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# A pilot framework for heritage-oriented soundscape analysis: Development and testing of the Materialized Sonic Memory Index in Chinese urban public spaces

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## Abstract

Sound is a significant yet frequently neglected aspect of how people experience architectural heritage. Cultural memory in Chinese heritage-oriented public space is shaped not only by visual form and material surface but also by the repetition of human and natural sound, by spatial enclosure, and by the masking effect of mechanical noise. This article develops and tests a pilot analytical framework for interpreting soundscape features and their relationship to cultural meaning-making through the concept of materialized sonic memory. Using a publicly available integrated multimedia database of urban soundscape surveys (the International Soundscape Database), 1,831 cleaned questionnaire records from eight non-heritage public-space sites in Shenyang and Shenzhen, China, were analyzed. The study computes ISO-style pleasantness and eventfulness coordinates, classifies dominant sound sources, and introduces the Materialized Sonic Memory Index (MSMI) to gauge the balance among culturally significant human and natural sonic presence, perceived pleasantness, and mechanical noise disturbance. Soundscape quality varied significantly across locations (one-way ANOVA, $F = 26.91$, $p < 0.001$ for MSMI); three Shenzhen park sites achieved the highest MSMI values (0.44–0.48), while four Shenyang civic squares showed strong negative cultural sonic balance. Human-sound-dominant typologies produced the strongest MSMI values (0.93 and 0.83); chaotic-negative traffic- and other-noise-dominant typologies yielded the weakest (−0.79 and −0.75). All variance inflation factors remained below 1.10, ruling out multicollinearity. A four-scheme weight-sensitivity analysis confirmed that the MSMI location ranking is robust to alternative weighting choices. Because none of the eight sampled sites is officially designated as a heritage site, the findings are presented as a methodological proof-of-concept that establishes a reproducible computational route from soundscape data to heritage-oriented architectural interpretation, providing a foundation for future fieldwork at officially designated heritage settings.

***Keywords:*** Chinese architecture; Heritage space; Acoustic perception; Cultural construction; sonic memory; Integrated multimedia database; Chinese cities

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## 1. Introduction

The traditional approaches to Chinese architectural heritage have been based on spatial form, construction technique, urban morphology, ornament, ritual order, and continuity. These dimensions cannot be replaced, but they do not fully capture how people experience heritage-oriented spaces in everyday life. Footsteps, voices, birdsong, water sounds, bells, performance, and the intrusion of traffic or mechanical sound are all part of the lived experience of a temple courtyard, a traditional village lane, a market street, a ritual square, or an urban park associated with local memory. Recent soundscape research therefore conceptualizes the acoustic environment as a perceived and contextually integrated state rather than as an object of decibel regulation in isolation (Hedfors *et al.*, 2025; Kang, 2023).

This shift toward perception-based soundscape research is especially important for Chinese architecture because many culturally meaningful spaces are living spaces rather than silent monuments. Soundscapes in European and Chinese public spaces have been shown to vary significantly with geographical and cultural context, which means that acoustic interpretation cannot be abstracted from place, social practice, and spatial memory (Aletta *et al.*, 2023; Ozturk *et al.*, 2025). Intangible cultural heritage, in particular, has a strong spatial basis. Geographic information system-based analyses of China demonstrate that heritage resources are unevenly distributed and shaped by intersecting regional, economic, and geographical conditions (Pang & Wu, 2023; C. Zhang *et al.*, 2025; Z. Zhang *et al.*, 2024). At a regional scale, studies along the Grand Canal, the Yellow River basin, and the ancient Qin–Shu roads show that intangible heritage is embedded in routes, settlements, and waterways with their own acoustic characteristics (Liu *et al.*, 2022; Mao *et al.*, 2025; S. Zhang *et al.*, 2024; Z. Zhang *et al.*, 2022). These findings indicate that intangible heritage should not be treated as a disembodied practice; it also requires architectural settings, routes, thresholds, surfaces, gathering places, and acoustic conditions that allow cultural practice to be heard, repeated, and remembered (Hu *et al.*, 2024; Sun *et al.*, 2024).

This article proposes and operationalizes the concept of materialized sonic memory. The term refers to the process through which recurring sounds become attached to architectural and public-space settings through spatial enclosure, surface material, movement pattern, vegetation, water features, and collective cultural interpretation (Deacon *et al.*, 2026). The concept builds on growing evidence that soundscape perception can influence sense of place and place attachment in historical and cultural areas (Z. Chen *et al.*, 2024; N. Li *et al.*, 2025; Yang *et al.*, 2024). It also extends existing soundscape context theory, which defines the sonic context of a space as the non-acoustic spatial, physical, and socio-cultural attributes within the experience scene (R. Zhang *et al.*, 2025).

The present study uses the China-focused subset of a publicly available integrated multimedia database that includes Chinese public-space sites in Shenyang and Shenzhen and that has been used in previous large-sample comparative work (Aletta *et al.*, 2023). The dataset combines in situ questionnaire data with standardized soundscape assessment protocols collected across multiple public-space locations in these two cities. None of the eight sampled sites is officially designated as an intangible cultural heritage architectural site. Accordingly, this article does not claim to evaluate the full range of Chinese heritage architecture; it develops and tests a transferable analytical framework that future fieldwork can apply to officially listed heritage buildings and districts (Y. Li *et al.*, 2025; D. Zhang *et al.*, 2025; Zhu *et al.*, 2024).

The study addresses four research questions. First, what are the main soundscape characteristics of the cleaned China subset? Second, how do sound-source dominance, pleasantness, and eventfulness differ across the eight locations? Third, can materialized sonic memory be operationalized through a transparent and reproducible index? Fourth, what design and conservation implications follow for heritage-oriented Chinese architectural spaces? The contribution is threefold: the article develops the Materialized Sonic Memory Index (MSMI), applies it systematically to a cleaned China-focused soundscape dataset, subjects the index to variance-inflation, location-stratified, and weight-sensitivity diagnostics, and translates the results into actionable strategies for the design and conservation of culturally meaningful architectural spaces.

The remainder of this article is organized as follows: Section 2 describes the data source, preprocessing, mathematical formulation of the MSMI, and statistical methods; Section 3 reports location-level results, soundscape circumplex analysis, correlation and regression diagnostics (including variance inflation factors [VIFs] and location-stratified regression), the typology analysis, and a weight-sensitivity test of the index; Section 4 discusses what the results mean for Chinese public-space soundscapes, links the findings to vernacular Chinese architectural typologies and surface materials, presents conservation and design implications, and outlines limitations and a research roadmap; Section 5 summarizes the main findings and concludes the article.


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## 2. Data and methods

### 2.1. Theoretical background and conceptual framework

Soundscape research has moved beyond noise-level minimization and now emphasizes how individuals listen to, judge, and construct meaning from the acoustic environment around them. Quantitative soundscape analysis has converged on a representation of perceptual quality along two orthogonal axes, pleasantness and eventfulness, which together define a circumplex space capable of describing the spectrum of soundscape experience (Mitchell *et al.*, 2022). More recent studies have developed single-value soundscape perception indices that summarize multidimensional perceptual quality into a portable comparative measurement (Mitchell *et al.*, 2024). This methodological advance directly motivates the MSMI proposed in the present study.

Soundscapes also help sustain place attachment: through repeated acoustic signals, they allow people to identify, evaluate, and emotionally bond with a place over time. Studies comparing residents and tourists in heritage park environments reveal that these groups perceive natural, human, and mechanical sound sources differently, supporting the claim that sonic meaning is informed by familiarity, anticipation, and a relational past with a place (Yang *et al.*, 2024). Soundscape context theory further explains that the meaning of a sound depends as much on the non-acoustic spatial, physical, and socio-cultural qualities of a space as on the acoustic signal itself (R. Zhang *et al.*, 2025). Studies of Greenlake Park in Kunming indicate that the presence of natural sound is positively correlated with acoustic environment evaluation and pleasure perception, whereas sound pressure level and mechanical sound perception are significantly negatively correlated with the outcome (Tian *et al.*, 2023). Work on Hakka traditional villages demonstrates that landscape–soundscape interaction shapes visual satisfaction, acoustic comfort, and audio-visual harmony, showing that sound is central to heritage experience (D. Zhang *et al.*, 2025); temple soundscape research and the Great Wall audio-visual study provide direct evidence that auditory evaluation affects visitor satisfaction and restorative experience at iconic heritage sites in China (Y. Li *et al.*, 2025; Zhu *et al.*, 2024).

