard and remembered the same sonic traces. Consistent with soundscape research emphasizing everyday sounds as carriers of shared meaning [40, 46], these cues supported social connection not through exceptional events, but through the persistence of familiar acoustic patterns over time. Voices also contributed to social connection, including voices of people participants did not know personally. Hearing narratives or background conversations elicited curiosity and interest, prompting participants to imagine others’ experiences and situate themselves within a broader community. This aligns with prior work showing that voices can evoke emotionally grounded forms of social presence even without personal familiarity [5], as well as HCI work emphasizing sound’s role in supporting affective presence across distance and time [44]. Rather than connecting people through direct interaction, sound supported social connection through the space itself, sustaining a sense of collective presence across non-overlapping cohorts. In this way, Sonic Portal echoes emerging notions of TeleAbsence, in which absent people and past moments remain experientially present through mediated traces embedded in shared environments [24].

**Open Questions and Future Directions** One question that emerges concerns the role of voice in supporting social connection. What makes certain voices resonate? Are there vocal qualities—such as affect, pacing, or expressive intensity—that function as recognizable social signatures within a community, and how might such qualities be identified, preserved, or potentially synthesized without reducing individuality? Second, while participants described a sense of connection with others across non-overlapping time periods, it remains unclear how such connections unfold and persist beyond the immediate experience. How long do these feelings of social connection endure, and how might they shape participants' sense of belonging to a community they no longer physically inhabit? More broadly, what methods are appropriate for capturing social connection mediated by place and sound, particularly when connection is enacted across time rather than through direct interaction? Finally, participants also framed Sonic Portal as a medium for connecting not only with past members of the community, but with future ones. Several suggested that such experiences could help prepare newcomers by conveying shared values, hopes, or ways of being, rather than preserving memories alone. This raises questions about how sonic traces might support future-oriented forms of social connection—extending beyond remembrance toward projection, transmission, and anticipation within evolving communities.

#### 6.4 Design Implications for Multisensory Environments

Our findings show that spatially anchored sound functioned not as a supplementary cue, but as a primary medium through which the reconstructed space was experienced, shaping how participants remembered and related to it. Compared with the visual-only condition, the audiovisual condition was associated with greater vividness and sensory detail, while qualitative accounts showed that sound made the environment feel inhabited, elicited embodied and affectively charged memories, and strengthened connections to people and shared histories. Building on these findings, we outline implications for multisensory virtual environments and interactive systems situated in physical spaces.

**Treat sound as integral to spatial experience, not as a supplementary layer.** Sound contributed to the perceived completeness and coherence of the environment: in its absence, participants often reported that the space felt partial or required imagined auditory cues. Designing sound as an integral component of spatial experience can support a stronger sense of presence and inhabitation.

**Spatially anchor sound to support autobiographical memory.** Sounds tied to specific locations elicited richer, more vivid, and more embodied recall than visual reconstruction alone. Aligning sound with spatial context can therefore support autobiographical memory and reinforce a coherent sense of place.

**Use sound to support people-centered attachment.** Participants' attachments were often oriented toward people and shared experiences rather than the environment in isolation. Voices, ambient activity, and recurring sonic traces can help re-anchor interpersonal memories within place and support emotionally grounded forms of attachment.

**Design sound for social connection across time.** Sound supported a sense of connection not only to known individuals but also to others across non-overlapping cohorts. Incorporating human traces through sound—such as conversations or ambient activity—can foster a sense of collective presence beyond direct interaction.

**Work with everyday sonic details as meaningful design material.** The most consequential cues were often subtle, everyday sounds—footsteps, echoes, conversations—rather than exceptional events. Treating these details as meaningful design material can support memory, continuity, and a sense of lived experience.

**Support accumulation and re-encounter of sonic traces over time.** Participants imagined systems that could grow through layered contributions and evolving sonic traces. Interactive systems can support this by enabling the capture, reintroduction, and re-contextualization of sound over time, in both virtual environments and physical settings.

#### 6.5 Limitations

This study was conducted within a community marked by unusually strong interpersonal ties and enduring attachment to place. The intensity of memory, attachment, and social connection observed here may therefore not generalize to more transient or weakly bonded settings. At the same time, this context offers a useful case for examining how sound mediates these phenomena where they are especially pronounced. Second, Sonic Portal combined ambient sound with spoken narratives, making it difficult to disentangle their respective contributions. Interview accounts suggest that ambient sound was more closely tied to presence and immersion, while narratives supported reflection and contextualization, but these distinctions remain qualitative. Finally, the authors maintain differing relationships to the studied environment, including variation in duration of involvement and temporal distance from the lab. While this provided multiple interpretive perspectives, it may also have shaped the analysis. We therefore ground our interpretations as closely as possible in participants' reported experiences.

