

Digitally ‘Living’ Preservation of Endangered Cultural Soundscapes: From Sampling and Spatial Audio Reconstruction to Interactive Narrative Design

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ABSTRACT

Under the dual pressures of global cultural homogenization and intergenerational transmission rupture, endangered cultural soundscapes are disappearing at an unprecedented rate. Living sonic texts—such as ritual songs, oral dialects, and festival acoustics—that carry collective memory and local knowledge face irreversible extinction. Traditional archival recordings preserve sound waveforms but strip away spatial orientation, ambient reverberation, and bodily presence, reducing sound to decontextualized specimens rather than perceivable living samples. This study proposes a digital living-preservation pathway structured as ‘sampling–reconstruction–narration.’ First, an integrated multi-dimensional capture mechanism synchronously records source signals and spatial acoustic impulse responses, yielding soundscape data that preserves both timbral detail and spatial information. Second, object-based spatial audio techniques and sound-field reconstruction methods position discrete sources in three-dimensional space according to their original layouts and simulate reverberation, restoring immersive acoustic fields of endangered soundscapes. Third, an interactive digital narrative framework embeds reconstructed spatial soundscapes into participatory narrative structures, enabling listeners to transform from passive reception to active experience with cultural depth. This study contends that digitalization is not a cold replication of endangered cultural soundscapes, but rather a technologically mediated channel through which these sounds become perceivable, participatory, and sustainable, regaining cultural life in the very act of being heard.

Keywords: Endangered Cultural Eoundscapes; Living Preservation; Spatial Audio Reconstruction; Interactive Narrative Design; Soundscape Digitalization.

1. Introduction

Cultural Soundscapes—living sonic texts such as ritual songs, oral dialects, festival acoustics, and work chants that carry collective memory and local knowledge—are disappearing worldwide at an unprecedented rate. Unlike tangible cultural heritage, the vitality of soundscapes is deeply rooted in specific spatiotemporal fields and bodily practices. The overtone singing in sacrificial ceremonies relies on the spatial reverberation of grasslands, the rhythmic cadence of marketplace cries depends on the acoustic reflections of alleys, and the ringing of ritual instruments is mutually shaped by the reverberant properties of architectural spaces. However, urbanization, intergenerational transmission rupture, and cultural homogenization are systematically eroding the physical spaces and social contexts upon which these sounds depend for survival. In recent years, UNESCO has advanced the digital documentation and re-creation of World Heritage soundscapes, with sounds from 270 heritage sites—from the clamor of the Sistine Chapel to the echoes of the Taj Mahal—incorporated into global soundscape archives. Yet being heard does not equate to being sustained. How to enable endangered soundscapes to be not merely archived as specimens but perceived and perpetuated as living cultural experience has become a core issue urgently demanding resolution in cultural heritage research. Conventional soundscape documentation—whether early analog recording in ethnomusicology or current mainstream stereo acquisition—captures waveform and timbre effectively, yet remains fundamentally limited in two dimensions. First, such methods strip away spatial orientation, ambient reverberation, and bodily presence, reducing sound to flattened audio files detached from their original cultural contexts rather than soundscapes with full perceptual integrity. Studies on Gion Festival music have shown that conventional stereo recordings fail to reproduce the spatial imaging and diffusion of instrumental sounds arriving from the rear and above—precisely the spatial cues that constitute the core ‘liveness’ of the festival soundscape.¹Second, conventional recording confines the listener to passive reception, depriving them of the active exploration, selection, and interpretation integral to the original soundscape experience. As scholars have cautioned, how can technological intervention in soundscape preservation avoid the dilemma of ‘technique without soul’? This question exposes a deeper tension in current digital soundscape practices: while technical means grow increasingly sophisticated, the liveness of cultural soundscapes—their perceivable, participatory, and sustainable cultural vitality—is often silently dissolved in digital translation. Recent digital heritage applications have evolved from mere documentation toward experiential reconstruction. In acquisition, integrated multi-dimensional capture mechanisms are advocated; in reconstruction,

¹KATO S, NAKAYAMA M, NISHIURA T, et al. Sound field reproduction based on mirror image source method using object-based audio for Japanese Gion festival music[J]. The Journal of the Acoustical Society of America, 2025, 158(4_Supplement): A139.

object-based spatial audio and Ambisonics provide technical support for restoring immersive acoustic fields; in dissemination, interactive digital narrative and immersive design are being introduced to public engagement. Yet most studies focus on individual technical links, rarely investigating ‘sampling–reconstruction–narration’ as a systematic whole. Sampling without spatial information undermines reconstruction; reconstruction without narrative guidance fails to elevate listening from sensory stimulation to cultural understanding.