In this article, materialized sonic memory is defined as the degree to which the soundscape of a building or public space supports the culturally meaningful identification, emotional acceptance, and repeated recollection of that specific place. The qualifier materialized signals that sonic memory is not a purely cognitive or psychological process. The concept builds on three converging lines of scholarship. First, memory studies and cultural geography work argue that collective memory is anchored in material settings and recurring practices rather than in individual minds alone. Second, heritage theory increasingly recognizes that intangible cultural heritage is sustained through tangible spatial structures—routes, courtyards, thresholds, gathering nodes—that allow recurring practice and audibility (Hu *et al.*, 2024; Sun *et al.*, 2024). Third, soundscape context theory shows that the meaning of a sound is co-produced by the non-acoustic spatial, physical, and socio-cultural attributes of the experience scene, so soundscape and architecture cannot be analyzed in isolation (R. Zhang *et al.*, 2025).

Sound becomes materialized in architectural space through several interacting mechanisms that go beyond a generic reference to spatial enclosure and surface materials: (i) repeated practice, whereby ritual, market, performance, and everyday social uses inscribe sound on a space by recurring on predictable temporal cycles; (ii) spatial geometry and enclosure ratio, where courtyard depth, wall heights, and openings shape reflection, reverberation, and the spatial reach of voices and natural sound; (iii) surface materials such as rammed earth, glazed tile, wood, screen-wall plaster, and bluestone paving, which differ in absorption and reflection and so privilege different sonic textures; (iv) vegetation, water, and microclimate, where planted edges, water features, and wind-exposed openings introduce seasonal and circadian natural sounds that bind cultural memory to the rhythms of place; and (v) social interpretation, whereby communities ascribe cultural meaning to particular sonic events that then orient attention and shape the perceived value of the space (Y. Li *et al.*, 2025; Yang *et al.*, 2024; D. Zhang *et al.*, 2025). The framework analyzes three dimensions of this process that are analytically separable: the composition of sound sources, the affective quality of the soundscape, and the level of mechanical noise disturbance.

Table 1 situates the present study within this literature, identifying the contribution of key works and the specific gap that the present framework addresses. The conceptual framework is shown in Figure 1.

Figure 1 is read from left to right: architectural space (geometry, materials, vegetation, water, circulation) and cultural interpretation (rituals, practices, social use) jointly produce a perceived soundscape whose affective quality, sound-source composition, and mechanical disturbance level together determine the materialized sonic memory of the place. The three analytical components on the right (cultural sonic balance [CSB], pleasantness, and mechanical disturbance) are the inputs to the MSMI defined in Section 2.3.

**Table 1. Comparative summary of recent literature and the contribution of the present study**

| Study | Context | Approach/focus | Relevance to the present work |
|---|---|---|---|
| Mitchell *et al.* (2022) | Quantitative soundscape representation | Soundscape circumplex; pleasantness and eventfulness axes | Provides the two perceptual coordinates adopted in the MSMI framework |
| Aletta *et al.* (2023) | Europe–China comparative survey | Large-scale on-site standardized survey protocol | Demonstrates cultural and geographical variation; no heritage-oriented index |
| X. Chen *et al.* (2024) | Real-world soundscape interventions | Taxonomy of spatial, governance, programming strategies | Guides design translation of results; not applied to Chinese heritage spaces |
| Z. Chen *et al.* (2024) | Taiyuan's historical and cultural areas | Mixed methods; sense-of-place and acoustic comfort | Empirically links soundscape and place meaning; no MSMI |
| Yang *et al.* (2024) | Residents and tourists in heritage parks | Place attachment and sound-source preference | Motivates differentiation of human-natural and mechanical sonic presence |
| R. Zhang *et al.* (2025) | Soundscape context theory | Systematic review; non-acoustic spatial and socio-cultural attributes | Theoretical basis for treating heritage architecture as a soundscape context |
| D. Zhang *et al.* (2025) | Hakka traditional villages | Audio-visual interaction experiment | Supports acoustic and visual integration; lacks a reusable index |
| Y. Li *et al.* (2025) | World Heritage temples | Soundscape perception and emotional response | Shows that heritage spaces have culturally specific sonic values |
| Zhu *et al.* (2024) | Great Wall of China | Audio-visual satisfaction and restoration model | Confirms heritage sound contributes to visitor experience |
| Present study | ISD China subset (Shenyang and Shenzhen) | MSMI construction; typology; full statistical pipeline (VIF, weight sensitivity) | Reproducible pilot index linking soundscape analysis with heritage architectural interpretation |

Abbreviations: ISD: International Soundscape Database; MSMI: Materialized Sonic Memory Index; VIF: variance inflation factor

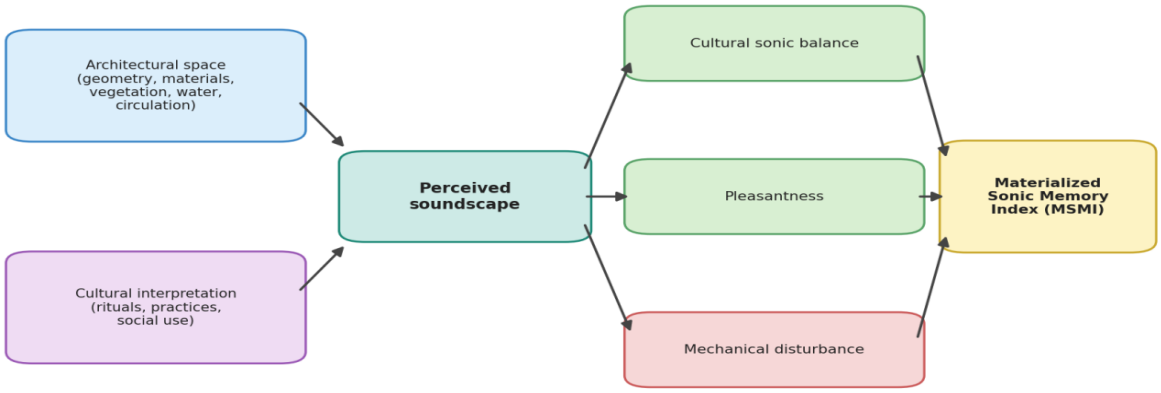



**Figure 1.** Conceptual framework of materialized sonic memory. Source: Diagram by the authors

### 2.2. Data source and preprocessing

This study uses a publicly available integrated multimedia database of urban soundscape surveys (the International Soundscape Database [ISD]) that combines in situ questionnaire data with binaural audio recordings, A-weighted sound-level readings, and spatial and contextual metadata collected through a standardized soundscape assessment protocol. The dataset has been used in earlier comparative studies of European and Chinese soundscape experience (Aletta *et al.*, 2023). The current analysis relies on the China-specific subset to align with the scope of the Journal of Chinese Architecture and Urbanism and the purpose of building a heritage-oriented framework based on Chinese public-space experience. None of the sites in the subset is an officially designated heritage site or a formally registered site associated with intangible cultural heritage. Accordingly, this article presents a pilot framework and uses the provided China subset as a representative empirical background to build and test the MSMI before future fieldwork at formally registered heritage sites.

