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Article

Preserving Human Perspectives in Cultural Heritage Acoustics: Distance Cues and Proxemics in Aural Heritage Fieldwork

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Abstract: We examine the praxis implications of our working definition of *aural heritage*: spatial acoustics as physically experienced by humans in cultural contexts; aligned with the aims of anthropological archaeology (the study of human life from materials). Here we report on human-centered acoustical data collection strategies from our project "Digital Preservation and Access to Aural Heritage via a Scalable, Extensible Method," supported by the National Endowment for the Humanities (NEH) in the USA. The documentation and accurate translation of human sensory perspectives is fundamental to the ecological validity of cultural heritage fieldwork and the preservation of heritage acoustics. Auditory distance cues, which enable and constrain sonic communication, relate to *proxemics*, contextualized understandings of distance relationships that are fundamental to human social interactions. We propose that source–receiver locations in aural heritage measurements should be selected to represent a comprehensive range of proxemics according to site-contextualized spatial-use scenarios, and we identify and compare acoustical metrics for auditory distance cues from acoustical fieldwork we conducted using this strategy in three contrasting case-study heritage sites. This conceptual shift from architectural acoustical sampling to aural heritage sampling prioritizes culturally and physically plausible human auditory/sound-sensing perspectives and relates them to spatial proxemics as scaled architecturally.

Keywords: heritage acoustics; archaeoacoustics; archaeological acoustics; historical acoustics; architectural acoustics; acoustical preservation; acoustical fieldwork; acoustical surveying; auralization fieldwork; intangible cultural heritage

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1. Introduction: Defining Aural Heritage

Cultural heritage takes many forms and meanings; UNESCO, the United Nations Educational, Scientific and Cultural Organization, the leading international protectorate of heritage around the world, advances cooperation across fields and with governmental entities to guide protections: "Heritage is our legacy from the past, what we live with today, and what we pass on to future generations... UNESCO seeks to encourage the identification, protection and preservation of cultural and natural heritage around the world considered to be of outstanding value to humanity. This is embodied in an international treaty called the Convention concerning the Protection of the World Cultural and Natural Heritage, adopted by UNESCO in 1972" [1]. While UNESCO maintains the World Heritage list, many cultural heritage sites have been identified by other organizations and individuals, and supervision/protection of heritage can be managed or shared by private entities, non-profit and non-governmental organizations, as well as governing bodies from the local level out to that of national governments. For example, in the USA, the National

Register of Historic Places "is the official list of the Nation's historic places worthy of preservation. Authorized by the National Historic Preservation Act of 1966, the National Park Service's National Register of Historic Places is part of a national program to coordinate and support public and private efforts to identify, evaluate, and protect America's historic and archeological resources" [2]. The complexities of heritage designations and constituency relationships imply politics of responsibility and control, entangled with managing risk and ensuring preservation [3].

Our working definition of *aural heritage* refers to *acoustical heritage as experienced by humans*, explored in the project "Digital Preservation and Access to Aural Heritage via a Scalable, Extensible Method" that is supported by the National Endowment for the Humanities (NEH) in the USA [4]. Spatial aural heritage research documents the acoustics of heritage sites particularly to represent their cultural uses and the human experiential potentialities of those contexts. Therefore, human sensory perspectives are prioritized in aural heritage data collection and reconstruction demonstrations. These principles ensure *ecological validity* (realism), a key principle of cultural heritage documentation and preservation. Ecological validity depends on both spatial-perceptual and use-contextual accuracy. The proposed definition and methodology for aural heritage research addresses both.

Current research paradigms applied to heritage acoustics do not simultaneously address cultural-use contextualizations and the documentation of human perspectives on a setting-constrained soundfield, without the research design strategies we propose as core principles. In particular, human-centered considerations are not necessarily prioritized in room acoustics practice. Although the soundscape approach to acoustical documentation surveys the experiences of living humans in current acoustical environments—with binaural or ambisonic recordings as supporting documentation according to the international standard [5]—neither acoustical measurements nor physics-based acoustical reconstruction and preservation are emphasized. In contrast, aural heritage research addresses the anthropological basis of cultural heritage in terms of acoustics: the intersection of human experience with socio-culturally contextualized soundfields. A comparison of approaches to heritage acoustics is charted in Table 1 (below).

Table 1. Comparison of approaches used in heritage acoustics research: *approach* (left column) vs. **cultural heritage acoustics concerns addressed** (across). * Indicates data that may be subjectively reported rather than measured.

	Acoustical Measurements	**Socio-Culturally Appropriate SOURCE Locations**	**Human Auditory Perspectives via Realistic RECEIVER Locations**	**Ecological Validity (Accurate Translation of Contextual Soundfield)**	**Purposes: Intervention; Preservation; Virtual Reconstruction**
Aural Heritage Data Collection	primary data	yes; determined from historical or archaeological background	spatial sampling of acoustics where humans would be in contextual scenarios	prioritized spatially and culturally	preservation; virtual reconstruction; intervention (infrequent)
Soundscape Approach	supportive data	site-dependent sources	primary data via participant survey *	* subjectively reported; if measured, contingent upon binaural locations	intervention and/or preservation
Room Acoustics	primary data	not requisite	not requisite	depends on source–receiver locations	intervention; preservation; virtual reconstruction

The human-centering principle is fundamental to aural heritage data collection, as it informs the selection of source and receiver positions for acoustical measurements as well as equipment features and configurations. We are in the process of analyzing data from our equipment comparison studies and will publish those results as a future output of our project. In the present article, we detail a strategy for acoustical measurement source and receiver locations to document spatial acoustics according to humanly possible and contextually plausible scenarios, required for ecological validity regardless of measurement equipment specifications.

Acoustical research in heritage sites implicitly deals with human sonic perception, and many archaeoacoustical approaches consider effects of sound for human listeners with respect to cultural context (e.g., studies in the seminal volume on archaeoacoustics that formally introduced this developing field [6]). However, acoustical data collection for research questions that involve sensory concerns does not by definition prioritize humanly possible or culturally appropriate measurement scenarios in the spaces being studied. We propose two co-related strategies in the spatial organization of aural heritage research to produce acoustical data that spatially translate realistic human perspectives on the contextual soundfield: (1) locating sound sources and receivers where contextually appropriate sound sources and humans could physically be, along with (2) locating sound sources and receivers in places appropriate to known/hypothesized use(s) of the heritage site. We point out that source and receiver locations for acoustical measurements reconstruct "sound-making and sound-sensing scenarios" [7] in heritage site fieldwork.

In combination with the perceptually and socio-culturally contextualized location of acoustical measurement sources and receivers, perceptually honed measurement techniques sharpen the accuracy of aural heritage data collection. Binaural recording—central to our toolkit but not the focus of our discussion here—is optimized for the translation of human physical perspectives on the soundfield, and other spatialized microphone arrays, such as ambisonics, locate receivers as proxies for human ears and bodies. In archaeoacoustical research that preceded our project, Kolar developed in-situ methods for participant psychoacoustics experiments to evaluate auditory localization in the interior architecture of the UNESCO World Heritage Centre archaeological site Chavín de Huántar, Perú, producing perceptual evaluations of acoustical measurement scenarios she captured as aural heritage data using binaural recordings, a technique employed in acoustical measurement fieldwork at that site since 2008 [8]. Archaeoacoustics researchers increasingly employ binaural techniques; an outstanding example is the fieldwork of architect and soundscape researcher Pamela Jordan, who employed a binaural recording and analysis system developed by Head Acoustics to document sound reception across the landscape of the Mount Lykaion site in Greece [9].