#### 7 Conclusion

This paper examined how adding spatially anchored sound to a navigable visual reconstruction of place shapes memory evocation, place attachment, and social connection when revisiting a shared environment. Through Sonic Portal, we compared a visual-only reconstruction of a familiar space with an audiovisually grounded re-experience, combining participatory sound curation with controlled comparison and a detailed phenomenological examination of the experience.

Across our findings, sound consistently shifted how participants related to the reconstructed space. Rather than simply enhancing recall, spatially anchored sound altered the mode of remembering—eliciting affective, embodied, and often temporally diffuse memories that were not always tied to discrete episodes. Sound also reshaped place attachment, which, in this community, was oriented less toward the physical environment itself than toward the people and relationships enacted there, with the space serving as a grounding structure for interpersonal bonds. Finally, sound supported social connection across time by sustaining a sense of

collective presence, allowing participants to feel connected not only to people they had known, but also to others who had inhabited the space at different moments.

These findings suggest that audiovisually reconstructed environments can function not merely as representations of past places, but as experiential settings in which memory, attachment, and social connection are actively mediated, even across time. Sound, in particular, emerged as a connective medium that binds experience to place and supports forms of social connection beyond immediate co-presence. Crucially, the most powerful sonic binders were not exceptional events, but subtle, everyday noises and acoustic details that are often taken for granted. That such details could elicit embodied re-experiences and surface emotionally charged memories—even within a constrained, screen-based setting, and in ways that lingered beyond the study session—speaks to their experiential significance. This work also situates Sonic Portal within a broader trajectory connecting HCI with architectural acoustics and soundscape research. Our findings demonstrate that sound is experienced differently across people and contexts, and that these differences matter in design. The participatory approach in Sonic Portal suggests one way of engaging occupants in shaping acoustic environments by centering lived experience—an approach that may inform not only the design of digital systems but also how physical spaces are conceived and evaluated, alongside technical acoustic measures. We hope this work encourages closer attention to sensory design of our lived spaces.

## Acknowledgments

Generative AI tools were used in a supportive capacity for brainstorming, synthesizing and editing text, and assisting with the organization and interpretation of data analyses.

We sincerely thank all participants for their time and for sharing their memories and reflections, without which this work would not have been possible. We are especially grateful to the MIT Media Lab for their support throughout the study and for providing access to the Matterport 3D scan of the lab. We also thank the Tangible Media Group for their support, and the Media Lab community for their generosity in sharing their time and participating in this project in various ways. We also thank Virginia Polytechnic Institute and State University for their support. Lastly, we remember Steve Keating, whose presence lives on in the memories shared by the community.