The raw ISD dataset contained 3,589 records across 142 columns. Preprocessing followed a 12-step algorithm (Table 2), beginning with the construction of a composite unique identifier formed by concatenating the location, session, group, and record identifier fields. Record identifiers alone are not unique across field sessions, and their naïve use would cause false duplicate removal. Exact duplicate rows sharing the same composite key were removed, followed by the extraction of the eight China-focused locations across Shenyang (four locations: Olympic Square, Dadong Square, Zhongshan Square, Zhongshan Park) and Shenzhen (four locations: Pingshan Park, Pingshan Street, Lianhuashan Park Entrance, Lianhuashan Park Forest). The four perceived sound-source variables (ssi01–ssi04: traffic noise, other noise, human sounds, natural sounds) and the eight soundscape descriptor variables (pleasant, chaotic, vibrant, uneventful, calm, annoying, eventful,

**Table 2. Twelve-step preprocessing and analysis pipeline, with the resulting record counts at each stage**

| Step | Operation | Output |
|---|---|---|
| 1 | Load raw soundscape questionnaire and metadata files (CSV and XLSX) | Raw data matrix (3,589 × 142) |
| 2 | Construct composite key: LocationID + SessionID + GroupID + RecordID | Reliable unique row identifier |
| 3 | Remove exact composite-key duplicates | Deduplicated records |
| 4 | Extract China-focused records (Shenyang and Shenzhen) | China subset (1,891 records) |
| 5 | Audit missing values; remove rows with incomplete key perceptual variables | Complete-case subset |
| 6 | Validate Likert range (1–5) for all source and descriptor columns | Range-clean records |
| 7 | Validate participant age (10–99) | Age-filtered records (1,887) |
| 8 | Compute ISO pleasantness and eventfulness; apply interquartile range outlier filter (factor = 1.5) | Final 1,831 main records |
| 9 | Compute HN, MN, CSB, Z-scores, and MSMI (Equations 1–6) | Derived analytical variables |
| 10 | Classify soundscape quadrant and dominant source; build sonic-memory typology | Typology labels |
| 11 | Run city-level, location-level, correlation, regression (VIF + stratified), and weight-sensitivity analyses | Statistical tables and figures |
| 12 | Interpret results for heritage-oriented architectural conservation and design | Design implications |

Abbreviations: CSB: Cultural sonic balance; HN: Human–natural sonic presence; ISO: International Organization for Standardization; MN: Mechanical sonic presence; MSMI: Materialized Sonic Memory Index; VIF: Variance inflation factor


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monotonous) were then subjected to range validation, with any values outside the expected Likert scale of one to five removed. Age values outside the range of 10 to 99 were also excluded. Tukey interquartile range outlier removal with a factor of 1.5 was applied to the International Organization for Standardization (ISO) pleasantness and eventfulness scores computed from the cleaned descriptor data, yielding a final main dataset of 1,831 records. A supplementary acoustic subset of 450 records, retaining only rows with valid A-weighted acoustic indicators, was used for supplementary analysis. The Shenyang:Shenzhen record ratio is approximately 5.59:1; Table 2 documents the full preprocessing pipeline together with the resulting record counts at each stage.

### 2.3. Mathematical formulation of the MSMI

Each observation is indexed by i = 1, 2, …, n. The four perceived sound-source scores—traffic noise ($T_i$), other noise ($O_i$), human sounds ($H_i$), and natural sounds ($N_i$)—are drawn directly from the ISD questionnaire items ssi01 to ssi04. Each is rated on a five-point Likert scale (1 = not at all, 5 = dominates completely). Human and natural sonic presence is computed as:

$$HN_i = (H_i + N_i) / 2 \quad (1)$$

**Equation 1** treats human and natural sounds symmetrically as the two forms of sonic presence most closely associated with cultural heritage experience, given that both voices and environmental sounds recur across seasonal, ritual, and daily heritage rhythms (Y. Li *et al.*, 2025; Tian *et al.*, 2023). Mechanical noise presence is computed as:

$$MN_i = (T_i + O_i) / 2 \quad (2)$$

**Equation 2** aggregates the two mechanical-source items in the ISD questionnaire (traffic noise and other non-traffic mechanical noise such as construction, ventilation, and amplified equipment) into a single index of mechanical sonic presence. This treatment follows the ISD scoring convention used in earlier large-sample work (Aletta *et al.*, 2023) and is consistent with soundscape studies that group traffic and other mechanical sources together because both function as cultural-signal maskers in heritage-oriented environments (Fang *et al.*, 2024; Tian *et al.*, 2023). CSB is then defined as the signed difference between human-and-natural presence and mechanical presence:

$$CSB_i = HN_i - MN_i \quad (3)$$

Positive CSB values indicate spaces where human and natural sounds dominate the soundscape; negative values indicate mechanical dominance. ISO-style pleasantness is computed from the eight soundscape descriptors following Mitchell *et al.* (2022):

$$P_i = (PL_i - AN_i) + (CA_i - CH_i) / \sqrt{2} + (VI_i - MO_i) / \sqrt{2} \quad (4)$$

In **Equation 4**, $PL_i$ is the rating on the "pleasant" descriptor, $AN_i$ on "annoying," $CA_i$ on "calm," $CH_i$ on "chaotic," $VI_i$ on "vibrant," and $MO_i$ on "monotonous," all on a five-point Likert scale. The three bracketed differences are the antonym pairs of the soundscape circumplex; division of the second and third pairs by $\sqrt{2}$ projects them onto the pleasantness axis of the circumplex (Mitchell *et al.*, 2022). $P_i$ is the only ISO coordinate that enters the MSMI computation. ISO-style eventfulness is used only for circumplex classification and typology construction (Section 3) and is defined after the MSMI formula.

All MSMI components are standardized before combination so that variables with different natural ranges contribute comparably:

$$Z(X_i) = (X_i - \text{mean}(X)) / \text{sd}(X) \quad (5)$$

The MSMI is then calculated as:

$$MSMI_i = 0.35\, Z(CSB_i) + 0.30\, Z(P_i) + 0.20\, Z(HN_i) - 0.15\, Z(MN_i) \quad (6)$$

The weights in **Equation 6** were derived in three steps. First, the four components were ordered theoretically by their conceptual proximity to the construct of materialized sonic memory. CSB directly measures the dominance of culturally meaningful sounds over mechanical noise and is therefore placed first. Pleasantness captures the affective appraisal that mediates extended engagement with a space and is placed second (Yang *et al.*, 2024). Human and natural presence reward spaces where culturally relevant sources are audible even when not dominant. Mechanical noise enters with a negative sign as a masking force that suppresses cultural sonic recognition. Second, the four weights were assigned descending magnitudes (0.35, 0.30, 0.20, −0.15) that respect this ordering and sum to 1.00 in absolute value, following the convention used for composite environmental indices when no validated empirical weighting yet exists (Mitchell *et al.*, 2024). Third, because the weights are theoretically motivated rather than empirically estimated, the robustness of the resulting index is tested in Section 3.5 by re-computing location rankings under alternative weighting schemes. **Equation 6** is thus the working specification of the MSMI; future work with primary heritage-site data may refine the weights through analytic hierarchy process, confirmatory structural equation modeling, or participatory stakeholder evaluation.


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$$E_i = (EV_i - UE_i) + (CH_i - CA_i) / \sqrt{2} + (VI_i - MO_i) / \sqrt{2} \quad (7)$$

where $EV_i$ and $UE_i$ are the eventful and uneventful descriptor ratings, and the remaining symbols are as defined for **Equation 4**. **Equation 7** is reported separately from the MSMI formula because eventfulness is used only for circumplex classification (Section 3.2) and typology construction (Section 3.4), not as an MSMI component.

### 2.4. Variables and statistical methods

Table 3 defines the main analytical variables, specifying their source within the ISD questionnaire, their scale, and their role in the MSMI framework. To assist architectural readers without an acoustics background, ISO pleasantness can be read as a composite score that captures how positively or negatively a soundscape feels overall (combining the pleasant–annoying, calm–chaotic, and vibrant–monotonous descriptor pairs). ISO eventfulness can be read as a composite score that captures how lively or quiet a soundscape feels.

City-level differences between Shenyang and Shenzhen were tested using Welch's *t*-test. Location-level differences were tested using one-way analysis of variance (ANOVA) and Kruskal–Wallis tests. Spearman's rank correlation was used to examine associations among sound-source scores, ISO coordinates, CSB, and the MSMI, because several variables are derived from ordinal Likert data. Ordinary least squares (OLS) regression was used to assess how the four perceived sound-source categories predicted ISO pleasantness, supplemented by VIF diagnostics to rule out multicollinearity and by location-stratified regression to test whether predictor coefficients are driven by specific locations. Effect sizes are reported as Cohen's d for *t*-tests. A weight-sensitivity analysis tests whether the MSMI location ranking is robust to alternative weighting schemes (Section 3.5). To address the unequal Shenyang–Shenzhen sample sizes (1,553 vs. 278), city-level results are cross-checked through a stratified resampling exercise (200 replications with seed = 42) reported in Section 3.3. All analyses were performed in Python 3.10 using pandas, NumPy, SciPy, and Matplotlib.

### 2.5. Methodological workflow

Figure 2 presents the methodological flowchart of the five workflow phases (data loading, preprocessing, variable construction, analysis, and output), color-coded and aligned with the 12-step algorithm in Table 2.