In its archaeological/historical reconstructive and preservation focus, aural heritage fieldwork contrasts with the soundscape approach to studying sonic environments that evaluates living humans' experiences at present [10], with binaural or ambisonic recording as documentation [5]. Soundscape research makes direct experiential evaluations of present-day settings with living participants; aural heritage research explores the cross-temporality of acoustics relevant to human experience through site measurements and reconstructive models that represent culturally relevant sound source locations and humanly plausible receiver positions. Both approaches similarly valorize sonic experience in the uses and meanings of places, yet aural heritage research targets preservation and reconstruction rather than the interventional design applications typical of soundscape research. However, both aural heritage research and the soundscape approach share theoretical and technical territory and can be engaged together in studies of living heritage or for the design of public interfaces at heritage sites.

By definition, any form of heritage acoustical fieldwork produces measurements and documentation of site acoustics in their extant conditions, enabling preservation and reconstructions. For historical and archaeological reconstructions, present-day features must be related to documented and hypothesized conditions during the previous time periods or events of interest. To address the often excluded but essential factor of ecological validity—our reason for preferring the term aural heritage—we propose the conceptualization of heritage acoustical data collection in two interrelated approaches that anticipate the application of this data in computational auralizations and/or acoustical models for reconstructive demonstrations and research: (1) measurements that capture specific human auditory/sound-sensing perspectives [7,11], and (2) measurements that can drive or verify physics-based computational architectural/spatial acoustical models, as widely practiced in archaeoacoustical research, e.g., [12,13]. Although these two applications may coincide, measurements that can drive modeling techniques based on architectural parameters do not necessarily capture specific human perspectives on a contextualized soundfield, thus our proposal for this human-centered, site-contextualized research paradigm for heritage acoustics.

Aural heritage data collection differs from standard room acoustical measurements (e.g., [14]) due to a cultural preservation and reconstruction purpose that emphasizes human experiential perspectives. One of the aims of our project is to create an extensible research framework that can be applied by others in acoustical fieldwork across a range of cultural heritage contexts; therefore, we selected three contrasting case-study sites in which to evaluate extensible fieldwork practices via cross-comparison. Here, we highlight contextual considerations related to spatial perception in three case-study sites having distinct architectural–acoustical features and socio-temporal significance. Our collaboration as three acoustical scientists and audio engineers who share background while bringing together distinct expertise supports the extensibility of our combined approach to cultural acoustical heritage research. Prior to our scholarly professions, we all had previous careers in the engineering of contemporary art music recordings and performance sound design, and we bring contrasting perspectives in our research approaches to spatial acoustics and the perceptual evaluation of sound. Dr. Kolar is an innovator of archaeoacoustics methdodologies with expertise in ecological psychoacoustics and auditory localization [15–17]. Dr. Ko is an expert in designing virtual acoustics for music recordings and performance, particularly in historical reconstructions [18–21]. Dr. Kim is an expert in spatial audio engineering and perceptual verification [22–25]. Ko and Kim have collaborated in previous heritage acoustical research [26,27].

We are developing best-practice recommendations for aural heritage data collection that address the pragmatics of access and constituencies surrounding cultural heritage sites. Worldwide, cultural heritage preservation involves a diversity of researchers and logistical situations, which means that any aural heritage research protocol must accommodate a wide range of expertise and access to tools as well as sites. Some sites can be documented with measurements that follow international acoustics standards with precision equipment, whereas other sites might only be documented using ubiquitous mobile devices or consumer audio recorders, via nonstandard approaches. We advocate for systematic measurements according to acoustical standards and with multifaceted, cross-comparable documentation; however, recognition that the fundamental goal of aural heritage preservation is to produce well-documented records of spatial acoustics from human perspectives—and given the many contingencies surrounding data collection in heritage sites—we contend that any thoughtful documentation is preferable to having no form of preservation, regardless of the tools used or the acoustical knowledge of practitioners. Our aim, therefore, is to provide methodological detail in publications to support acoustically informed praxis in cultural heritage documentation most broadly.

Given that the majority of cultural heritage practitioners are neither acousticians nor audio engineers, to produce a research protocol that can flexibly support the cultural heritage community, we have evaluated a range of audio equipment towards making tiered recommendations for equipment and data collection procedures based on portability, ease of use, target application, and budget; we will publish our recommendations after completing the corresponding perceptual evaluations currently in progress. To aid in broader adoption of aural heritage research, we are developing various software tools in conjunction with the procedural protocol, among the digital resources to be freely released at the completion of our project. This article introduces our methodological framework for aural heritage fieldwork, detailing a specific acoustical fieldwork strategy to produce acoustical data reflective of a range of human experiential perspectives at a heritage site.

In this article, via a comparison of our fieldwork at three heritage sites with contrasting architecture and purposes, we explore what has emerged from our research as a fundamental principle of aural heritage data collection: representing the range of distance cues pertinent to each site. We cross-compare site-responsive acoustical fieldwork in three cultural heritage sites: the historical and now educationally leveraged Columbia A Recording Studio on Nashville's shrinking Music Row; the Rochester (New York) Savings Bank, a 1927 public building on the National Register of Historic Places (NRHP) whose main hall boasts extensive glass mosaics, marble, arches and a half-dome in its Byzantine Revival-styled interior; and the interior architecture of the first-millennium BCE ceremonial center at the UNESCO World Heritage Centre archaeological site Chavín de Huántar in the north-central highlands of Perú.

2. Materials and Methods: Perceptually and Contextually Relevant Acoustical Survey Locations

We propose that a key technique to represent human sensory perspectives in spatial acoustical datasets is locating measurement sound sources and receivers in positions that are humanly plausible given the cultural context(s) of the site. Implicit in this strategy is the concept of *proxemics*, defined by anthropologist Edward T. Hall [28] as socio-cultural distance relationships contextually perceived by individuals (detailed in Section 2.1, below). We further propose that proxemics can be addressed in aural heritage data collection through acoustical survey points that sample the representative range of distance relationships possible in each particular site. To this point, we identify relevant acoustical metrics for auditory distance cues, and we provide examples from our case-study research that demonstrate such data collection and analysis techniques. In the following cross-comparison of aural heritage fieldwork in our three case-study sites, we illustrate strategies for the collection and analyses of acoustical data relevant to auditory distance cues and the representation of site-contextualized proxemics.

2.1. Case-Study Aural Heritage Measurements: Research Background and Proxemics Theory

We collected aural heritage data in 2019 and 2020 at the three cultural heritage sites we selected for our collaborative project, though Kolar has conducted archaeoacoustical fieldwork at Chavín de Huántar since 2008. Pre-planning included selecting audio equipment from tools we previously used in room acoustical measurements and archaeoacoustics fieldwork, as well as testing several other tools. It was important to specify measurement equipment that we would be able to use in at least two of the three case-study sites for intra-site comparisons of efficacy; location logistics in part determine what equipment can be used in cultural heritage settings.

A fundamental aspect of heritage acoustics research is the site-responsive development of measurement strategies that incorporate knowledge about the cultural use context(s) of each site. The music recording purpose of Columbia Studio A on Nashville's Music Row (Tennessee, USA) and its use history as documented around the development of commercial recordings from the 1950s to early 1980s provide specific information about past uses of that space, enabling us to infer and reproduce in measurements appropriate sound source and receiver locations. Likewise, historical and photographic documentation of the Rochester Savings Bank's use history in the early and mid-20th century (New York, NY, USA) indicates public ways that people interacted within this financial institution, determining functionally representative locations for measurement sources and receivers. In contrast, cultural uses of the interior architecture of the first-millennium BCE ceremonial center Chavín de Huántar (in north-central highland Perú) must be inferred from material archaeology without written texts; Kolar previously reconstructed site sonic communication affordances by comparing acoustics of its architecture and instruments in relation to human experience via psychoacoustics [11,15,29]. One strategy used for locating measurement sources and receivers in Chavín architecture is to place them throughout a range of humanly accessible places within a contiguous space, emphasizing the small rooms, alcoves, interconnecting spaces, and ends and intersections of corridors. While the recording studio room and bank's main hall are rectangular, large-volume spaces (though on different scales) built with manufactured materials and regularized surfaces, the labyrinthine interior architecture at Chavín is made of uneven stone and earth, characterized by narrow corridors with long dimensions and very low ceilings: volumes that are largely constrained to 1–2 m in two dimensions that reinforce mid-frequency resonant modes [13].