Based on the above, this study proposes a digital living-preservation pathway structured as ‘sampling–reconstruction–narration.’ First, an integrated multi-dimensional capture mechanism synchronously records source signals and spatial acoustic impulse responses, yielding soundscape data that retains both timbral detail and spatial information. Second, object-based spatial audio techniques and sound-field reconstruction methods position discrete sources in three-dimensional space according to their original layouts with simulated reverberation, restoring immersive acoustic fields of endangered soundscapes. Third, an interactive digital narrative framework embeds the reconstructed spatial soundscapes into participatory narrative structures, transforming listeners from passive reception to active experience with cultural depth. This study contends that digitalization is not a cold replication of endangered soundscapes, but a technologically mediated channel through which these sounds become perceivable, participatory, and sustainable, regaining cultural life in the very act of being heard.

2 Conceptual Framework And Theoretical Foundations

2.1 Core Concepts Defined

2.1.1 Cultural Soundscape

The term ‘soundscape’ was formally introduced in the 1970s by Canadian composer and ecologist R. Murray Schafer, defined as ‘an environment of sound that emphasizes the way it is perceived and understood by individuals or societies²’. Schafer classified soundscapes into natural, human-made, and those shaped by temporal memory, and through the World Soundscape Project promoted systematic documentation of environmental sounds. In 2014, the International Organization for Standardization (ISO) formally defined soundscape as ‘the acoustic environment as perceived, experienced, or understood by people in a given context³’. The core value of the soundscape concept lies in liberating sound from isolated physical signals and restoring it as an interplay among listener, sound, and environment. Cultural soundscape is a specific extension of the soundscape concept into the heritage domain, referring to complex acoustic environments shaped by human activities, cultural

² SCHAFER R M. The soundscape: our sonic environment and the tuning of the world[M]. Rochester, Vermont: Destiny Books, 1994.

³ ISO 12913-1:2014, Acoustics — Soundscape — Part 1: Definition and conceptual framework[S]. Geneva: International Organization for Standardization, 2014.

practices, and natural acoustic phenomena—the integral presentation of all sounds in a given area filtered through human culture and perception. Cultural soundscapes encompass not only human sounds such as ritual songs, oral dialects, and work chants, but also the physical spaces and their acoustic properties upon which these sounds depend. From a heritage perspective, cultural soundscapes possess both the liveness of intangible cultural heritage and the spatial grounding of tangible heritage: sound practices are themselves intangible, yet their meanings are deeply embedded in specific sites, architecture, and geographical environments. This dual nature entails that digital preservation of cultural soundscapes must record not merely waveforms, but the acoustic relationships between sounds and their native spatial contexts.

2.1.2 Dynamic Inheritance

Dynamic inheritance refers to the preservation and transmission of intangible cultural heritage within its original generative and developmental contexts, achieved through the ongoing productive and social activities of communities. This model emphasizes sustaining the authentic character of heritage while revitalizing its vitality through innovative practices. UNESCO, in the Convention for the Safeguarding of the Intangible Cultural Heritage, defines such heritage as ‘living heritage,’ highlighting its evolving nature through intergenerational transmission and community interaction⁴. The ‘liveness’ of intangible heritage inheres in its processual character—it is culture in motion, its vitality residing in continuous evolution. Some scholars liken the safeguarding of intangible heritage to sustaining fish in living water, emphasizing that protection targets not the specimen but the living environment upon which it depends. Notably, dynamic inheritance does not preclude digital technology. On the contrary, when original transmission environments have collapsed or are near extinction, digital means may serve as alternative channels for sustaining liveness. The crux lies in whether digitalization produces sound specimens or living samples—the former extracts sounds from cultural contexts as static archives, while the latter reconstructs perceivable, participatory, and sustainable cultural fields in digital space. The digitally enabled living preservation proposed in this study is a methodological inquiry grounded precisely in this distinction.