## References

- [1] Alaa Algargoosh. 2024. The link between the acoustic characteristics of worship spaces and their emotional impact. *The Journal of the Acoustical Society of America* 155, 5 (May 2024), 3027–3036. doi:10.1121/10.0025923
- [2] Alaa Algargoosh, Babak Soleimani, Sile O'Modhrain, and Mojtava Navvab. 2022. The impact of the acoustic environment on human emotion and experience: A case study of worship spaces. *Building Acoustics* 29, 1 (March 2022), 85–106. doi:10.1177/1351010X211068850
- [3] Gaston Bachelard. 1994. *The Poetics of Space*. Beacon Press. Google-Books-ID: BxNldGr\_FOWC.
- [4] Amy M. Belfi, Brett Karlan, and Daniel Tranel. 2016. Music evokes vivid autobiographical memories. *Memory* 24, 7 (Aug. 2016), 979–989. doi:10.1080/09658211.2015.1061012
- [5] Pascal Belin, Shirley Fecteau, and Catherine Bédard. 2004. Thinking the voice: neural correlates of voice perception. *Trends in Cognitive Sciences* 8, 3 (March 2004), 129–135. doi:10.1016/j.tics.2004.01.008
- [6] Dorthe Berntsen. 1996. Involuntary Autobiographical Memories. *Applied Cognitive Psychology* 10, 5 (1996), 435–454. doi:10.1002/(SICI)1099-0720(199610)10:5<435::AID-ACP408>3.0.CO;2-L \_eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/%28SICI%291099-0720%28199610%2910%3A5%3C435%3A%3AAID-ACP408%3E3.0.CO%3B2-L.
- [7] Inci Boyacioglu and Serap Akfirat. 2015. Development and psychometric properties of a new measure for memory phenomenology: The Autobiographical Memory Characteristics Questionnaire. *Memory* 23, 7 (Oct. 2015), 1070–1092. doi:10.1080/09658211.2014.953960 \_eprint: https://doi.org/10.1080/09658211.2014.953960.
- [8] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (Jan. 2006), 77–101. doi:10.1191/1478088706qp0630a \_eprint: https://www.tandfonline.com/doi/pdf/10.1191/1478088706qp0630a.
- [9] Virginia Braun and Victoria Clarke. 2019. Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health* 11, 4 (Aug. 2019), 589–597. doi:10.1080/2159676X.2019.1628806 \_eprint: https://doi.org/10.1080/2159676X.2019.1628806.
- [10] Baptiste Caramiaux, Alessandro Altavilla, Scott G. Pobiner, and Atau Tanaka. 2015. Form Follows Sound: Designing Interactions from Sonic Memories. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 3943–3952. doi:10.1145/2702123.2702515
- [11] Kai Chen, Jian Kang, and Hui Ma. 2025. Perceived attachment to indoor acoustic environments in high-rise residential buildings: Quantization, prediction, and population-based comparison. *Building and Environment* 276 (May 2025), 112914. doi:10.1016/j.buildenv.2025.112914
- [12] Giulia Concina, Annamaria Renna, Anna Grosso, and Benedetto Sacchetti. 2019. The auditory cortex and the emotional valence of sounds. *Neuroscience & Biobehavioral Reviews* 98 (March 2019), 256–264. doi:10.1016/j.neubiorev.2019.01.018
- [13] Martin Conway and Christopher Pleydell-Pearce. 2000. The Construction of Autobiographical Memories in the Self-Memory System. *Psychological review* 107 (May 2000), 261–88. doi:10.1037//0033-295X.107.2.261
- [14] Juliet Corbin and Anselm Strauss. 2008. *Basics of qualitative research: Techniques and procedures for developing grounded theory, 3rd ed.* Sage Publications, Inc, Thousand Oaks, CA, US. doi:10.4135/9781452230153 Pages: xv, 379.
- [15] Lina Dib, Daniela Petrelli, and Steve Whittaker. 2010. Sonic souvenirs: exploring the paradoxes of recorded sound for family remembering. In *Proceedings of the 2010 ACM conference on Computer supported cooperative work (CSCW '10)*. Association for Computing Machinery, New York, NY, USA, 391–400. doi:10.1145/1718918.1718985
- [16] Zihan Ding and Francesco Aletta. 2024. Acoustical Traditions and Cultural Identity: Exploring Kunqu's Contribution to Collective Memory. *Acoustics* 6, 4 (Dec. 2024), 1115–1139. doi:10.3390/acoustics6040061
- [17] Leonard Faul and Felipe De Brigard. 2022. The moderating effects of nostalgia on mood and optimism during the COVID-19 pandemic. *Memory* 30, 9 (Oct. 2022), 1103–1117. doi:10.1080/09658211.2022.2082481 \_eprint: https://doi.org/10.1080/09658211.2022.2082481.
- [18] Karmen Franinovic and Stefania Serafin. 2013. *Sonic Interaction Design*. MIT Press. Google-Books-ID: 54\_uDvxQe94C.
- [19] Tom Gayler, Corina Sas, and Vaiva Kalnikaite. 2020. Co-Designing Flavor-Based Memory Cues with Older Adults. In *Companion Publication of the 2020 International Conference on Multimodal Interaction*. ACM, Virtual Event Netherlands, 287–291. doi:10.1145/3395035.3425644
- [20] Rachel S. Herz. 2004. A naturalistic analysis of autobiographical memories triggered by olfactory visual and auditory stimuli. *Chemical Senses* 29, 3 (March 2004), 217–224. doi:10.1093/chemse/bjh025
- [21] Maarten Houben, Rens Brankaert, Saskia Bakker, Gail Kenning, Inge Bongers, and Berry Eggen. 2019. Foregrounding Everyday Sounds in Dementia. In *Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19)*. Association for Computing Machinery, New York, NY, USA, 71–83. doi:10.1145/3322276.3322287
- [22] Yiming Hu, Qi Meng, Mengmeng Li, and Da Yang. 2024. Enhancing authenticity in historic districts via soundscape design. *Heritage Science* 12, 1 (Nov. 2024), 396. doi:10.1186/s40494-024-01515-8
- [23] David M. Hummon. 1992. Community Attachment. In *Place Attachment*, Irwin Altman and Setha M. Low (Eds.). Springer US, Boston, MA, 253–278. doi:10.1007/978-1-4684-8753-4\_12
- [24] Hiroshi Ishii, Daniel Pillis, Pat Pataranutaporn, Xiao Xiao, Hayoun Noh, Lucy Li, Alaa Algargoosh, and Jean-Baptiste Labrune. 2025. TeleAbsence: A Vision of Past and Afterlife Telepresence. *PRESENCE: Virtual and Augmented Reality* 34 (March 2025), 65–95. doi:10.1162/PRES\_a\_00441
- [25] Kelly Jakubowski and Anita Ghosh. 2021. Music-evoked autobiographical memories in everyday life. *Psychology of Music* 49, 3 (May 2021), 649–666. doi:10.1177/0305735619888803
- [26] Petr Janata. 2009. The Neural Architecture of Music-Evoked Autobiographical Memories. *Cerebral Cortex* 19, 11 (Nov. 2009), 2579–2594. doi:10.1093/cercor/bhp008
- [27] Petr Janata, Stefan T. Tomic, and Sonja K. Rakowski. 2007. Characterisation of music-evoked autobiographical memories. *Memory* 15, 8 (Nov. 2007), 845–860. doi:10.1080/09658210701734593