To identify factors that might be relevant to aural heritage data collection in any site, we reviewed our fieldwork procedures in all three case-study sites to identify common structuring premises. Our prioritization of measurement scenarios to reconstruct human experiences of spatial acoustics highlighted the importance of contextually scaled distance relationships. Distance is salient to people's understandings of events in the world, with sound as an indicator of activity; distance constrains sonic communication. Through the proxemics framework proposed by anthropologist Hall, "a consultant to architects on human factors in design and to business and government agencies in the field of intercultural relations" [28], human perception of distance relates to social interaction affordances, scaled by spatial features. Of particular relevance to acoustical applications of this framework is that Hall related understandings of intimate, personal, social, and public distance with the human-centered acoustical cue he called "loudness of voice" ([28] p. 114), noting that these ranges scale subjectively in terms of contextual factors such as social relationship and activity (pp. 111–129). Proxemics theory was previously applied in Andean archaeology by anthropologist Jerry Moore, who emphasized its utility for parsing private vs. public space [30], and by Helmer and Chicoine, who used proxemics in terms of speech transmission to map communication boundaries [31]. In several studies, archaeologist Matthew Helmer has cited Moore in the design of proxemics-based archaeoacoustical surveys at the Andean sites of Caylán and Samanco, particularly "around the concept of scales of loudness [following Hall] where different types of interactions are reflected through distances of comprehension on a scale from intimate-personal experience on one end, to public at the other"([31] p. 97). Our approach detailed here contributes acoustical specificity to proxemics theory: we relate acoustical distance cues to proxemics that are architecturally scaled.

We have observed from our collective spatial acoustical measurement and performance engineering experience that source and receiver positions can be associated with estimations of proxemics. Following Hall's definition, proxemics are subjective, yet we propose that the scaling of proxemics varies according to functional spatial boundaries that can be documented acoustically and thus related to measured acoustical parameters. In order to comprehensively sample the range of human auditory/sound-sensing perspectives possible within a specific heritage setting, acoustical measurements must be made to capture a range of associated proxemical distinctions via contrasting sound source and receiver configurations.

This conceptualization for aural heritage data collection differs from room acoustics measurement practice that is motivated by computational parameterization and architectural representation, a praxis comparison that merits further exploration. Here, we focus instead on examples from our aural heritage fieldwork that show representative and contrasting source–receiver distance relationships with corresponding acoustical metrics at each case-study site. We first summarize the acoustical metrics that are commonly associated with auditory distance cues and then analyze data from our case-study fieldwork in terms of these metrics. We propose that these acoustical metrics relevant to auditory distance specifically relate acoustical data to spatially scaled proxemic categories, therefore providing a metrical basis for addressing site-contextualized interpretations of human experience in aural heritage research. In addition, the cross-comparison of our choices of source–receiver locations for acoustical measurements in the three case-study sites highlights common and contrasting contextual factors to inform our recommendations for aural heritage best practices.

2.2. *Acoustical Metrics for Auditory Distance Cues*

Accurate representation of human auditory/sound-sensing perspectives in aural heritage data requires the inclusion of a variety of distance relationships between measurement sources and receivers according to the context of each site. "*Auditory perspective* is not a metaphor in relation to visual perspective, but rather a phenomenon that seems to follow general laws of spatial perception" ([32] p. 274), a cognitive process based on relating prior knowledge with contextual information. There are multiple acoustical cues that aid humans in perceiving the distance of a sound source. The availability and reliability of these cues as predictors of perceived distance can vary substantially depending upon the stimulus, the properties of the environment, and the directivity of the sound source [33]. In most indoor environments, sound level, direct-to-reverberant energy Ratio (DRR), and spectral shape/balance are considered stable and representative metrics.

Sound Level is a relative distance cue that is available in most environments [34–36] and is effective over a wide range of distances. Perceived source distance generally increases with decreasing level of the sound at the ears of the listener (receiver). However, the identification and familiarity of sound sources constrain the utility of these level cues; for example, the related perception of *loudness constancy* that contextualizes level reductions requires prior knowledge of the source [32]. In an anechoic environment, the relationship between level and distance between a sound source and receiver is characterized by the inverse-square law: the level falls by approximately 6 dB for each doubling of the source distance (e.g., [35]). The rate of decrease in level varies in reverberant environments, depending on the reflectiveness of boundaries with respect to spectrum of reinforced sound. For example, in an auditorium used by Zahorik [36], the rate was approximately 4 dB per doubling of distance. Modal reinforcements alter the spectral balance as well as the rate of level reduction over distance. The rate of level reduction also depends on the directivity of the sound source and the position of the sound source in relation to reflective and absorptive boundaries (e.g., as documented in this archaeoacoustical survey: [17]).

Direct-to-Reverberant Energy Ratio (DRR) has been demonstrated to provide distance information [37] and is primarily useful in indoor environments. For localization in terms of azimuth (horizontal plane), reverberation degrades performance [38]. However, the presence of reverberation for distance judgments is beneficial in terms of the DRR decrease with source distance from the listener [36,39,40]. Direct sound energy travels in a straight uninterrupted line (though with curved wavefronts) from the source to the listener; for an omni-directional source, sound level falls by 6 dB for each doubling of distance. Reverberant sound energy is reflected from surfaces and objects before reaching the listener and can be approximated by a diffuse sound field with constant energy throughout if the room is not too small (colloquially referred to as a "well-mixed room"). In well-mixed rooms, the level of the reverberant soundfield for continuous sources varies only slightly with distance from the source. For example, in the small auditorium utilized by Zahorik [36], the level of the reverberant sound reduced by only about 1 dB for each doubling of the source distance. The magnitude of reverberant energy is determined by the room size and shape, and by the absorption coefficients of materials on surfaces, including walls, floor, ceiling, and any objects, people, or other living beings in the room, as well as through structural interactions. DRR cues depend on the listener's identification of the sound source, or at least the parsing of sonic information to distinguish the direct spectral content (early energy) from the reflected content, which eventually becomes stochastic in late reverberation.

Spectral Shape (sometimes referred to as spectral balance) of received sound can be used to perceive the distance of sound sources typically more than 15 m from the listener [41]. As sound travels through air, higher frequencies become more attenuated than lower frequencies, altering the spectral shape of received sound. Sounds with decreased high frequencies relative to low frequencies are typically perceived to be farther away [42,43]. Spectral cues do not provide distance information for sounds located in the nearfield range of 1–1.5 m from the listener, for which the sound has not traveled far enough to have lost a detectable amount of energy at higher frequencies; the low-frequency cues provided by diffraction around the head are too small to be detected at these distances [44]. Like sound-level cueing, spectral cueing is influenced by the identification and familiarity of the sound source.

Auditory distance cues interrelate spatial acoustics with auditory perception and spatial cognition. For this reason, we recommend that the design of spatial acoustical measurements for cultural heritage research and preservation should prioritize accurate spatial translations of human perceptual scenarios that are contextually plausible. Aural heritage data collection methods ensure receiver placements where humans could be located in relation to source locations that represent known and inferred uses of the heritage space. These principles proceed—and constrain the utility of—the use of auditory perceptual proxies via measurement equipment, such as binaural, ambisonic, and spaced microphone arrays, and sound sources that are physically representative of real-world sounds appropriate to the site's cultural context. Equipment selection is a separate but related discussion; here, we focus on the more fundamental survey design principles that ensure site-realistic and humanly plausible spatial–positional distance cues in resultant acoustical data.

2.3. Distance and Acoustics in Case-Study Sites: Cultural Contexts in Measurement Fieldwork

We analyzed acoustical data we collected at our three case-study sites to understand how researchers' estimations of distance ranges between sound sources and receivers relate to standardized acoustical parameters [45]. In all three sites, we followed the standard room acoustics practice of measuring impulse responses from one sound source to one or more receivers (microphones) arranged in a variety of paired and spaced-array/multichannel forms, including ambisonics microphones and binaural microphones both as in-ear (blocked meatus) microphones worn by a researcher and a commercial binaural dummy-head microphone system (the Neumann KU 100) for comparison in the recording studio case-study site.