2.1.3 Spatial Audio Reconstruction

Spatial audio refers to audio designed with three-dimensional quality, enabling precise reconstruction of three-dimensional sound fields through various technical means. By digitally mapping the acoustic properties of the physical world, it creates highly realistic immersive listening experiences. Its core implementation paths can be categorized into three technical systems: channel-based, object-based, and scene-based. Directly relevant to this study are object-based audio and scene-based audio. Object-

⁴ United Nations Educational, Scientific and Cultural Organization. Convention for the Safeguarding of the Intangible Cultural Heritage[S]. Paris: UNESCO, 17 October 2003.

based audio treats each sound source as an independent sonic object, with metadata describing its position, trajectory, and acoustic properties in three-dimensional space—meaning drumbeats, chants, and ambient noise in rituals can be separately recorded, independently positioned, and rearranged according to their native spatial layout upon playback. Scene-based audio, represented by higher-order Ambisonics, employs spherical harmonics for global modeling and reconstruction of the complete sound field. The integration of both paths—object-based audio for flexible positioning of sources and scene-based audio for physical-level restoration of ambient reverberation and spatial diffusion—constitutes the technical foundation for spatial reconstruction of cultural soundscapes.

2.1.4 Interactive Narrative Design

Interactive narrative refers to a mode of storytelling in digital media environments where narrative is no longer unidirectional linear transmission, but enables audiences to transform from passive information recipients to active participants who engage with and drive narrative development through interactive mechanisms. Within the interactive narrative framework, story structures shift from linear ‘beginning-development-resolution’ to radial tree-like or networked architectures, where choices at each narrative node generate personalized story versions. Some scholars conceptualize this as an evolution of digital narrative from ‘post-linear’ to ‘spatial’ and ‘multimodal’ narration. The theoretical rationale for introducing interactive narrative design into the digital preservation of cultural soundscapes is that the liveness of soundscapes inheres not only in spatial acoustic integrity but also in the mode of encounter between listener and soundscape. In native environments, listeners actively explore, select, and perceive soundscapes through bodily presence; in traditional playback, they are confined to fixed passive reception. Interactive narrative design is precisely intended to restore listener agency within digital space through structural design, enabling audiences to discern cultural contexts embedded in soundscapes through exploration and achieve deeper cultural understanding through active choice.

2.2 Theoretical Foundations

The theoretical construction of this study rests upon three interrelated academic domains. The first is soundscape theory and cultural geography. Schafer's soundscape theory establishes the ontological foundation for understanding sound's cultural attributes—sound is not merely a physical signal but a carrier of cultural meaning. Cultural geography further regards soundscapes as integral components of cultural landscapes, recognizing their distinctive value in shaping regional cultural identities, cultivating place-based cognition, and anchoring local perception. This theoretical perspective furnishes two core propositions: the meaning of soundscapes cannot exist independently of their spatial contexts, and the loss of soundscapes signifies not merely the disappearance of sounds but the erosion of sense of place and cultural identity. The second is the liveness theory of intangible cultural

heritage. UNESCO's living heritage framework and cultural anthropology's living-history theory together constitute the philosophical foundation for dynamic inheritance of intangible cultural heritage. This theory reveals that the fundamental goal of safeguarding intangible heritage is not to freeze culture as artifact but to sustain its cultural vitality amid change. This sets the evaluative criterion for this study: the ultimate measure of digitalization is not technical precision but whether it can perpetuate the cultural life of soundscapes in digital space. The third is digital narratology and immersive media theory. Digital narratology examines how medium characteristics reshape narrative structure and experience, while immersive media theory emphasizes the centrality of spatiality, participation, and embodied cognition in digital experience. Together they point to a judgment: digital transmission of soundscapes must not remain at the audible level but must pursue the perceivable, the participatory, and the intelligible. This judgment ultimately channels the technical links of sampling and reconstruction toward the meaning-generating link of narrative, providing theoretical justification for the tripartite 'sampling–reconstruction–narration' pathway (Fig. 1). The intrinsic interconnections among these three concepts and three theories—the spatiality of soundscapes determining the multidimensionality of sampling, the value claim of liveness determining the completeness of reconstruction, and the experiential logic of narrativity determining the necessity of interactivity—collectively constitute the methodological foundation of this study.