- [28] Keisha Jayaratne. 2016. The Memory Tree: Using Sound to Support Reminiscence. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16)*. Association for Computing Machinery, New York, NY, USA, 116–121. doi:10.1145/2851581.2890384
- [29] Stine S. Johansen, Niels van Berkel, and Jonas Fritsch. 2022. Characterising Soundscape Research in Human-Computer Interaction. In *Proceedings of the 2022 ACM Designing Interactive Systems Conference (DIS '22)*. Association for Computing Machinery, New York, NY, USA, 1394–1417. doi:10.1145/3532106.3533458
- [30] Patrik N. Juslin. 2010. *Handbook of Music and Emotion: Theory, Research, Applications* (1 ed.). Oxford University Press/Oxford. doi:10.1093/acprof:oso/9780199230143.001.0001
- [31] Helmi Järviuoma and Lesley Murray. 2023. *Sensory Transformations: Environments, Technologies, Sensobiographies*. Taylor & Francis. Google-Books-ID: kResEAAAQBAJ.
- [32] Jian Kang, Xiang Fang, Francesco Aletta, Andrew Mitchell, Tin Oberman, Gunnar Cerwén, Xiaochao Chen, Jieling Xiao, and Prateek Mittal. 2025. Soundscape Practice And Interventions: A Framework. In *Proceedings of the 11th Convention of the European Acoustics Association Forum Acusticum / EuroNoise 2025*. European Acoustics Association, Málaga, Spain, 4699–4705. doi:10.61782/fa.2025.0802
- [33] Jian Kang and Brigitte Schulte-Fortkamp (Eds.). 2018. *Soundscape and the Built Environment*. CRC Press, Boca Raton. doi:10.1201/b19145
- [34] Judy Kendall. 1999. Axial Coding and the Grounded Theory Controversy. *Western Journal of Nursing Research* 21, 6 (Dec. 1999), 743–757. doi:10.1177/019394599902100603
- [35] Igor Knez, Louise Ljunglöf, Artin Arshamian, and Johan Willander. 2017. Self-grounding visual, auditory and olfactory autobiographical memories. *Consciousness and Cognition* 52 (July 2017), 1–8. doi:10.1016/j.concog.2017.04.008
- [36] Hatice Kurukose Cal, Francesco Aletta, and Jian Kang. 2025. Exploring the factors influencing school soundscapes: Insights from teachers and acoustic experts. *Indoor and Built Environment* (Oct. 2025), 1420326X251383003. doi:10.1177/1420326X251383003
- [37] Joonwoo Kwon, Heehwan Wang, Jinwoo Lee, Sooyoung Kim, Shinjae Yoo, Yuewei Lin, and Jiook Cha. 2025. Revisiting Your Memory: Reconstruction of Affect-Contextualized Memory via EEG-guided Audiovisual Generation. In *Proceedings of the 1st International Workshop on Cognition-oriented Multimodal Affective and Empathetic Computing*. ACM, Dublin Ireland, 1–10. doi:10.1145/3746277.3760413
- [38] Debra Mashke, Lisa W. Cannaday, and June P. Tangney. 2007. Inclusion of community in self scale: A single-item pictorial measure of community connectedness. *Journal of Community Psychology* 35, 2 (2007), 257–275. doi:10.1002/jcop.20146\_eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/jcop.20146
- [39] David W. McMillan and David M. Chavis. 1986. Sense of community: A definition and theory. *Journal of Community Psychology* 14, 1 (Jan. 1986), 6–23. doi:10.1002/1520-6629(198601)14:1<6::AID-JCOP2290140103>3.0.CO;2-I
- [40] Gerard Oleksik and Lorna M. Brown. 2008. Sonic Gems: Exploring the Potential of Audio Recording as a Form of Sentimental Memory Capture. BCS Learning & Development. doi:10.14236/ewic/HCI2008.16
- [41] Juhani Pallasmaa. 2005. *The Eyes of the Skin: Architecture and the Senses*. Academy Press.
- [42] Daniela Petrelli, Nicolas Villar, Vaiva Kalnikaitė, Lina Dib, and Steve Whittaker. 2010. FM radio: family interplay with sonic mementos. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. Association for Computing Machinery, New York, NY, USA, 2371–2380. doi:10.1145/1753326.1753683
- [43] Daniela Petrelli, Steve Whittaker, and Jens Brockmeier. 2008. AutoTopography: what can physical mementos tell us about digital memories?. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08)*. Association for Computing Machinery, New York, NY, USA, 53–62. doi:10.1145/1357054.1357065
- [44] Samann Pinder, William Odom, MinYoung Yoo, Ayush Misra, Henry Lin, Carman Neustaedter, and Samuel Barnett. 2025. Queue Player: Investigating Distributed Co-Listening Experiences for Social Connection across Space, Time, and Tempo. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, 1–24. doi:10.1145/3706598.3714293
- [45] B. Plakke and L.M. Romanski. 2016. Neural circuits in Auditory and Audiovisual Memory. *Brain research* 1640, Pt B (June 2016), 278–288. doi:10.1016/j.brainres.2015.11.042
- [46] David B Ramsay, Ishwarya Ananthabhotla, and Joseph A Paradiso. 2019. The Intrinsic Memorability of Everyday Sounds. York, United Kingdom.