The variable construction phase includes computation of the MSMI components (CSB, HN, MN, $P_i$) and the soundscape circumplex coordinates used for typology

**Table 3. Definition and analytical role of main study variables**

| Variable | Definition | Scale/source | Analytical role |
|---|---|---|---|
| Traffic noise (T) | Perceived presence of mechanical traffic sound | Likert 1–5 (ssi01) | Mechanical disturbance component of CSB |
| Other noise (O) | Perceived presence of non-traffic mechanical noise | Likert 1–5 (ssi02) | Mechanical disturbance component of CSB |
| Human sounds (H) | Voices, activity, and social sounds | Likert 1–5 (ssi03) | Cultural and social sonic presence |
| Natural sounds (N) | Birds, water, wind, and vegetation | Likert 1–5 (ssi04) | Ecological and cultural sonic presence |
| Pleasantness ($P_i$) | ISO affective soundscape coordinate | Composite (**Equation 4**) | Positive appraisal component in MSMI |
| Eventfulness ($E_i$) | ISO activity coordinate | Composite (**Equation 7**) | Soundscape liveliness; quadrant and typology classification |
| Cultural sonic balance (CSB) | HN minus MN (**Equation 3**) | Continuous, range ≈ −4 to +4 | Core cultural indicator; highest MSMI weight |
| MSMI | Materialized Sonic Memory Index (**Equation 6**) | Standardized composite | Primary outcome; heritage sonic supportiveness |

Abbreviations: HN: Human–natural sonic presence; ISO: International Organization for Standardization; MSMI: Materialized Sonic Memory Index; MN: Mechanical sonic presence

assignment. The analysis phase incorporates descriptive, comparative, and regression analyses together with VIF diagnostics, location-stratified regression, and weight-sensitivity testing. The output phase translates the statistical results into architectural and conservation implications.

## 3. Results

### 3.1. Location-level soundscape differences

Materialized sonic memory is most informative at the location scale. Figures 3–6 visualize the location-level distributions of ISO pleasantness, ISO eventfulness, CSB, and MSMI, respectively, across the eight sites, with locations ordered by mean MSMI for comparability.

The trends shown in Figures 3–6 indicate that materialized sonic memory is not evenly distributed. Pingshan Park and the two Lianhuashan Park sub-locations (all in Shenzhen) achieve the highest mean MSMI values (0.48, 0.48, and 0.44, respectively), reflecting strong CSB and pleasantness. Olympic Square is the best-performing Shenyang site (MSMI = 0.16), followed by Dadong Square (MSMI = 0.06). The weakest sonic-memory values are at Pingshan Street, Zhongshan Park, and Zhongshan Square (MSMI = −0.16, −0.16, and −0.18), driven by strongly negative CSB (Zhongshan Square has CSB = −0.58, the lowest in the dataset). The difference cannot be reduced to city identity: Pingshan Street, although located in Shenzhen, performs as poorly as the Shenyang parks. Local spatial form, sound-source composition, and activity pattern appear to be stronger determinants of materialized sonic memory than city-level geography (R. Zhang *et al.*, 2025).

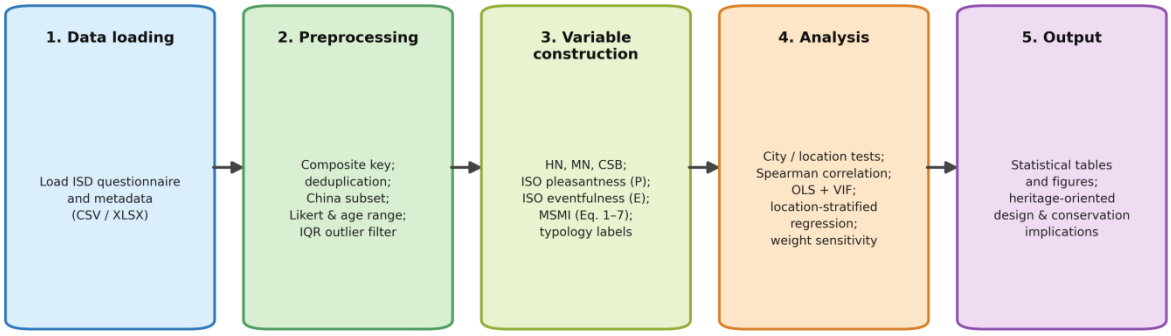



**Figure 2.** Methodological flowchart from data loading to heritage-oriented design implications. Source: Diagram by the authors
Abbreviations: CSB: Cultural sonic balance; E: Eventfulness; HN: Human–natural sonic presence; IQR: Interquartile range; ISD: International Soundscape Database; ISO: International Organization for Standardization; MN: Mechanical sonic presence; MSMI: Materialized Sonic Memory Index; OLS: Ordinary least squares; P: Pleasantness; VIF: Variance inflation factor

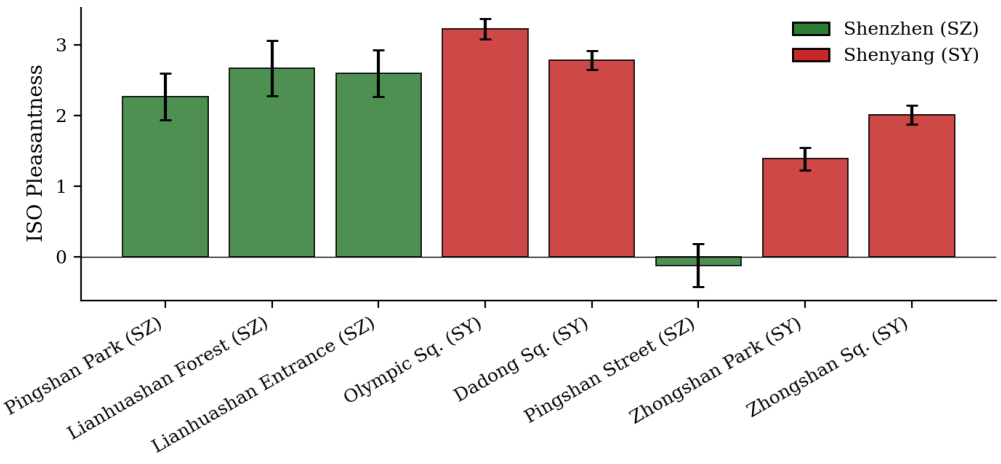



**Figure 3.** Mean ISO pleasantness by location (positive values indicate pleasant soundscapes). Error bars represent ± 1 SEM. Source: Graph by the authors

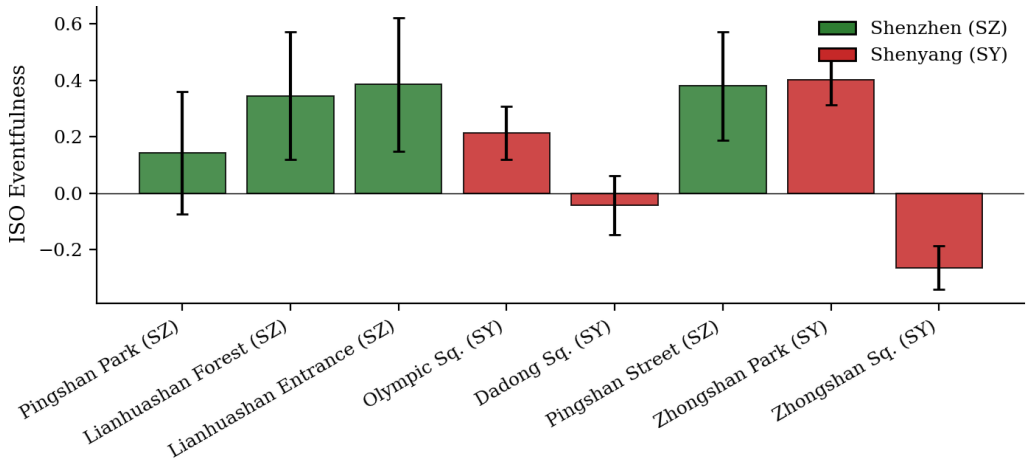



**Figure 4.** Mean ISO eventfulness by location (positive values indicate lively soundscapes). Error bars represent ± 1 SEM. Source: Graph by the authors