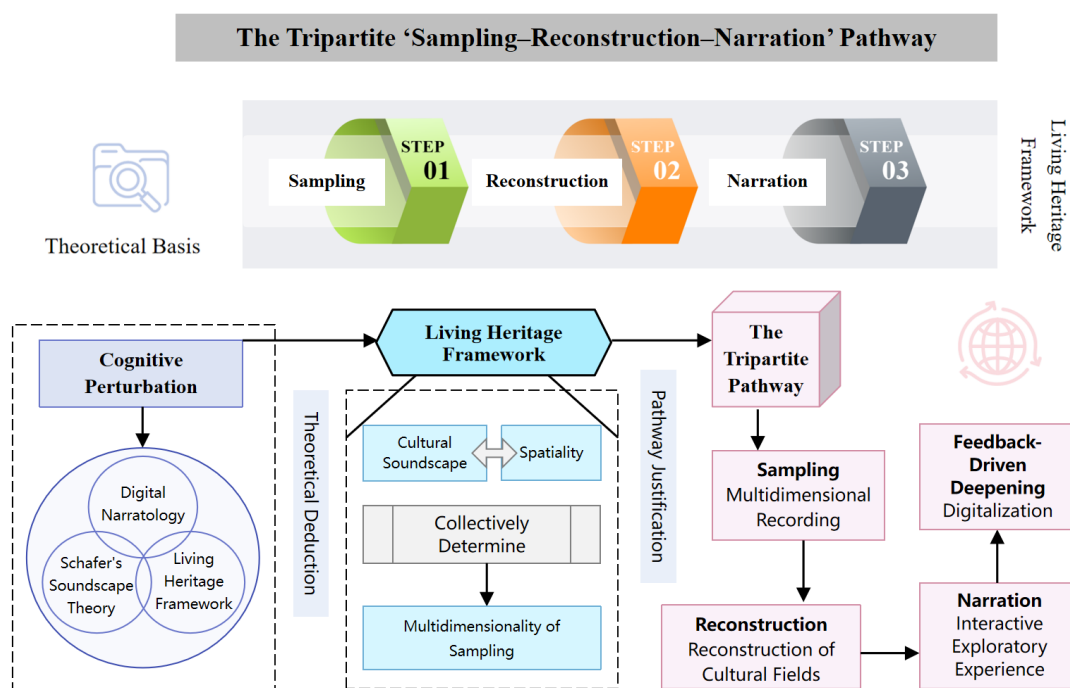


Fig. 1 The Tripartite Pathway of 'Sampling–Reconstruction–Narration'

(Source: Drawn by the author)

3 Technical Pathways For Digital Living Preservation

The digital living preservation of cultural soundscapes centers on restoring sounds from isolated physical signals into perceivable fields embedded in spatial contexts and cultural fabrics. Achieving this goal requires a complete technical chain from data acquisition to meaning generation. This section elaborates the technical solutions and key logics sequentially through the three links of ‘sampling–reconstruction–narration’.

3.1 Multidimensional Sampling: A Spatial-Information-First Acquisition Method

Conventional soundscape recording typically employs single-point stereo pickup as the primary approach, prioritizing timbral clarity and cleanliness at the expense of two critical types of information: the directional distribution of sound sources in native space and the acoustic shaping of sounds by the environment. This reduces recordings to context-stripped sound specimens, allowing listeners to identify what sounds are present but not where they originate or in what space they resonate. A spatial-information-first acquisition scheme requires simultaneous advancement along three dimensions. First, multi-track simultaneous recording of sound source signals. For core sources such as ritual songs, work chants, and festival acoustics, a multi-channel pickup array captures dry signals of each source separately, ensuring that every sonic element retains independent timbral detail and dynamic range for subsequent reconstruction. Second, measurement and recording of spatial impulse responses. Concurrent with or before/after source emission, impulse responses are measured in the target space using swept sine signals or starter pistols, capturing acoustic parameters including reverberation time, early decay time, and frequency response. Third, simultaneous annotation of scene visuals and metadata. Panoramic imaging documents source positions and scene layouts, while metadata such as time, location, cultural event name, and participants are recorded to inform subsequent spatial positioning and cultural interpretation. After synchronized acquisition of the three data streams—source signals, spatial acoustic characteristics, and visual references—a mutually calibratable dataset is formed, providing the data foundation for reconstruction that restores rather than imagines the original.