- [47] Sarah Robinson. 2011. *Nesting: Body, Dwelling, Mind*. William Stout Publishers. Google-Books-ID: H7SJZwEACAAJ.
- [48] Clay Routledge, Jamie Arndt, Constantine Sedikides, and Tim Wildschut. 2008. A blast from the past: The terror management function of nostalgia. *Journal of Experimental Social Psychology* 44, 1 (Jan. 2008), 132–140. doi:10.1016/j.jesp.2006.11.001
- [49] David C. Rubin. 2006. The Basic-Systems Model of Episodic Memory. *Perspectives on Psychological Science* 1, 4 (Dec. 2006), 277–311. doi:10.1111/j.1745-6916.2006.00017.x
- [50] Margaret Sandelowski. 1995. Qualitative analysis: What it is and how to begin. *Research in Nursing & Health* 18, 4 (1995), 371–375. doi:10.1002/nur.4770180411\_eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/nur.4770180411
- [51] Marta Shilova, Hui-Ting Hong, Chu-Yin Chen, and Ray-Kuang Lee. 2025. A Sensory Experience Through the Entanglement of Dynamic Virtual Memories. In *Companion of the 2025 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, Espoo Finland, 1243–1247. doi:10.1145/3714394.3756248
- [52] Alexander A. Sulpharo, Amanda K. Robinson, and Thomas A. Carlson. 2024. Properties of imagined experience across visual, auditory, and other sensory modalities. *Consciousness and Cognition* 117 (Jan. 2024), 103598. doi:10.1016/j.concog.2023.103598
- [53] Angelina R. Sutin and Richard W. Robins. 2007. Phenomenology of autobiographical memories: The Memory Experiences Questionnaire. *Memory* 15, 4 (May 2007), 390–411. doi:10.1080/09658210701256654\_eprint: https://doi.org/10.1080/09658210701256654
- [54] Rupert Till. 2019. Sound Archaeology: A Study of the Acoustics of Three World Heritage Sites, Spanish Prehistoric Painted Caves, Stonehenge, and Paphos Theatre. *Acoustics* 1, 3 (Aug. 2019), 661–692. doi:10.3390/acoustics1030039
- [55] Simone Torresin, Rossano Albatici, Francesco Aletta, Francesco Babich, Tin Oberman, Agnieszka Elzbieta Stawinoga, and Jian Kang. 2021. Indoor soundscapes at home during the COVID-19 lockdown in London – Part I: Associations between the perception of the acoustic environment, occupant activity and well-being. *Applied Acoustics* 183 (Dec. 2021), 108305. doi:10.1016/j.apacoust.2021.108305
- [56] Dylan Trigg. 2020. The role of atmosphere in shared emotion. *Emotion, Space and Society* 35 (May 2020), 100658. doi:10.1016/j.emospa.2020.100658
- [57] Jolanda Tromp, Damian Schofield, Pezhman Raeisian Parvari, Matthieu Poyade, Claire Eaglesham, Juan Carlos Torres, Theodore Johnson, Teele Jürivete, Nathan Lauer, Arcadio Reyes-Lecuona, Daniel González-Toledo, María Cuevas-Rodríguez, and Luis Molina-Tanco. 2025. Designing and Evaluating XR Cultural Heritage Applications Through Human-Computer Interaction Methods: Insights from Ten International Case Studies. *Applied Sciences* 15, 14 (Jan. 2025), 7973. doi:10.3390/app15147973
- [58] Daniel Västfjäll, Pontus Larsson, and Mendel Kleiner. 2002. Emotion and Auditory Virtual Environments: Affect-Based Judgments of Music Reproduced with Virtual Reverberation Times. *CyberPsychology & Behavior* 5, 1 (Feb. 2002), 19–32. doi:10.1089/109493102753685854
- [59] Johan Willander, Sverker Sikström, and Kristina Karlsson. 2015. Multimodal retrieval of autobiographical memories: sensory information contributes differently to the recollection of events. *Frontiers in Psychology* 6 (Nov. 2015). doi:10.3389/fpsyg.2015.01681
- [60] Daniel R. Williams and Jerry J. Vaske. 2003. The Measurement of Place Attachment: Validity and Generalizability of a Psychometric Approach. *Forest Science* 49, 6 (Dec. 2003), 830–840. doi:10.1093/forestscience/49.6.830
- [61] Xiao Xiao, Hayoun Noh, Adrien Lefevre, Lucy Li, Holly McKee, Alaa Algaroosh, and Hiroshi Ishii. 2025. ReMirrorFugue: Examining the Emotional Experience of Presence and (Illusory) Communications Across Time. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama Japan, 1–26. doi:10.1145/3706598.3713328
- [62] MinYoung Yoo, William Odom, Arne Berger, Samuel Barnett, Sadbhbh Kenny, Priscilla Lo, Samein Shamsher, Gillian Russell, and Lauren Knight. 2024. Remembering through Sound: Co-creating Sound-based Mementos together with People with Blindness. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems (CHI '24)*. Association for Computing Machinery, New York, NY, USA, 1–19. doi:10.1145/3613904.3641940
- [63] Zhongyue Zhang, Lina Xu, Xingkai Wang, Xu Zhang, and Mingming Fan. 2025. Understanding and Co-designing Photo-based Reminiscence with Older Adults. *Proc. ACM Hum.-Comput. Interact.* 9, 2 (2025), CSCW196:1–CSCW196:30. doi:10.1145/3711094