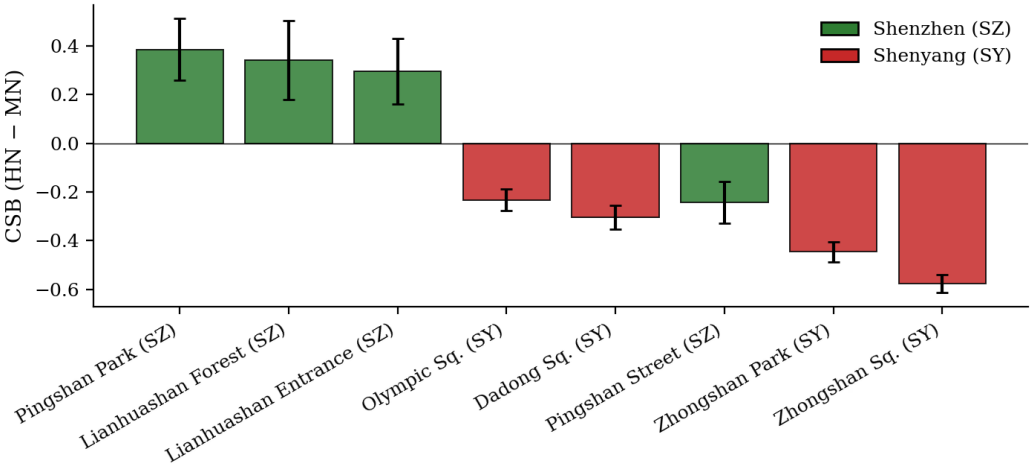



**Figure 5.** Mean cultural sonic balance (CSB) by location. Error bars represent ± 1 SEM. Source: Graph by the authors

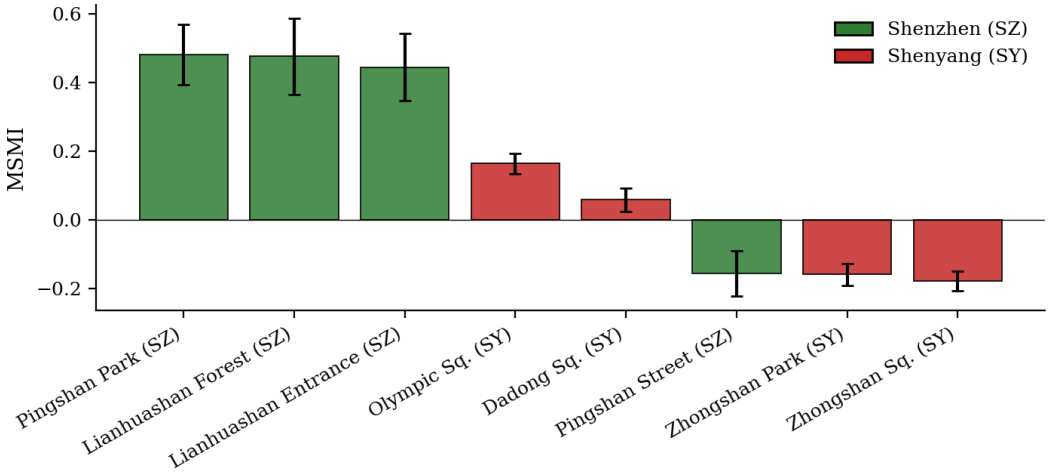



**Figure 6.** Mean Materialized Sonic Memory Index (MSMI) by location. Error bars represent ± 1 SEM. Source: Graph by the authors

### 3.2. Soundscape circumplex and sound-source structure

The soundscape circumplex underpins the MSMI in two ways: it provides the pleasantness coordinate $P_i$ that enters **Equation 6**, and it provides the joint pleasantness–eventfulness coordinates that are used to assign each observation to one of four quadrants for typology construction (Section 3.4). Examining the circumplex distribution is necessary to verify that the cleaned subset spans the perceptual space. Figure 7 plots the soundscape circumplex, and Figure 8 shows the sound-source profile by location.

Figure 7 shows that observations are distributed across all four circumplex quadrants, with a concentration in the vibrant-positive and calm-positive regions consistent with the overall positive mean ISO pleasantness in the subset. This confirms that the MSMI is computed on a perceptually heterogeneous sample. Figure 8 reveals the sound-source mechanism behind the MSMI variation. The three Shenzhen park sites display strong natural-sound presence, whereas the Shenyang civic squares are characterized by elevated mechanical sources alongside moderate human and natural sound, producing the negative CSB shown in Figure 5.

### 3.3. Statistical tests and city-level sensitivity

Table 4 presents the city-level comparison between Shenyang and Shenzhen on the four main analytical outcomes. Because the Shenyang–Shenzhen sample ratio is approximately 5.59:1, the table also reports a stratified-resample sensitivity column, in which 278 Shenyang observations were drawn at random without replacement (seed = 42, averaged across 200 replications) to match the Shenzhen sample size before the test was recomputed.

ISO pleasantness, CSB, and MSMI all differ significantly between cities, and the effect sizes survive the stratified-resampling check with only modest attenuation. This

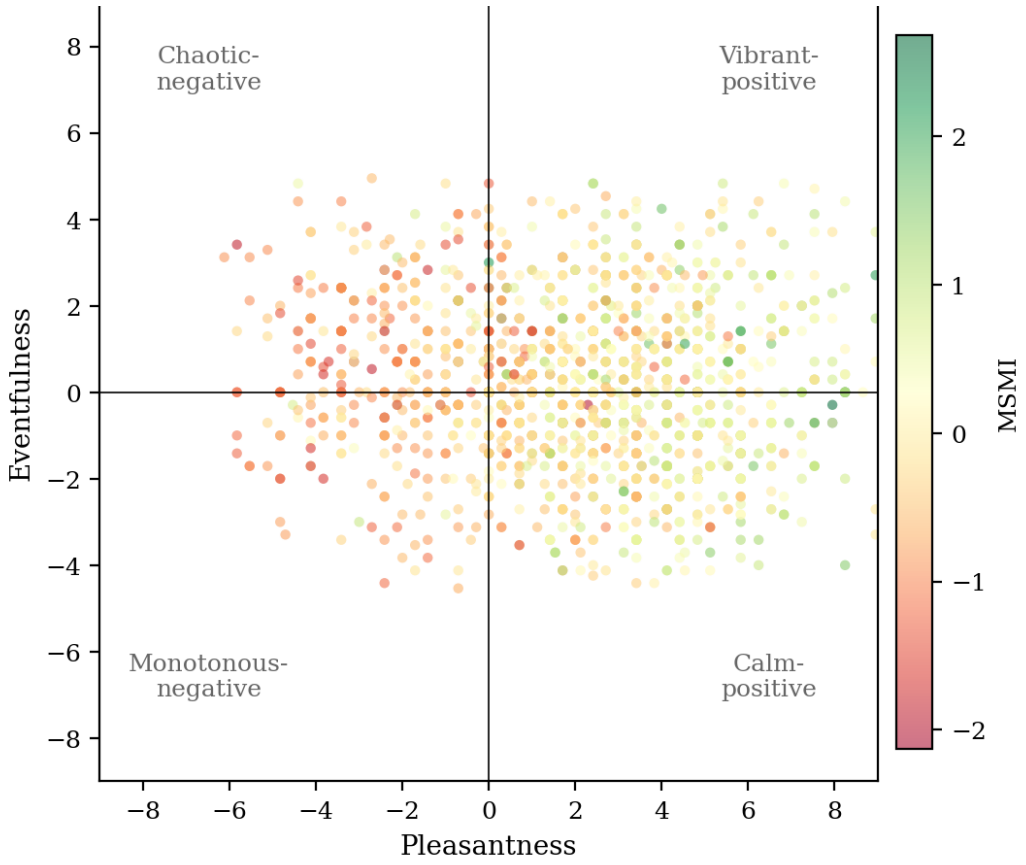



**Figure 7.** Soundscape circumplex of the China subset ($n$ = 1,831). Point color encodes Materialized Sonic Memory Index (MSMI). Source: Graph by the authors