Our acoustical surveying strategy for both historical sites (the 1927 bank and 1950s recording studio) was similar, in that we selected source–receiver locations that cover the range of distance relationships afforded by the boundaries of these medium and large rooms. In Chavín's 1st century BCE Andean architecture, we employed a similar strategy: source and receiver measurement positions provide a representative sample of the range of sound transmission and reception possible within the functional bounds of each of several interior spaces. Related in terms of socio-cultural research questions that might be addressed using measured data, this strategy for survey locations captures proxemics from Hall's range of "intimate" space through "personal" and "social" space to the farthest "public" sonic interaction possible within the same contiguous structure [28]. Depending on dimensions and uses, the proxemics afforded by a particular space may or may not cover the range of Hall's scaling designations. Aural heritage acoustical measurements in all three sites were designed to sample the range of sound transmission and reception possible given the architectural boundaries of each measured space, prioritizing locations where humans could and would likely be in terms of cultural use scenarios. This strategy emphasizes both perceptual and contextual ecological validity in data collection from heritage sites.

Our first case-study site was Columbia Studio A (CSA) in Nashville, TN, USA, part of historical Music Row. As shown in Figure 1 (below), this single room is an acoustically treated recording studio founded in 1954 by brothers Owen and Harold Bradley, the site of recordings by artists including Bob Dylan, Buddy Holly, Loretta Lynn, Johnny Cash, Patsy Cline, and Brenda Lee [46]. CSA is a medium-size rectangular room 15.9 m long by 10.5 m wide by 5.6 m high. The side walls feature flat sections of framed and stretched textile for sound absorption in the low-mid frequencies that alternate with angled and tiered varnished panels of smooth wood that provide flexional sound absorption in the low-mid frequencies as well as mid-high reflectivity. The hard floors are tiled, and the back wall can be covered with a sliding heavy draped curtain for additional sound absorption as desired. A large multi-paned glass window in the absorptively treated front wall (opposite the curtain) provides visual communication with the control booth and mixing room that is connected via a soundproof door. We conducted measurements with all doors closed and the curtain across the back wall in May 2019 with two student assistants.

Figure 1. Columbia Studio A (Nashville, TN, USA): photo and schematic of aural heritage fieldwork configurations showing multiple acoustical source and receiver locations, iteratively measured using a variety of equipment and microphone configurations. Diagram by Doyuen Ko.

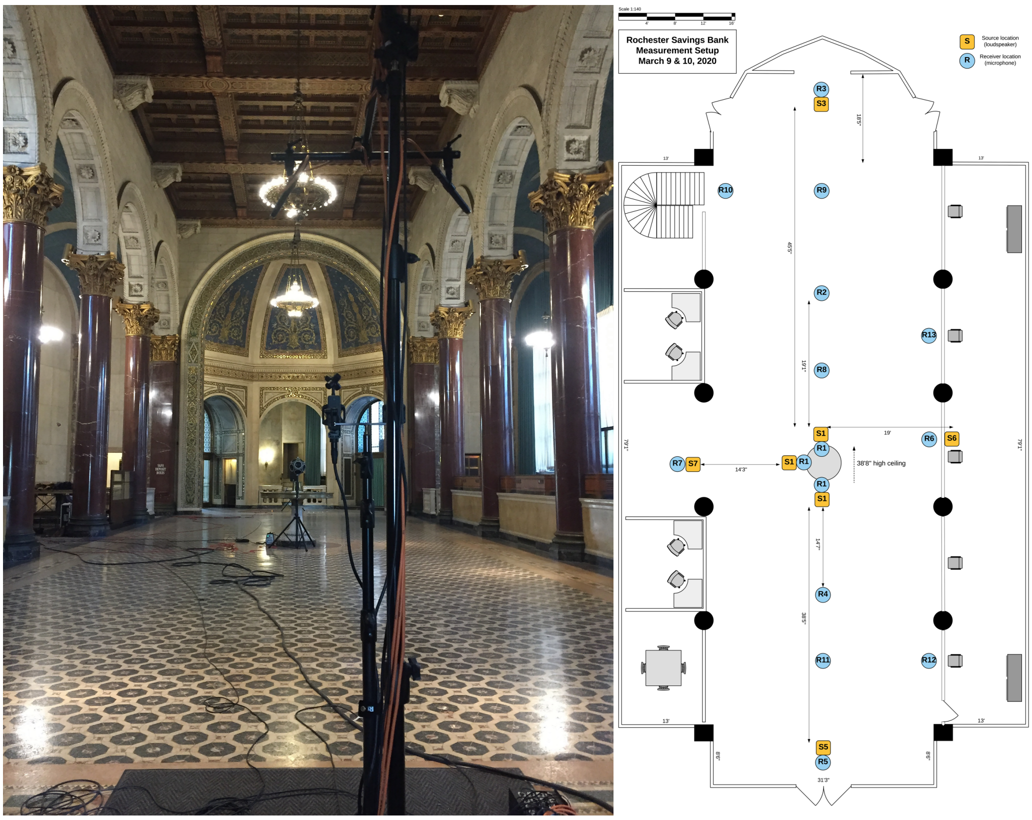

Figure 2. Rochester Savings Bank (Rochester, NY, USA): photo and schematic of aural heritage fieldwork configurations showing multiple acoustical source and receiver locations, iteratively measured using a variety of equipment and microphone configurations. Diagram by Doyuen Ko.

Our second case-study site was the Rochester Savings Bank (RSB), a once-public commercial building listed on the National Register of Historic Places (NRHP) in downtown Rochester, New York. This large stone and masonry building was built on a steel framework in 1927. The building opened for banking on 9 January 1928, impressing customers with an ornate Byzantine Revival-styled main hall that is currently closed to the public.

As shown in Figure 2 (above), the main hall measures approximately 29 m long by 18 m wide by 11.8 m high. Interior marble and terrazzo walls, a ceiling dome, and arches feature elaborate glass mosaics, stone tilework, and marble columns with sculptural entablatures. The floors are made of acoustically reflective marble mosaic, and the ceilings feature an elaborate matrix of wood coffering. "The entire wall surface of the room is of various marbles, chief among which are the Rouge Royal Pilasters and Botticino and convent grey Sienna panels", with contrasting yellow Sienna marble teller counters [47,48]. We conducted fieldwork in RSB in March 2020 with student and visiting research assistants.

Our third case-study site was the Andean archaeological site and Peruvian National Monument at the UNESCO World Heritage Centre, Chavín de Huántar. The site's interior architectural spaces most accessible to humans are known as galleries but also include the slate-lined canal system, which underlaces much of the site, with many areas similar to gallery architecture: short-ceilinged, narrow spaces with long dimensions. The aural heritage project case-study data from Chavín can be compared with data from previous archaeoacoustics fieldwork. First, we summarize canonical architectural acoustics from several locations in Chavín interior architecture in terms of the acoustical metrics that we evaluated in IRs from the historical case-study sites. Then, we present sound-level data used for measurement calibration and important to the contextual interpretation of sound transmission through Chavín's distinct waveguide-like architecture, and thus a key metric for documenting the site's aural heritage, as well as calibrating acoustical models.