3.2 Spatial Audio Reconstruction: From Discrete Sources to Immersive Sound Fields

What the acquisition stage yields are multi-track dry signals and spatial impulse responses; the reconstruction stage must integrate the two to rebuild an immersive sound field with perceptible directionality, distance, and spatial envelopment in digital space. The core technical framework is the integration of object-based and scene-based audio. Object-based audio treats each sound source as an independent sonic object—drumbeats, chants, and ambient footsteps in rituals each as separate objects, each carrying metadata describing its spatial position. During reconstruction, these objects are repositioned in the three-dimensional sound field according to their native spatial coordinates, enabling listeners to perceive them distinctly. Scene-based audio, represented typically by higher-

order Ambisonics (Fig. 2), employs spherical harmonics for global modeling of the complete sound field. Integrating measured impulse responses with Ambisonic encoding reconstructs the spatial diffusion characteristics of ambient reverberation—sound not only arrives from a direction but also exhibits how it decays and reflects within that space. The integration logic is that object-based audio enables flexible positioning and independent control of sources, while scene-based audio enables physical-level restoration of environmental acoustics; their yields for listeners an immersive sound field with identifiable sources and credible space. Notably, parameter calibration in reconstruction cannot remain at merely physical accuracy. Discrepancies often exist between objective acoustic measurements and the auditory memory of community members—the former measuring the current acoustic state of the space, the latter carrying soundscape imagery embedded in cultural memory. Validation of reconstruction effects thus requires the introduction of subjective assessments by culture-informed insiders, seeking negotiated balance between physical precision and cultural authenticity.

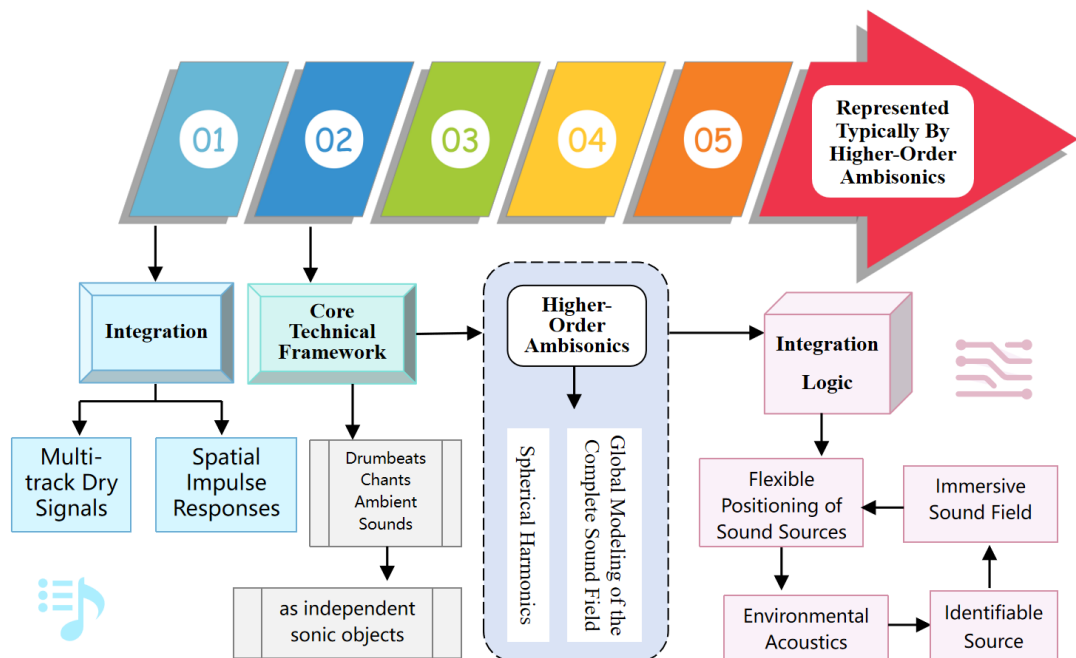


Fig. 2 Scene-Based Audio Represented Typically by Higher-Order Ambisonics

(Source: Drawn by the author)