## 8 Appendix

### 8.1 Sonic Memory Co-Creation Workshop – Questions Guide

This question guide was intended as a reference rather than a fixed script; interviews were semi-structured, with questions adapted to salient participant responses.

#### *Part 1 – Recalling without the map.*

- When you think of the Lab, what kinds of sounds come to mind? Why those?
- What kind of emotions do those sounds trigger for you?
- Do you associate any specific people with specific sounds? (e.g., someone’s laugh, the way someone walked or typed, your PI’s voice)
- Is there a moment or situation when one of those sounds came back to you – outside the lab? If so, when, and what was the experience like?
- If you had to choose one sound that symbolizes the lab for you, what would it be?
- Are there any sounds you still hear? Are there any sounds you miss?
- Were there sounds that felt iconic or reflective of what was happening at the time?
- Was there a space that felt most like “home” to you at the lab? If so, what did it sound like there?
- Is there a sound you think your lab friends would instantly recognize or think of when they remember the lab?
- Embodied sensory experience (before the map)

#### *Part 2 – Recalling with the map.*

- As you look at this floor/room/space, do any sound-related memories come to mind?
- Is there a sound you would want to hear when entering this space?
- Is there a space on the map that evokes a strong emotional or sonic memory?
- How clearly do you remember what it sounded like to walk through or work in this particular space?
- Did certain rooms have a distinctive acoustic quality, like echoes, muffled voices, or reverberations?
- Was there a space where you had meaningful conversations or collaborations that you can still “hear” in your mind?
- Can you recall what the lab sounded like during major events when you revisit these spaces visually?
- Now that you’re seeing the space again, are any new sound memories coming back to you?

#### *Part 3 – Reflections.*

- How did it feel to recall your lab memories without the map? And how did that differ from your experience with the map? Was one approach more emotional, nostalgic, or vivid than the other?
- How did it feel to recall your lab memories through the perspective of sound?
- How has revisiting these memories through sound affected the way you remember the lab?
- As you were recalling, or even now afterward, what kinds of thoughts or feelings came up? (e.g., wanting to reach out to someone, missing those times, reflecting on who you were then, reflecting on past events)
- What was it like to go through this memory-sharing process together with others who were also part of the lab?
- Did hearing other people’s stories or sound memories spark any of your own, or make you remember something you had forgotten?