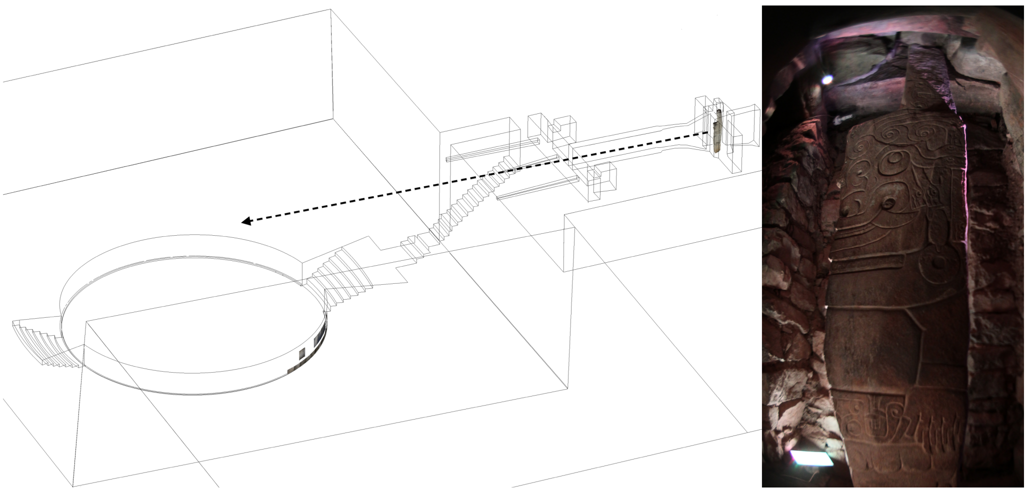

Figure 3. The Lanzón Gallery at Chavín de Huántar, Perú: geometrical model used in computational acoustical reconstructions (**left**) and photo of the Andean Formative granite monolith (**right**) also shown in its location at the western end of the stone-and-earthen gallery. Figure previously published in [16]; model and illustration by José L. Cruzado Coronel.

Chavín's Lanzón Gallery (LAN) was constructed of stone block walls within a thickly matrixed stone-and-earthen mortared building renovated several times during the first millennium BCE [49]. Chavín's well-preserved structures reflect the form of this extensive ceremonial complex at the end of construction during the late Andean Formative Period. LAN has a packed earthen floor, with a stone slab ceiling averaging 1.9 m high except in a small sunken room on its western end. Its form is two 1 m-wide corridors intersecting in a T-shape on the eastern end, with a sunken and taller cruciform room at the narrowed western end that contains a 4.5 m high carved granite monolith (the "Lanzón") located 13 m from the eastern-most wall, as shown in the geometric model with photograph in Figure 3 (above). The eastern corridor is 10.75 m long and contains two symmetrical alcoves that face two of three parallel horizontal ducts that taper from 40 cm-diameter square apertures until their coupling with the outdoor Circular Plaza. There is an open doorway and short entrance staircase at the southern end of the eastern wall, created in the 20th century to facilitate research and touristic access to the space. Dr. Kolar conducted fieldwork at LAN in August 2019 with a Peruvian assistant.

3. Discussion and Results: Site-Contextualized Acoustical Metrics

3.1. Acoustical Analyses of Distance-Related Metrics in the Two Historical Case-Study Sites

In our cross-comparison of spatial aural heritage measurement techniques, we first compare our measurement process in the two historical buildings. We performed acoustical measurements between many source (loudspeaker) and receiver (microphone) positions, starting with the central axis of both CSA and RSB following standard room acoustics practice and then expanding to include a range of culturally plausible locations for humans in each space following music-recording (CSA) and banking (RSB) contextual scenarios. As noted previously, although we used a variety of equipment and configurations of source and receivers (Figures 1 and 2, above), including binaural and ambisonics capture techniques, in the following analyses, we present metrics calculated from omnidirectional sources and receivers.

Figure 4 (below) highlights and compares source–receiver locations along the median axis in both historical rooms, representing the architecturally scaled analogous proxemical scenarios for acoustical comparison. These analogical source and receiver pairs were separated by the following distances: 3 and 6 m (CSA) and 6 and 14 m (RSB). For these measures, for source reproduction of a 20 s exponential sine sweep, we used an omnidirectional loudspeaker (the NTI DS3 Dodecahedron Speaker, whose frequency response is 50 to 10 kHz and complies with ISO16283, ISO140, ISO3382, ISO354, DIN52210, and ASTM-E2235/-E336/-E90). We calibrated the playback level to 87 dB-SPL (C-weighted) at the center of each room (set to maximize gain before apparent distortion/mechanical nonlinearities). Our receiver for this particular comparison was an omnidirectional measurement microphone (DPA 4006) moved between the noted survey locations. We deconvolved the recorded room-sweeps into spatial impulse responses (IRs) using customized MATLAB code, and analyzed the IRs using the Electronic & Acoustic System Evaluation & Response Analysis (EASERA) system software.

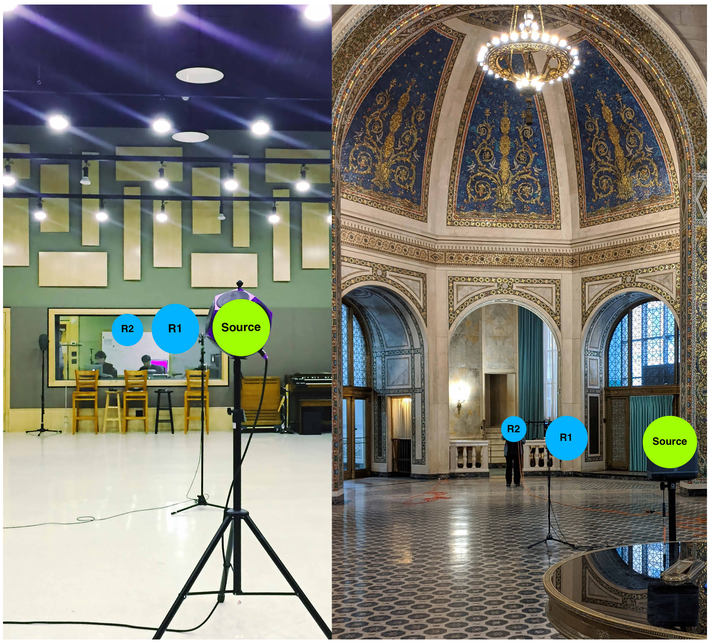

Figure 4. Comparison of analogous source-receiver proxemics between the two historical case-study sites: source (omnidirectional loudspeaker; green circles) and receiver (omnidirectional microphone; blue circles labeled R1 and R2) locations in Columbia Studio A (CSA), Nashville, TN, USA (**left**) and the Rochester Savings Bank (RSB), Rochester, NY, USA (**right**). Laser-measured distances from each source to its receivers labeled in each room are 3 and 6 m (CSA) and 6 and 14 m (RSB).

We analyzed the measured IRs from CSA and RSB in terms of three acoustical metrics reliably associated with auditory distance cues: level (relative reduction), direct-to-reverberant ratio, and spectral shape/balance in terms of the definition (D) metric, averaged across the response spectrum from 100 to 10 kHz, shown in Table 2 (below). In CSA, the distance from the source to R1 was exactly doubled at R2, but in RSB, the analogous construct of placing R2 near the far boundary was more than double the distance between the source and R1 at a factor of 2.333. The reverb time T30 metric (decay time from −5 to −35 dB) clearly reveals the notable acoustical dissimilarity in apparent reverberation between the two rooms due to differences in scale and materials. Notably, there is no significant change in reverb time between these two receiver positions within each room, indicative of uniform decay within each architectural volume; both historical spaces therefore reverberate as well-mixed rooms. Comparison of acoustical metrics between the two historical rooms provides numerical values for subjectively observed features of these uniformly diffuse spaces, enabling predictions of speech communication efficacy, among other functional features relating to the socio-cultural contexts of these sites.

Table 2. Comparison of acoustical metrics from IR measurements in Columbia Studio A (CSA), and Rochester Savings Bank (RSB). Metrics (computed in EASERA) selected for relevance to auditory distance cues.