3.3 Interactive Narrative Design: From Linear Playback to Exploratory Soundscapes

The reconstructed immersive sound field, if merely played back as a linear audio file, still consigns listeners to passive reception—they can hear the soundscape but cannot explore it. The introduction of interactive narrative design aims to elevate listening from mere sensory stimulation to active experience with cultural depth. The core of interactive narrative design lies in restructuring the narrative architecture. Traditional narrative presents a linear ‘beginning-development-resolution’

model, whereas the interactive narrative of soundscapes should shift to a spatialized ‘exploration-discovery-understanding’ structure. Ultimately, interactive narrative transforms the digital transmission of soundscapes from one-way playback to two-way dialogue—users no longer simply listen to a recording but undergo a cultural encounter through the process of exploration.

4 The Impact Mechanism of Human–Computer Collaboration on Creative Cognition

The construction of technical pathways addresses the ‘how-to’ question. Yet the deeper issue in digital living preservation is whether, as algorithms grow increasingly precise in source localization, reverberation modeling, and narrative generation, human cultural creativity is replaced or activated by technology. This section addresses this question by analyzing the pathways through which human–computer collaboration affects participants’ creative self-efficacy and original thinking, revealing the cognitive effects underlying technical tools. Understanding this mechanism requires recognizing a fundamental shift in collaborative roles. In conventional digital humanities applications, machines serve as executors—performing repetitive calculations according to preset instructions—while humans act as operators. In spatial audio reconstruction and interactive narrative design, however, machines become possibility generators, producing dozens of combinations of azimuth and reverberation parameters for a chant or multiple branching narrative structures from the same soundscape materials. Humans, in turn, ascend from operators to curators and meaning-makers, selecting, recombining, and re-creating algorithmic outputs based on cultural intuition and aesthetic judgment. This role transformation constitutes the deeper premise for changes in creative cognition.

Within this collaborative framework, three parallel pathways influence designers’ creative cognition. First, algorithmic redundancy supply and critical selection. Spatial audio engines typically generate numerous parametric variants—combinations of azimuth, elevation, distance, and reverberation time—for a single source, creating a redundant solution pool. Designers must filter these for both acoustic plausibility and cultural contextual fit. Each successful ‘select–verify–satisfy’ cycle confirms the irreplaceability of the designer’s cultural judgment, directly enhancing creative self-efficacy. Second, embodied real-time feedback from spatial audio. Unlike data visualization, spatial audio adjustments are fed back to designers in real time via immersive listening devices in auditory and somatic spatial forms. This embodied feedback triggers not only technical judgment but also auditory imagination. Hearing a drumbeat from behind rather than ahead may instantly activate associations with its cultural metaphors—such sensory-driven unconventional associations serve as crucial catalysts for original thinking. Third, unexpectedness generation and cognitive restructuring in interactive narrative. Narrative engines recombine, branch, and unexpectedly combine soundscape materials algorithmically, often producing plot structures or sonic sequences beyond designers’ initial expectations. Confronted with such algorithmic serendipity, designers must break free from existing

cognitive frameworks, transforming defamiliarized narrative structures into culturally meaningful expressions. This process of forging unconventional connections under unexpected stimuli effectively exercises original thinking. These three pathways form a mutually reinforcing cognitive activation mechanism: redundancy supply confirms designers' judgmental authority, embodied feedback activates sensory-driven imaginative associations, and unexpectedness generation compels cognitive breakthroughs and restructuring. Together they point to a conclusion: in digital living preservation, the human role is not diminished but re-emphasized through technological collaboration—the more powerful the algorithm, the more cultural judgment and creative imagination become decisive determinants of preservation quality. This also responds to the earlier 'technique without soul' concern: when human–computer collaboration is properly organized, technology becomes precisely the medium that activates rather than extinguishes human cultural creativity.