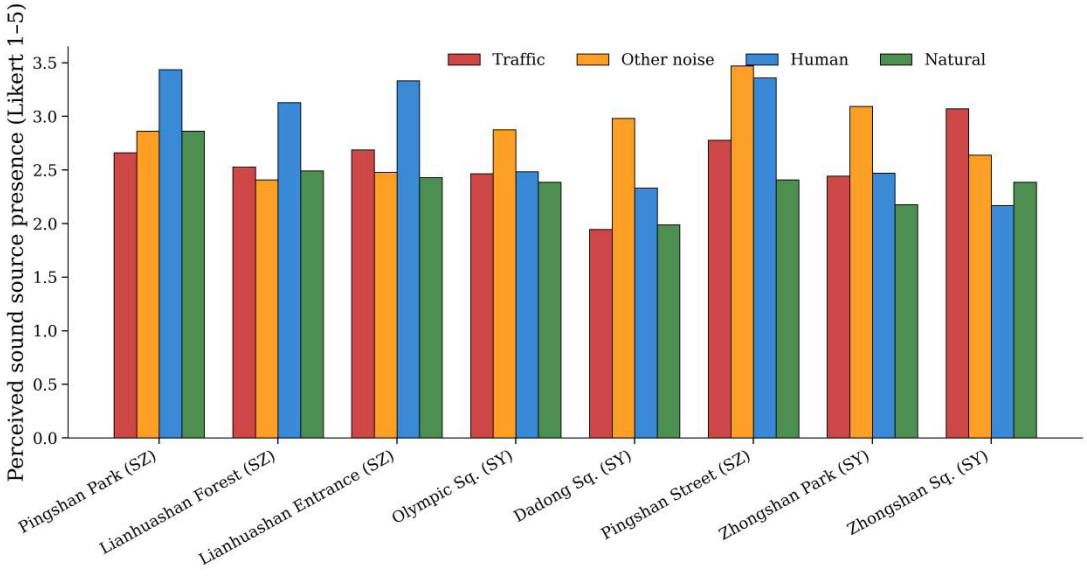



**Figure 8.** Sound-source profile by location. Source: Graph by the authors
Abbreviations: SY: Shenyang; SZ: Shenzhen

**Table 4. City-level comparison between Shenyang and Shenzhen (Welch's *t*-test) with stratified-resampling sensitivity**

| Variable | Shenyang M | Shenzhen M | Welch *t* | *p*-value | Cohen's *d* | Stratified *d* (resampled) |
|---|---|---|---|---|---|---|
| ISO pleasantness | 2.27 | 1.60 | 3.35 | <0.001 | 0.23 | 0.22 |
| ISO eventfulness | 0.07 | 0.32 | −2.12 | 0.035 | −0.14 | −0.13 |
| Cultural sonic balance | −0.41 | 0.14 | −8.23 | <0.001 | −0.62 | −0.57 |
| Materialized Sonic Memory Index | −0.05 | 0.25 | −6.05 | <0.001 | −0.45 | −0.43 |

indicates that the city-level differences are not solely an artifact of unequal sample sizes; the Shenzhen sample (dominated by the three park sites) does carry a more positive CSB than the Shenyang sample (dominated by the four civic squares). These differences should nevertheless be read as indicative rather than definitive, given the small number of sampled sites per city. Table 5 presents the location-level tests across all eight locations.

All four outcomes differ significantly across locations under both parametric ANOVA and non-parametric Kruskal–Wallis tests, with $p < 0.001$ in every case. The convergence of parametric and non-parametric results reinforces confidence that the location-level differences hold under different distributional assumptions and are not artifacts of the ISO composite formula.

### 3.4. Correlation, regression diagnostics, and typology

Figure 9 presents the Spearman correlation matrix for the main analytical variables, and Table 6 presents the OLS regression model predicting ISO pleasantness from the four perceived sound-source scores.

**Table 5. Location-level statistical tests (one-way ANOVA and Kruskal–Wallis)**

| Variable | ANOVA *F* | ANOVA *p* | Kruskal *H* | Kruskal *p* |
|---|---|---|---|---|
| ISO pleasantness | 23.27 | <0.001 | 139.89 | <0.001 |
| ISO eventfulness | 5.61 | <0.001 | 36.28 | <0.001 |
| Cultural sonic balance | 22.27 | <0.001 | 117.03 | <0.001 |
| Materialized Sonic Memory Index | 26.91 | <0.001 | 154.58 | <0.001 |

**Table 6. Ordinary least squares regression predicting ISO pleasantness, with variance inflation factors**

| Predictor | β | SE | *t* | *p*-value | VIF |
|---|---|---|---|---|---|
| Intercept | 4.132 | 0.337 | 12.25 | <0.001 | – |
| Traffic noise | −0.322 | 0.072 | −4.50 | <0.001 | 1.10 |
| Other noise | −0.333 | 0.076 | −4.39 | <0.001 | 1.03 |
| Human sounds | 0.137 | 0.072 | 1.89 | 0.059 | 1.02 |
| Natural sounds | −0.225 | 0.070 | −3.23 | 0.001 | 1.10 |

Abbreviations: SE: Standard error; VIF: Variance inflation factor

All VIFs are well below the conventional threshold of 5 and the more cautious threshold of 2.5 (maximum VIF = 1.10), so multicollinearity does not explain the regression results. The pattern in the correlation matrix (Figure 9) is consistent with the theoretical weighting in **Equation 6**: MSMI is positively associated with human- and natural-sonic presence and ISO pleasantness, and negatively associated with mechanical noise presence. In the regression model, traffic noise (β = −0.322, $p < 0.001$) and other noise (β = −0.333, $p < 0.001$) significantly reduce ISO pleasantness, as expected. Human sounds show a positive but non-significant coefficient (β = 0.137, $p = 0.059$). Natural sounds show a small negative coefficient (β = −0.225, $p = 0.001$), which runs counter to the broader soundscape literature and requires further inspection.

To test whether the negative natural-sounds coefficient is a data-pooling artifact, the model was re-estimated separately for each of the eight locations. Table 7 reports the natural-sounds coefficient and its p-value for each location.

Table 7 reveals that the pooled negative natural-sounds coefficient is driven primarily by two Shenyang civic squares: Olympic Square (β = −0.792, $p < 0.001$) and Dadong Square (β = −0.270, $p = 0.033$). In Pingshan Street, the coefficient is positive and significant (β = +0.842, $p = 0.037$), and in Lianhuashan Park Forest, the coefficient is positive though not significant. The pooled negative coefficient should therefore not be read as evidence that natural sounds are disliked in general. Rather, in mechanically loaded settings such as the large Shenyang civic squares, where traffic and crowd noise occur around the perimeter, natural sounds coexist with sources of disturbance, and adjustment for the other sound-source variables produces a negative adjusted regression coefficient. This pattern is best interpreted as an

**Table 7. Location-stratified ordinary least squares regression: natural-sounds coefficient on ISO pleasantness**

| Location | *n* | β (Natural) | *p*-value | Direction |
|---|---|---|---|---|
| Lianhuashan Park Forest (SZ) | 57 | +0.453 | 0.275 | Positive (n.s.) |
| Pingshan Street (SZ) | 95 | +0.842 | 0.037 | Positive * |
| Lianhuashan Park Entrance (SZ) | 61 | −0.153 | 0.726 | Negative (n.s.) |
| Zhongshan Park (SY) | 427 | −0.023 | 0.891 | Negative (n.s.) |
| Zhongshan Square (SY) | 442 | −0.214 | 0.137 | Negative (n.s.) |
| Dadong Square (SY) | 355 | −0.270 | 0.033 | Negative * |
| Pingshan Park (SZ) | 65 | −0.524 | 0.219 | Negative (n.s.) |
| Olympic Square (SY) | 329 | −0.792 | <0.001 | Negative *** |

Note: n.s.: not significant; * $p < 0.05$; *** $p < 0.001$
Abbreviations: SY: Shenyang; SZ: Shenzhen

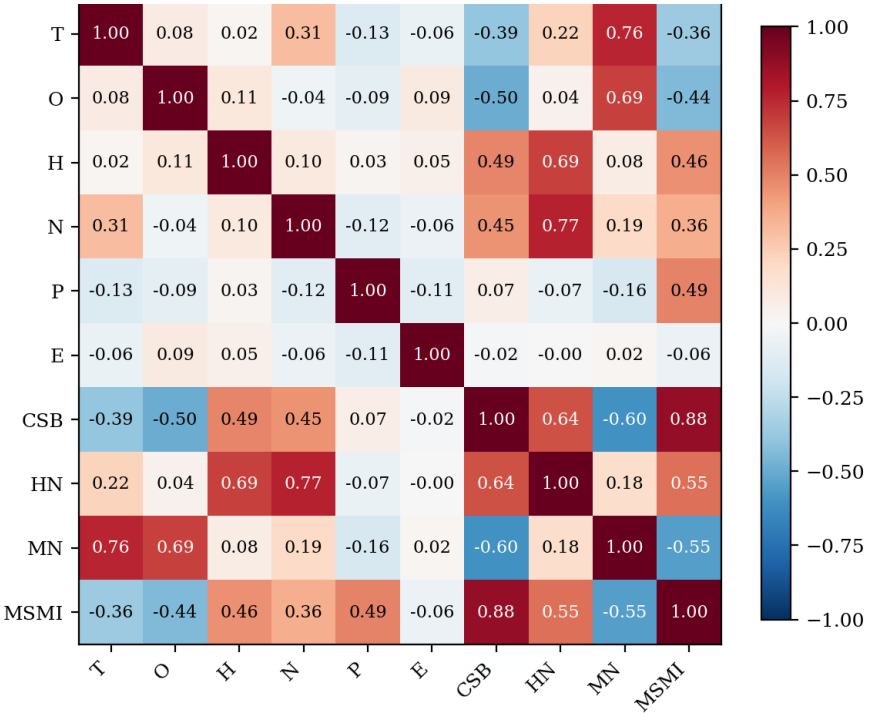



**Figure 9.** Spearman correlation matrix. Source: Diagram by the authors
Abbreviations: CSB: Cultural sonic balance; E: Eventfulness; H: Human sounds; HN: Human–natural sonic presence; MN: Mechanical sonic presence; MSMI: Materialized Sonic Memory Index; N: Natural sounds; O: Other noise; P: Pleasantness; T: Traffic noise