	CSA		**RSB**	
	R1	**R2**	**R1**	**R2**
Distance from Source	3 m	6 m	6 m	14 m
Reverb Time (T30, 250–2 kHz)	0.54 s	0.54 s	2.26 s	2.29 s
Level (relative reduction)	−0.1 dB-FS	−2.3 dB-FS	−8.1 dB-FS	−11.6 dB-FS
Direct to Reverberant Ratio	1.5 dB	−3.2 dB	0.9 dB	−11.3 dB
Definition (D)	0.883	0.811	0.674	0.343

Between the R1 and R2 positions in both historical rooms, there is a similar relative reduction in level of 2.2 dB (CSA) and 3.5 dB (RSB). The level unit presented here is dB-FS (full scale), different from the dB-SPL (sound pressure level) reference commonly used in the calibration of acoustical measurements. We report the dB-FS metric here because it is relevant in the comparison of digital signals, our method of analysis from these digitally recorded impulse responses. There is no direct conversion between the two units, although the dB-FS metric can be calibrated via a sound-level reference measure; in this case, the 2.2 to 3.5 dB-FS decrease translates to a similar dB-SPL value acoustically, a result that agrees with the surveyed literature [35,36]. Level reduction between source and receivers is determined by several physical factors beyond absolute distance, such as the room size, shape, and absorption coefficients of all surfaces, as well as objects and beings within.

Direct-to-reverberant energy ratio (DRR) is the metric that measures the ratio between the direct sound energy and the reflected (reverberant) sound energy calculated from a room's impulse response. The larger the value, the more direct sound energy in the response, which provides human perceivers with more intelligible sonic characteristics, such as clarity in speech reception (thus, a metric relevant to Hall's proxemical consequent, speech communication [28]). The DRR is decreased by 4.7 dB (CSA) and 10.4 dB (RSB) from the R1 to R2 positions. The differences we measured are significant enough (around or above the 5–6 dB threshold reported in Zahorik's study, [40]) for listeners to perceive these DRR energy contrasts between the R1 and R2 positions in both rooms, especially in the apparently reverberant RSB.

Definition (D; also known as D50) is the ratio between the energy received during the first 50 ms of the impulse response and the overall signal energy [5]. The closer the value to 1, the clearer the signal reception. The typical range is between 0.3 and 0.7, and for good speech intelligibility, the value should be above 0.5. CSA has a high D-value for all receiver locations, relevant to its history as a renowned music recording room, whereas RSB presents medium (R1) to low (R2) values due to its large volume with abundant late reflected energy. Speech interactions between people located physically close to one another in the bank would be most intelligible, with distance affording privacy in vocal communication—a socio-culturally relevant factor useful to the economic transactional function of this public space.

Spectral shape is referred to as "spectral balance" in the EASERA software we used to analyze this data. The sound spectrum can provide important cross-contextually consistent cues for distance judgment, particularly because high-frequency energy is reduced with increasing source–receiver distance due to air absorption. The magnitude spectra shown in Figure 5 (below) demonstrate energy distribution over logarithmically scaled frequency from the two case-study sites. In both CSA and RSB, the spectral balance between R1 (blue) and R2 (red) is similar except for high frequencies above 3 kHz, where both rooms' R2 (red) graphs show decreasing energy. The reduction in high-frequency energy is slightly more evident for RSB due to its larger scale and increased distance between source and both receivers, as expected according to references for air absorption ([50] pp. 64–71).

Analysis of the acoustical metrics direct-to-reverberant energy ratio (DRR), definition (D), spectral shape/balance, and sound-level reduction between analogous survey locations in the historical case-study sites provide numerical data on architecturally scaled proxemical ranges, thereby relating spatial–acoustical data to auditory distance cues. In evaluating the acoustics of these rooms with respect to their cultural uses, we find that DRR would particularly influence human interactions (speech and musical communication) within in each of these historical spaces. Therefore, both DRR and the related metric D may be considered the most functionally important acoustical metrics of those discussed here. This finding contrasts with data from our third case-study site that have distinct architectural and acoustical features.

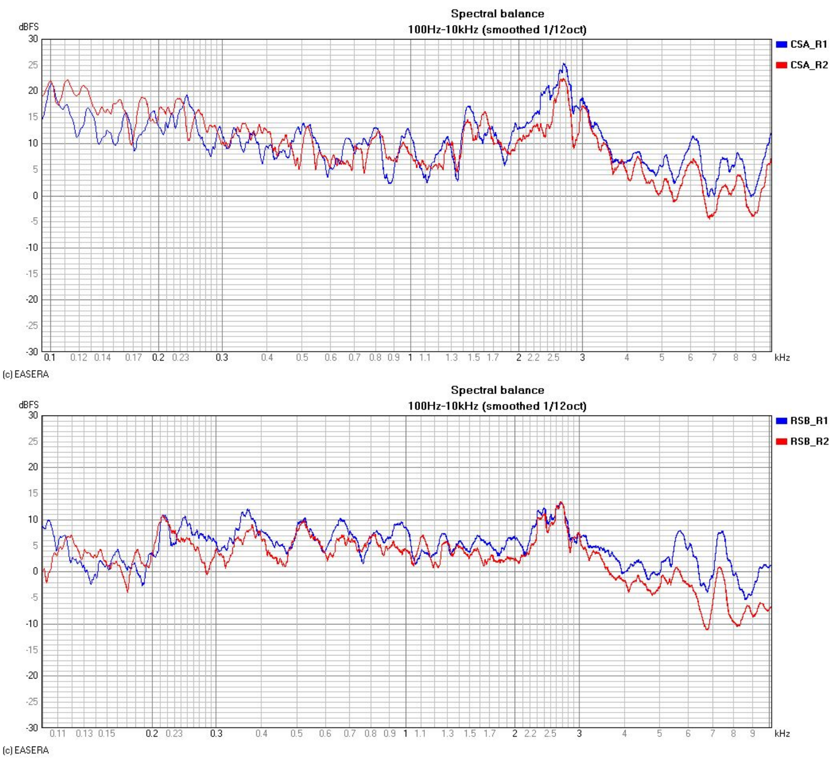

Figure 5. Spectral balance (magnitude response, on a logarithmic frequency scale) from impulse response measurements in CSA (**above**), and RSB (**below**). The R2 positions (red) in both historical case-study sites show decreased high-frequency energy above 3 kHz as compared to R1 (blue), as expected due to air absorption.

3.2. Acoustical Analyses of Distance-Related Metrics in the Ancient Case-Study Site

In contrast with the rectangular, uniformly diffusive rooms from the case-study historical sites, the ancient earth-and-stone interior architecture at Chavín de Huántar exhibits waveguide-like behavior, with strong modal resonances. The acoustics of Chavín's interior spaces are characterized by short reverberation times (RT), except in the lowest frequencies, and low inter-aural correlation [51]. Each gallery has a unique floorplan, though gallery forms are characterized by long corridors with widths and heights under 2 meters in most cases, sometimes flanked by small rooms or shallow alcoves. Previous research by Kolar and colleagues demonstrated that RT increases with corners (right-angle"turns") between source and receiver [51].

The initial study of Chavín gallery acoustics led to the proposal that "the quick transition to the late field along with the large fraction of energy arriving after the direct path would tend to obscure the perceived arrival direction and perhaps distance cues" [51]. In subsequent research, Kolar conducted in-situ auditory localization experiments with volunteer participants to evaluate that hypothesis. Kolar's study found, in contrast, that auditory localization cues are sufficient for accurate directional localization in many places, with accuracy linked to the position(s) of aperture(s) within the waveguide-like corridors and small rooms: multiple sound paths enhanced localization accuracy for both direction and distance [15]. However, distance localization in Chavín's interior architecture is complicated by strong axial and tangential modal resonances [52] that skew spectral balance, as well as the greater relative difficulty in accurate distance perception compared to directionality. Therefore, the explication of auditory distance cues in Chavín's unique architecture requires additional research.