5 General Discussions

Following the technical pathway of 'sampling–reconstruction–narration' and the theoretical approach of human–computer collaboration in activating creative cognition, this study constructs a framework for the digital living preservation of endangered cultural soundscapes. At this juncture, critical reflection on the framework's core propositions, along with identification of limitations and future directions, is warranted. The central question is whether digitalization can genuinely sustain liveness. This paper adopts a cautiously optimistic stance: with a complete technical chain and appropriate human–computer collaboration, digitalization can indeed open a perceivable, participatory, and sustainable pathway for endangered soundscapes. However, a fundamental rupture—bodily absence—exists between digital reconstruction and native transmission. The meaning of native soundscapes inheres not only in being heard but in the embodied co-presence among sound-makers, listeners, and space—bodily rhythms in rituals, social gatherings in festivals, and kinesthetic rhythms in labor—none of which can be fully captured by audio data. Digital living preservation should therefore be positioned as an alternative continuity pathway after the rupture of native transmission, rather than a perfect substitute; its core value lies in slowing the rate of disappearance, expanding the scope of perception, and stimulating community cultural awareness, not in replacing authentic community practices. The position and limits of community participation constitute a second issue for reflection. This study's technical pathway positions professional designers as core actors, which may face legitimacy questions of 'whose culture is being reconstructed by whom' in practice. An ideal model would incorporate community members throughout the entire process from sampling to narrative design—making them co-designers and co-interpreters of meaning rather than merely subjects of recording. How to balance technical precision and cultural democracy remains a topic for sustained future investigation.

The limitations of this study are threefold: the proposed technical framework aims at general applicability and has not been differentiated for specific cultural contexts such as ritual versus everyday soundscapes, Eastern versus Western traditions, or oral versus religious traditions; the elucidation of the cognitive mechanism of human–computer collaboration is based on theoretical deduction and lacks systematic empirical validation; and the coordination between physical precision and cultural authenticity in soundscape reconstruction currently relies on qualitative assessment with no quantifiable decision-making model yet available. Future research may extend in three directions: integrating generative AI to explore culturally-contextualized automatic recombination and style transfer of soundscapes, lowering technical thresholds while empowering community-led creation; incorporating augmented reality (AR) and haptic feedback to supplement auditory reconstruction with visual and somatic dimensions, partially bridging bodily absence; and building an open community digital archive platform to facilitate crowdsourced collection, annotation, and narrative co-construction, grounding digital preservation in the daily practices of culture-holders. Digitalization is not a mechanical replication of endangered soundscapes, but an endeavor to sustain cultural life through technological assistance—its success ultimately depending on whether technology serves humanity, whether algorithms stimulate rather than supplant creativity, and whether communities become genuine subjects rather than mere recorded objects in the process.

6 Conclusions

The ‘sampling–reconstruction–narration’ technical pathway and the human–computer collaboration cognitive mechanism proposed in this study provide a systematic framework for the digital living preservation of endangered cultural soundscapes. Critical reflection on the framework's core propositions is warranted. First, can digitalization truly sustain liveness? With a complete technical chain and appropriate human–computer collaboration, digitalization can indeed open a perceivable and participatory pathway. However, digital reconstruction cannot remedy the fundamental rupture of bodily absence—the meaning of native soundscapes is deeply embedded in embodied co-presence among sound-makers, listeners, and space, where bodily rhythms in rituals and social gatherings in festivals cannot be fully captured by audio data. Digital living preservation should therefore be positioned as an alternative continuity after the rupture of native transmission, not a perfect substitute. Second, the position and limits of community participation merit scrutiny. Ideal practice should incorporate community members throughout the entire design process, making digitalization a catalyst for community cultural awareness rather than external appropriation of local knowledge. The limitations of this study include the framework's lack of differentiated validation across diverse cultural contexts, the absence of empirical testing for the cognitive effects of human–computer collaboration, and the lack of quantifiable decision-making models for balancing physical precision

and cultural authenticity. Future research may extend in three directions: integrating generative AI to empower community-led creation; incorporating AR and haptic feedback to partially bridge bodily absence; and building an open crowdsourced platform to facilitate co-construction of soundscapes, grounding digitalization in the daily practices of culture-holders.

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The author(s) declare that it is not applicable.

Consent for publication

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Competing interests

The author(s) declare that they have no competing interests.

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