indication of mechanical masking in large hard-surfaced public squares rather than as a contradiction of the wider soundscape literature (Fang *et al.*, 2024; Tian *et al.*, 2023).

Table 8 presents the dominant sonic-memory typologies. Figure 10 visualizes the typology on the pleasantness and eventfulness plane, scaled by sample size and colored by MSMI.

The typology analysis is the analytical core of this study. The two traffic-dominant typologies together account for 33.5 percent of observations, yet they produce among the weakest MSMI values in their respective quadrants (−0.17 and −0.08). By contrast, the two human-sound-dominant typologies, despite representing a smaller proportion of observations (11.7 percent), achieve the strongest MSMI values in the dataset (0.93 and 0.83). This contrast shows that sonic memory is not a by-product of pleasantness or liveliness alone: spaces can be comfortable, lively, and positively rated on the ISO coordinates while still being culturally shallow from an acoustic-heritage standpoint (Z. Chen *et al.*, 2024). The chaotic-negative mechanical typologies (−0.75 and −0.79) confirm that noise-dominated discomfort and cultural sonic weakness co-occur, producing the most adverse conditions for heritage architectural experience. Figure 11 presents the supplementary acoustic analysis by location.

### 3.5. Weight-sensitivity of the MSMI

Because the weights in **Equation 6** are theoretically motivated rather than empirically estimated, the robustness of the resulting MSMI was tested by recomputing the location-level mean MSMI under four alternative weighting schemes: (W1) the working specification of **Equation 6**; (W2) equal weights of 0.25 for each component, with mechanical noise still entering with a negative sign; (W3) a CSB-emphasized scheme (0.50, 0.20, 0.20, −0.10); and (W4) a pleasantness-emphasized scheme (0.20, 0.50, 0.20, −0.10). Table 9 reports the location rankings under each scheme.

The relative ordering is highly stable across the four weighting schemes. The three top-ranked Shenzhen park sites occupy positions 1–3 under all four weighting schemes, and Olympic Square and Dadong Square remain in positions 4 and 5 under every scheme. Zhongshan Square is last under W1, W2, and W3. The consistency suggests that the MSMI captures a stable underlying ordering rather than an artifact of any single weight choice, which is a desirable property for adoption by future researchers and conservation practitioners.

## 4. Discussion

### 4.1. What the results mean for Chinese public-space soundscapes

The results reveal a contradiction in the soundscapes of Chinese public space that the current literature has not systematically named. A space can be perceived as

**Table 8. Dominant sonic-memory typologies (*n* = 1,831 observations, top eight typologies)**

| Typology | *n* | % | Pleasantness | Eventfulness | MSMI |
|---|---|---|---|---|---|
| Vibrant-positive/traffic-dominant | 341 | 18.62 | 2.80 | 1.05 | −0.17 |
| Vibrant-positive/other-noise-dominant | 317 | 17.31 | 3.34 | 1.34 | −0.06 |
| Calm-positive/traffic-dominant | 273 | 14.91 | 3.23 | −1.59 | −0.08 |
| Calm-positive/other-noise-dominant | 213 | 11.63 | 3.45 | −1.49 | −0.01 |
| Vibrant-positive/human-sound-dominant | 130 | 7.10 | 3.58 | 1.42 | 0.93 |
| Chaotic-negative/other-noise-dominant | 93 | 5.08 | −2.56 | 1.67 | −0.75 |
| Chaotic-negative/traffic-dominant | 86 | 4.70 | −2.42 | 1.45 | −0.79 |
| Calm-positive/human-sound-dominant | 85 | 4.64 | 3.56 | −1.62 | 0.83 |


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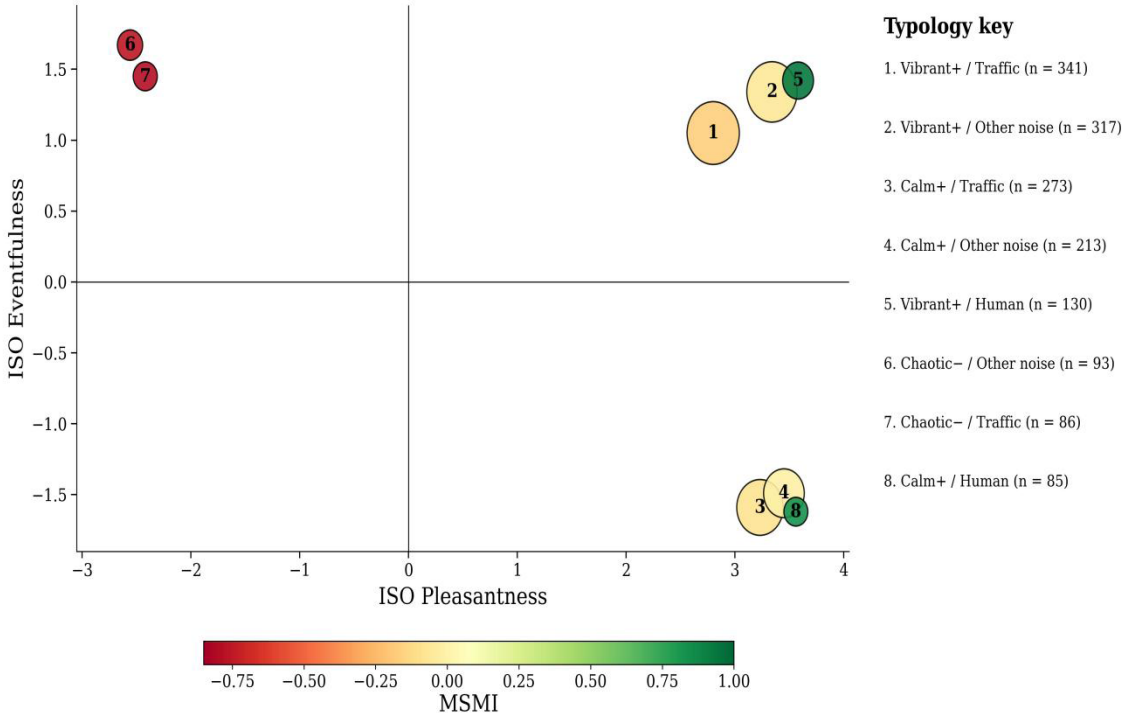



**Figure 10.** Dominant sonic-memory typologies plotted on the soundscape circumplex. Source: Diagram by the authors
Abbreviation: MSMI: Materialized Sonic Memory Index