One starting point towards a comprehensive characterization of Chavín's unusual interior acoustics is the comparison of standard acoustical metrics for distance cues from Chavín's waveguide-like architecture with measurements from diffusive, single-volume rooms, such as CSA and RSB. We focus here on metrics from direct-path acoustical impulse response measurements from several separate spaces within Chavín's interior architecture: from a typical gallery (Laberintos) and also from one area of the subterranean canal system (Rocas, under the Circular Plaza) that is similar to gallery architecture, but with a stone floor and decreased cross-sectional area (lower ceilings and narrower widths). Table 3 (below) gives metrics computed from these selections of Chavín IRs calculated using EASERA software, following the format of Table 2 (above), for comparison with impulse responses collected in the historical studio and bank. Note the theoretical match with the reference values measured on axis at 1 m.

Table 3. Acoustical metrics from the interior architecture of Chavín de Huántar, Perú: calculated (using EASERA software) from a variety of direct-path impulse response (IR) measurements using the repeated exponential sinusoidal sweep method. Source reproduced using a Meyer MM-4XP directional single-driver loudspeaker (as a proxy for speech-signal directivity, for ecological validity); receivers were Countryman B6 omnidirectional microphones at an average human head-height.

Comparison of Acoustical Metrics from Representative Architectural Structures at Chavín de Huántar	**Laberintos: Corridor Typical of Galleries**	**Rocas Canal: Atypical Dimensions; Low Ceilings; Stone Floors**		
	Direct Path	**Reference at 1 m**	**Direct Path under Vertical Chimney**	**Direct Path adjacent to Wall Niche**
Distance from Source	7.58 m (8 m)	0.99 m (1 m)	8.76 m (9 m)	6.7 m (7 m)
Reverb Time (T30, 400–5 kHz); due to dimensions, RT longer in frequencies < 300 Hz	0.614 s	0.098 s	0.158 s	0.13 s
Level (relative reduction)	N/A	0 dB-FS (reference)	−13.8 dB-FS	−13.6 dB-FS
Direct to Reverberant Ratio (DRR)	1.4 dB	24 dB	4.8 dB	9.9 dB
Definition (D)	0.888	1	0.954	0.992

Short T30 reverb times (above 400 Hz) and high definition values are consistent across a variety of Chavín interior source–receiver contexts at similar distances; RT within a space is not uniform in part due to modal activity. Note the extremely short RTs for comparable distances between source and receiver in the Rocas canal; the cross-sectional area of any canal at Chavín is approximately 1/4 to 1/2 of that of a gallery, though the long dimensions of canals in many areas are similar to gallery corridors, and floor materials contrast between slate tiles for the canals and packed earth for the galleries. In the Chavín analyses, RT30 and D from the Laberintos Gallery measurement (8 m direct path) are similar to those from the case-study recording studio (CSA at 6 m direct path), whereas the Chavín canal measurements at similar distances (7 and 9 m) show much lower reverb time, significantly higher DRR, and high D values. All Chavín and CSA metrics contrast significantly with those from the more voluminous bank (RSB), which is not a surprise given the dimensional differences. However, a comparison of isolated metrics without situating them in spatial relationships within site architecture and with respect to cultural use scenarios tells an incomplete story about the relationships of these cues to distance perception in those spaces.

Mapping changes in metrics throughout a space can aid in the contextualization and therefore accurate interpretation of findings, as demonstrated with sound-level measures in Chavín's Lanzón Gallery (LAN). Due to the reconstructive computational modeling applications with archaeoacoustical data collected at Chavín, we typically make reference sound-level measurements in fieldwork there using hand-held sound-level meters. Figure 6 (below), shows a floorplan of the Lanzón Gallery (adapted from laser-scan study by Sylvia R. Kembel [49]), annotated with measured sound-level readings between one selected sound source (marked S3) — broadband noise reproduced through a directional, single-driver loudspeaker as a proxy for human vocal directivity—and a range of receiver locations. Table 4 (below) charts the sound-level study that is mapped in Figure 6 and provides free-field propagation estimates for the same distances for comparison.

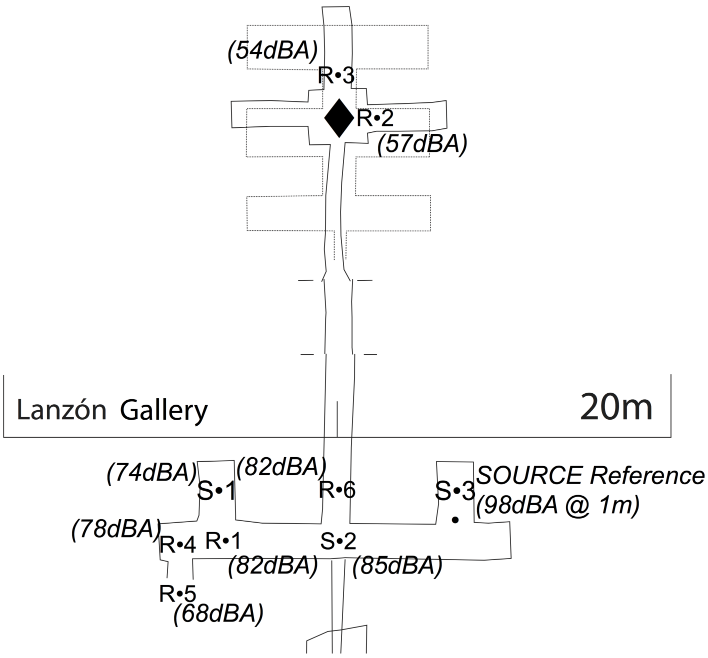

Figure 6. Mapped locations of sound-level measures (peak dB-SPL, A-weighted) of broadband noise in the Lanzón Gallery at Chavín, from directional source (Meyer MM-4XP single-driver loudspeaker) at average human head-height for ecological validity with speech communication. Reference measurement 98 dBA@1 m on-axis from the loudspeaker (floorplan from [49]). Analysis charted in Table 4 (below). 3D model of gallery shown in Figure 3 (above).

Table 4. Sound-level measures, dB-SPL (A-weighted), Lanzón Gallery, Chavín, from directional broadband noise source 98 dBA@1 m. Survey map Figure 6 (above) shows spatial relationships.

Survey Location	Location Features	Approx. Distance from Source	Measured Sound Level (peak dBA)	Measured Reduction from SOURCE in NE Alcove: 98 dBA@1 m	vs. Estimated Level (dB) (Freefield)	vs. Estimated Reduction (dB) (Freefield)
S1—in SE alcove	2 corners	10 m	74	−24	78	−20
R4—SE end	2 corners	9 m	78	−20	79	−19
R5—just outside SE open door	elevated doorway; 2 corners	10 m	68	−30	78	−20
R1	1 corner	8 m	82	−16	80	−18
S2	intersection; 1 corner	4 m	85	−13	86	−12
R6—EW corridor	2 corners	6 m	82	−16	82	−16
R2—beside monolith	adjacent volume; 3 corners	18 m	57	−41	73	−25
R3—behind monolith	adjacent volume; 3 corners	20 m	54	−44	72	−26

In the sound-level survey of Chavín's Lanzón Gallery, it is interesting to note that for many measures, level changes over distance are comparable to those expected in free space, which suggests robust auditory distance cues. However, per results from Kolar's previous auditory localization experiments in Chavín galleries [15], strong modal resonances were associated with a decrease in accuracy of distance perception. The high-frequency spectral reductions from air absorption that may be relevant to distance perception in the well-mixed historical rooms of our study may be less relevant in Chavín's modally active interior architecture. Within a particular acoustical setting, cross-comparison of several acoustical metrics—evaluated in terms of the spatial relationships between sources and receivers with respect to architectural forms and cultural-use contexts—is necessary to evaluate the acoustical factors relevant to proxemics, the socio-cultural experience of distance in a space. Our cross-comparison of the same metrics and measurement strategies across architecturally and culturally distinct heritage sites further demonstrates the importance of context to heritage acoustical data: that context is both inherent to the site, but selectively emphasized in data via the determination of sound source and receiver positions for acoustical measurements. Aural heritage data by definition translate spatial-perceptual relationships in acoustical terms.