### 8.2 Questionnaire for the Controlled Experimental Study

Section	Survey Questions / Response Options
Demographics data and Lab affiliation information	Age range: 18-30, 31-40, 41-50, 51-60, 61-70, 71-80 Gender: Lab affiliation (ex. Student, faculty, staff, alum, etc.): Lab research group: Time period at the Lab (ex. 2015- 2020):
Current Engagement with the Lab	How often do you currently engage with the lab? • None • Once a year • Twice a year • Three times a year • Four times a year or more In what ways are you currently engaged with the lab? (ex., Research collaborations, events, etc.)

Virtual Interactive Experience	The following links will take you into the virtual environment of the lab. Each link will take you to a different floor. Click on each and follow the numbers that show you the path. After you complete the path, feel free to walk around if you choose, then return to the survey to complete it.
Memory Recall	If this experience evoked a specific memory, tell us about it. If you have more than one memory, select one, and tell us why you selected it.
Memory Experiences Questionnaire (MEQ)	<p>Select the answer that best describes the evoked memory in each category</p> <p><b>Vividness</b></p> <ul style="list-style-type: none"> <li>• My memory for this event is very vivid.</li> <li>• My memory for this event is very detailed.</li> <li>• My memory for this event is dim.</li> </ul> <p><b>Accessibility</b></p> <ul style="list-style-type: none"> <li>• This memory was easy for me to recall.</li> <li>• It was difficult for me to think of this memory.</li> <li>• I had to think for a while before I could recall this event.</li> </ul> <p><b>Coherence</b></p> <ul style="list-style-type: none"> <li>• The order of events in the memory is clear.</li> <li>• This memory is of an event that occurred once at a particular time and place, not a summary or merging of many similar or related events.</li> <li>• This memory comes back to me in bits and pieces, not as a logical, coherent story.</li> <li>• This memory is a blending of many similar, related events rather than a specific memory about a particular event.</li> </ul> <p><b>Sensory details</b></p> <ul style="list-style-type: none"> <li>• As I remember the event, I can hear it in my mind.</li> <li>• When I recall this event, I think the same things I thought when the event originally happened.</li> <li>• My memory for this event does not involve a lot of sensory information (sounds, smells, visuals, etc.) .</li> <li>• As I remember the event, I have a difficult time recalling the particular physical reactions and sensations I had during the experience.</li> </ul> <p><b>Visual perspective</b></p> <ul style="list-style-type: none"> <li>• In my memory, I see this experience through my own eyes.</li> <li>• I view this memory as if I was an observer to the experience.</li> <li>• As I remember this event, I feel like an observer watching myself.</li> </ul> <p><b>Emotional Intensity</b></p> <ul style="list-style-type: none"> <li>• My emotions are very intense concerning this event.</li> <li>• The memory of this event evokes powerful emotions.</li> <li>• This memory does not evoke strong emotions in me.</li> </ul> <p><b>Sharing</b></p> <ul style="list-style-type: none"> <li>• I have talked about this event many times.</li> <li>• I frequently think about or talk about this event with others.</li> <li>• I rarely tell others about this memory.</li> </ul> <p><b>Distancing</b></p> <ul style="list-style-type: none"> <li>• I feel like the person in this memory is a different person than who I am today.</li> <li>• When I recall this memory, I think, “that’s not me anymore.”</li> <li>• I feel like I am the same person in the memory as I am today.</li> </ul> <p><b>Valence</b></p> <ul style="list-style-type: none"> <li>• The overall tone of the memory is positive.</li> <li>• The overall tone of the memory is negative.</li> </ul>

Reflections	<p>1. Is this memory something that has always been a part of you, or something you had forgotten and re-ignited after this experience?</p> <p>2. Was there something surprising to you during this experience?</p> <p>3. Has this experience changed the way you think of this memory?</p>
Place Attachment	<p>Please indicate how strongly you agree or disagree with each statement by selecting a number from 1 (Strongly Disagree) to 5 (Strongly Agree).</p> <p>1. The lab place is very special to me</p> <p>2. The lab place provides me with a sense of companionship</p> <p>3. I feel connected to the lab place through this experience</p>
Social Connection	<p>Did you consider reaching out to your colleague from your time at the lab? For instance, a text message to your colleague or an email to your PI.</p> <p>Yes/ No/ Not sure</p> <p>Has experiencing this changed how you think of your time at the lab?</p> <p>Yes/ No/ Not sure</p> <p>Has this changed or influenced how you think of people at the lab?</p> <p>Yes/ No/ Not sure</p> <p>Do you think your connection to the lab has increased after this experience? 1 (Not at all) to 5 (Very strongly).</p>
Future Engagement	<p>Would you be interested in joining virtual future lab community events? These informal sessions offer an opportunity to connect with other past, current or future members of the lab, and engage in casual conversations that may lead to ongoing community involvement. Please select the option that best represents your interest in joining these sessions:</p> <p>None/ Once a year/ Twice a year/ Three times a year/ Four times a year</p> <p>Would you be interested in joining virtual one-on-one coffee chats? These informal sessions offer an opportunity to share your experiences with a current or future lab member and engage in casual conversations that may lead to mentorship. Please select the option that best represents your interest in joining these sessions:</p> <p>None/ Once a year/ Twice a year/ Three times a year/ Four times a year</p>
Open-ended	<p>Is there anything else you would like to share with the researchers?</p> <p>If you are interested in a follow-up interview, please provide your email.</p>