3.3. Cross-Comparisons in the Evaluation of Distance-Related Acoustical Metrics in Aural Heritage Research

Architectural and corresponding acoustical contrasts between the uniformly diffusive historical rooms and the modally active archaeological spaces of our study imply the contextual utility of particular acoustical metrics. By focusing on the socio-cultural question of contextual distance perception (proxemics), we identified acoustical metrics associated with distance cues as being particularly informative to heritage acoustics research. While reverberation time and DRR metrics stand out in our comparison of acoustical contrasts with respect to distance relationships among survey points in the two historical case-study spaces, the most useful metric in beginning to evaluate acoustically scaled distance relationships for the ancient architecture appears to be measured sound level. That is not to say that sound level is not informative regarding the historical rooms or that reverberation has no relevance in the archaeological architecture; rather, a range of acoustical metrics associated with auditory distance cues must be evaluated at each site to determine which cues are the most contextually operational.

We tested our methodological premises and fieldwork praxis for aural heritage research across structurally, culturally, and acoustically contrasting heritage sites. Particularly in the contrast between Chavín's architecture and the two historical rooms, we found that each of the acoustical metrics relevant to auditory distance cues illuminates different spatial relationships not only scaled architecturally but scaled according to places within the architecture that humans can be located as receivers of sound from contextually plausible source locations. Depending on the architectural paradigm and use function of a space, different acoustical metrics were more useful in demonstrating the heritage site's proxemical affordances in terms of its socio-cultural context. For example, because the frequency spectrum is notably skewed by strong modal resonances in Chavín architecture, sound-level difference estimations may be more salient in providing auditory distance cues within that specific acoustical environment. In contrast, reverberation metrics align with proxemical estimations related to speech and music communication scenarios in the two historical rooms. The aural heritage data collection strategy (ecologically valid source–receiver configurations across a range of proxemical scenarios) illuminates contextual factors that influence the utility of particular acoustical metrics. Depending on architectural features, a given acoustical metric associated with auditory distance cues will be more or less useful for characterizing the ways that acoustical distance relationships relate to proxemics in that site. For continued research, the interaction between auditory distance cues in each case-study acoustical environment merits exploration to identify trade-offs between the contextually present cues.

4. Concluding Proposal: Human-Centered Data Collection in Aural Heritage Research

Room acoustical measurements involve selecting source and receiver locations that are in some way representative of the architectural features of a space. These locations determine the spatial acoustical perspectives recorded in that data: "spatial acoustical samples", we will call them here, following terminology by computational acoustics modeling pioneer Julius O. Smith III [53]. Comprehensive spatial sampling to populate wave-propagation models is time-consuming and requires specialized equipment and techniques customized to the particular features of a space. Reductionist sampling techniques for room acoustics tend to focus on key architectural features and presentational paradigms, particularly related to musical performance venues or speech communication applications. Analogous to these reductionist models for the spatial sampling of room acoustics, our proposal to prioritize human-centered factors (plausible and socio-culturally appropriate human receiver and source locations) constitutes a methodologically parallel approach. Aural heritage data collected in this way represent a spatially scaled range of auditory distance cues that can be evaluated via contrasts in associated acoustical metrics. This aural heritage spatial sampling strategy ensures that human perspectives on the soundfield are included to cover the range of possible proxemics (socio-contextual distance perceptions) in that space.

In summary, to conceptualize aural heritage data collection, we propose that spatial acoustics be sampled according to human-centered perspectives, particularly to represent the range of proxemical relationships that each heritage site space enables and constrains. This conceptual shift from architectural acoustical sampling to aural heritage sampling prioritizes culturally and physically plausible human auditory/sound-sensing perspectives and relates them to the socio-cultural functionality of a space as scaled by its architecture. Fieldwork conceptualized in this way ensures human-centered documentation and preservation of heritage acoustics, aligning data collection with the anthropological concerns fundamental to cultural heritage research and preservation.

We recognize that computational acoustical modeling is a powerful and useful tool for heritage reconstructions. However, acoustical modeling techniques do not comprehensively reconstruct the soundfield but rather produce estimations based on specific architectural features or spatial sampling strategies. Therefore, it is a reasonable proposition to conceptualize aural heritage data collection according to survey locations that spatially represent human sound receivers and contextually appropriate sound sources and to prioritize the translation of these spatial perspectives in heritage acoustical modeling. As noted previously, binaural and ambisonic microphone techniques and spatial microphone arrays strengthen the ecological validity of measurements and enable spatially accurate auralization reconstructions. In combination with the human-centered and site-responsive contextualizing strategy we propose for ecological validity, these equipment techniques can produce data that accurately preserve realistic human perspectives on cultural heritage acoustics.

Accuracy in spatial translation is a key aspect of both the documentation of aural heritage data collection and for computational reconstructions using these data. The realism of collected data depends on equipment precision and survey configurations; however, realism in its application is tied to the translation of spatial relationships and the scaling of those relationships in reproductions, such as auralization demonstrations and analytical acoustical models. In aural heritage measurements, microphone receivers are proxies for human listeners/sensors of realistically located sound sources. Acoustical data from aural heritage measurements encapsulate the spatial relationships among source, receiver, and architecture selected during the data collection process. Therefore, the acoustical impulse responses (IRs) generated in the measurement process will produce accurate auralizations if measured spatial relationships are preserved in reconstructive computational modeling and audio reproduction techniques using these IRs. Contextually appropriate sonic materials further enhance the ecological validity of reconstructive research and demonstrations using the aural heritage data if accurate spatial translations are preferred. The ability to translate preserved data into representative computational models and spatial audio reproductions also depends on documentation of the data collection process, a topic of interest to our ongoing research project.

Through a meta-analysis of this aural heritage work as room-measurement praxis (and considering the methodologies we three researchers brought to this project from our prior work in room acoustics), we propose that such perspective-range-sampling selection of source–receiver relationships demonstrates implicit conceptualization of the distance of sound transmission and reception according not only to architectural scale but to the socio-cultural proxemics that are emphasized and constrained by architectural design. Although we expect coincidences in spatial acoustical sampling techniques between "human-centered" room acoustics research (as per as our aural heritage paradigm) and measurement approaches more focused on architectural acoustical parameterization and auralization specifically as "the auditory presentation of acoustical numerical models" (i.e., the exemplary research discussed by Katz, Murphy, and Farina [54]), to serve the aims of heritage preservation, there is particular need to prioritize plausible human perspectives and contextually appropriate sound sources in heritage acoustical fieldwork.

Ensuring a proxemically comprehensive range of distance relationships in measured acoustics of cultural heritage sites, therefore, relates architectural and culturally pertinent landform spaces to spatial perception in salient ways. Designing aural heritage measurements that anticipate and represent contrasts in the proxemics afforded by a particular space is a useful strategy towards a humanly comprehensive preservation of acoustical heritage. Given the combined cultural and perceptual contextualizations of spatial acoustics in aural heritage research, the concept of distance emerges as a question of relative distance perception with respect to setting-contextualized proxemics rather than one dictated by metrics. Future research on sound-sensing proxemics and the parsing of measureable acoustical cues that inform these perceptual–spatial understandings will enable greater specificity in the development of guidelines for comprehensive spatial acoustical sampling of proxemical space in a heritage site. We are exploring these topics in the ongoing research of our aural heritage project, implementing perceptual experimentation to evaluate collected aural heritage data and auralizations created with these data.

We have presented this aural heritage fieldwork framework as a starting point for continued explorations and methodological refinements. Perceptually and contextually structured spatial acoustical sampling enables systematic explorations of human auditory/sound-sensing implications of the undervalued sonic dimension of cultural heritage.

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
BCE	Before Common Era (date reference)
IR	Impulse Response
DRR	Direct-to-Reverberant Energy Ratio
RT	Reverb Time (T30)
CSA	Columbia Studio A, Nashville, TN, USA
RSB	Rochester Savings Bank, Rochester, NY, USA
LAN	Lanzón Gallery at the Chavín de Huántar archeological site, Áncash, Perú

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