**Table 3: Survey questions used in the study**

### 8.3 Interviews – Questions Guide

This interview guide was intended as a reference rather than a fixed script; interviews were semi-structured, with questions adapted to salient participant responses.

#### *Visual Only Group.*

##### *Part 1: reflections on visual experience.*

- What was your overall experience like navigating the lab through the visual map?
- Were there particular areas that felt emotionally significant? Did the experience spark any emotions or memories that surprised you?
- Did the visual experience feel immersive, or more observational?
- Did you feel a desire to share this experience with anyone else, such as fellow alums or people who haven't been to the lab?
- Did the experience make you feel more emotionally connected to the lab community? If so, what played a role in fostering that connection?

##### *Part 2: absence of sound & imagining the presence of sound.*

- Were there any moments or spaces where you found yourself imagining, or where it prompted you to think about, the kinds of sounds that might have been present?
- If any, can you think of a place or moment where hearing a sound, real or imagined, would have made a memory more vivid?
- If you could revisit the experience with sound added, what would you be most curious to hear?
- If sound had been part of the experience, what kinds of sounds do you imagine would have helped you reconnect more deeply?
- How do you think your experience would have changed?

*Part 3: thoughts on audiovisual experience (after showing the audiovisual version).*

- How did your experience change when sound was added to the system?
- Did the addition of sound evoke any new memories or feelings that didn't come up during the visual-only experience? If so, how?
- In what ways did the sound layer affect your sense of presence or connection to the lab?
- Did the sound help you recall specific people, times, or memories more vividly?

*Part 4: broader reflections on sound & memory.*

- What role do you think sound plays in memory and remembering a place or time?
- Has this experience, in any way, changed the way you think about the role of sound? If so, how?
- In your own life, do you associate sound with how you remember certain places or periods?
- Is sound something you've found yourself using to remember other places or periods in your life?
- Outside of the lab, are there moments in your life you wish had been captured in sound (beyond photos or videos)?
- If you could redesign this experience, what would you add? What kind of sounds would feel meaningful to include? (e.g., songs you used to listen to, environmental sound, conversations, etc.)

*Audiovisual Group.**Part 1: reflection on audiovisual experience.*

- Can you recall a moment where a sound brought back something you had forgotten?
- Was there a time when the sound caught you by surprise?
- Were the sounds you heard similar to what you expected or imagined them to be?
- Were there any sounds you had hoped to hear but didn't?

*Part 2: sound vs. visual – experiential reflection.*

- What did the sound help you feel or remember that the visual alone may not have?
- How do you imagine your experience would have been if the system had only visuals and no sound?
- Did the sound make the space feel more alive or immersive to you? If so, how?

*Part 3: relational memory, temporal aspect, people, emotional connection.*

- Were any of the sounds tied to specific people, events, or memories?
- How did those sound cues affect your sense of relational memory (e.g., remembering colleagues, mentors, or shared experiences)?
- Did any of the sounds relate to particular periods or phases of your time at the lab?
- Did you feel a desire to share this experience with anyone else, such as fellow alums or people who haven't been to the lab?
- Did the sound make you feel more emotionally connected to the lab community? If so, how and why?
- (If relevant) Do you think sound played a role in fostering that connection?

*Part 4: Broader reflection on sound & memory.*

- What role do you think sound plays in memory and remembering a place or time?
- Has this experience, in any way, changed the way you think about the role of sound? If so, how?
- In your own life, do you associate sound with how you remember certain places or periods? Is sound something you've found yourself using to remember other places or periods in your life?
- Outside of the lab, are there moments in your life you wish had been captured in sound (beyond photos or videos)?
- If you could redesign this sound-based memory experience, what would you add? (e.g., songs you used to listen to, voice memos, layered personal recordings, more environmental cues)
- How do you think this experience will help new/existing generations at the lab?