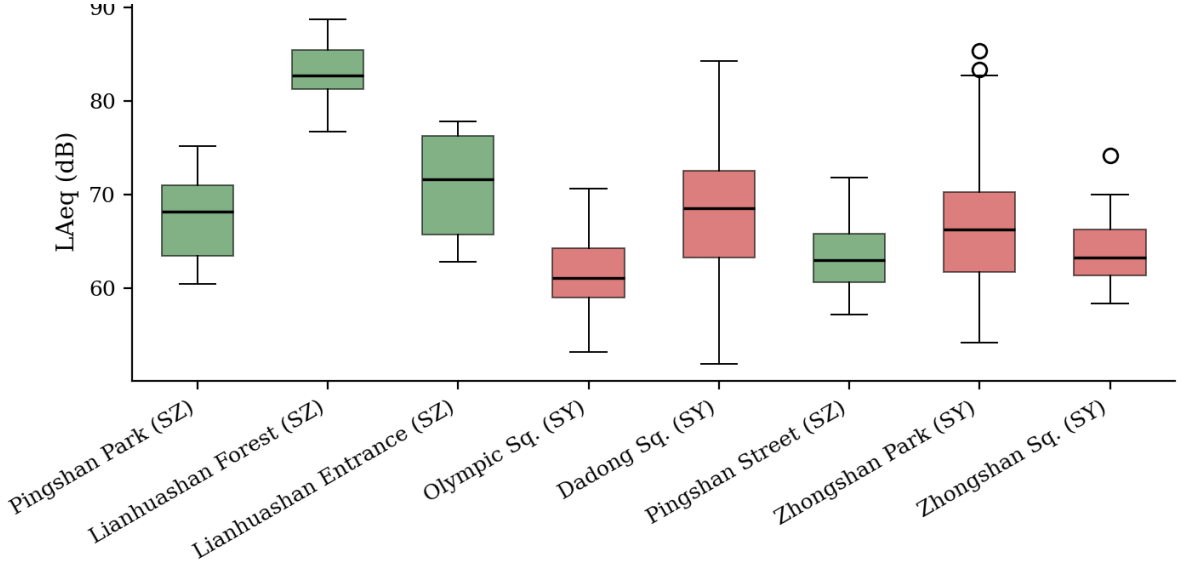



**Figure 11.** Supplementary acoustic level (LAeq) by location ($n$ = 450). Source: Graph by the authors
Abbreviations: SY: Shenyang; SZ: Shenzhen

**Table 9. MSMI location rankings (1 = highest) under alternative weighting schemes**

| Location | W1 (Equation 6) | W2 (equal) | W3 (CSB) | W4 (Pleasant) |
|---|---|---|---|---|
| Pingshan Park (SZ) | 1 | 2 | 1 | 2 |
| Lianhuashan Park Forest (SZ) | 2 | 1 | 2 | 1 |
| Lianhuashan Park Entrance (SZ) | 3 | 3 | 3 | 3 |
| Olympic Square (SY) | 4 | 4 | 4 | 4 |
| Dadong Square (SY) | 5 | 5 | 5 | 5 |
| Pingshan Street (SZ) | 6 | 7 | 6 | 8 |
| Zhongshan Park (SY) | 7 | 6 | 7 | 7 |
| Zhongshan Square (SY) | 8 | 8 | 8 | 6 |

Abbreviations: CSB: Cultural sonic balance; MSMI: Materialized Sonic Memory Index; SY: Shenyang; SZ: Shenzhen

**Table 10. Conservation and design implications by soundscape condition**

| Soundscape condition | Sonic-memory risk | Recommended architectural intervention |
|---|---|---|
| Traffic-dominant positive spaces | Pleasant but culturally weak; mechanical sound masks human and natural presence | Buffer traffic at boundaries with acoustic screening walls or tree belts; restore screen-wall and ying-bi placement at gateways to deflect traffic noise inward |
| Other-noise-dominant spaces | Ambiguous sonic identity; commercial or equipment noise obscures cultural signals | Regulate mechanical-equipment placement; enforce quiet zones in heritage precincts; revive arcade depth and qilou frontage as acoustic refuges |
| Human-sound-dominant positive spaces | Strong living heritage potential; social sounds align with cultural memory | Protect and program social-activity nodes; retain market stalls, performance courtyards, and ritual gathering spaces; respect courtyard enclosure ratios |
| Natural-sound-dominant calm spaces | Strong restorative sonic memory; landscape sounds anchor seasonal heritage rhythms | Maintain water features, tree canopies, and permeable ground; preserve Jiangnan-style spatial layering that brings natural sound to the foreground |
| Chaotic-negative spaces | Weak comfort and weak cultural memory; sonic overload suppresses recognition | Reorganize activity zones to separate conflicting sources; add absorptive surfaces (porous rammed earth, planted screens) at high-energy nodes |
| Monotonous-negative spaces | Low vitality and weak sonic identity; absence of meaningful sound produces placelessness | Introduce culturally appropriate sound programming (seasonal ritual events, craft demonstrations, performance) coordinated with surface materials that sustain those sounds |

pleasant, vibrant, or comfortable, and that perception can be entirely valid, even when the space is architecturally inadequate for transmitting and sustaining cultural sonic memory. This tension arises because pleasantness and cultural supportiveness are related but empirically distinct aspects of soundscape quality that current single-score indices do not capture (Mitchell *et al.*, 2024). The MSMI operationalizes this distinction by prioritizing CSB over pleasantness: it assigns a lower score to a mechanically pleasant space that nevertheless obscures human speech, seasonal sounds, and environmental cues, and a higher score to a space in which the human voice, seasonal sounds,

and environmental cues remain audible and dominant. This is consistent with soundscape context theory, which holds that the meaning of a sound is inseparable from the spatial and cultural context in which it is heard (R. Zhang *et al.*, 2025).

The finding that location-level MSMI variation is more pronounced than city-level variation is particularly important for architectural practice. The ANOVA F-statistic for MSMI at the location level ($F = 26.91$, $p < 0.001$) is substantially larger than the city-level Welch $t$-statistic ($t = -6.05$, $p < 0.001$) in standardized effect terms, and the location-level differences are clearly visible in Figure 6. This confirms that the acoustic quality of a heritage-oriented space is determined primarily by its local spatial characteristics, including enclosure ratio, surface material, vegetation cover, sound-source adjacency, and circulation pattern, rather than by the city in which it is located. Architects and conservation planners therefore cannot rely on city-scale acoustic planning to protect sonic memory. Site-specific design decisions at the level of the individual courtyard, street section, or park edge are what matter (X. Chen *et al.*, 2024).

### 4.2. Architectural meaning of materialized sonic memory

Materialized sonic memory is operationalized here as a measurable relationship among three analytically grounded dimensions: human and natural sonic presence, mechanical noise disturbance, and pleasantness. It is calculated from data collected with a standardized questionnaire that can be administered in any public space using the ISD protocol. From an architectural point of view, this idea translates into a series of concrete spatial conditions: enclosing walls and planted edges that resonate with the human voice and absorb traffic noise; water surfaces and permeable ground surfaces that maintain natural acoustic signatures throughout the seasons; courtyard geometry that promotes social behavior and limits spatial penetration of mechanical sound; and material selection that preserves acoustic clarity without causing excessive reverberation. None of this is new to the Chinese architectural tradition. The enclosed courtyard, the planted lane, and the water-feature garden have always served a dual acoustic role, even though they are rarely studied or conserved as such (D. Zhang *et al.*, 2025).

The finding that human-sound-dominant typologies carry the highest MSMI values (0.93 and 0.83) has clear implications for the conservation of living heritage. It suggests that the sonic life of heritage spaces—the community voices, craft sounds, performances, and social interactions they host—is not only a desirable aesthetic quality but also a measurable indicator of cultural sonic health. When these sounds are masked by mechanical noise or designed out so that social human presence is no longer audible, the heritage space loses not only its acoustic comfort but also its capacity to transmit cultural memory (Y. Li *et al.*, 2025; Zhu *et al.*, 2024).

#### *4.2.1. Linking the MSMI findings to vernacular Chinese architectural typologies*

The eight ISD sites are not officially designated heritage sites; the patterns identified by the MSMI can be related to several typologies of vernacular Chinese architectural heritage. The three Shenzhen sites (Pingshan Park, Lianhuashan Park Forest, and Lianhuashan Park Entrance) resemble, in MSMI terms, the garden enclosures of Jiangnan and the courtyards of Qiantang, where planted edges, water features, and the placement of screen walls work together to sustain natural sound and to buffer mechanical intrusion. The high CSB at these sites aligns with the design intent of the literati garden tradition, which sought to make natural sound a foreground element rather than a background one through spatial layering. The Shenyang civic squares (Olympic Square, Dadong Square, Zhongshan Square, and Zhongshan Park) are closer, in soundscape terms, to the open ritual and market squares of older Chinese settlements: large, hard-surfaced, and edge-exposed spaces whose sonic memory depends on temporary, programmed events staged at their center. This pattern is reflected in the location-stratified regression in Table 7: natural-sound presence has a negative association with ISO pleasantness in some hard-surfaced Shenyang squares, but not consistently in the more enclosed Shenzhen park settings. The only commercial-street site, Pingshan Street, is typologically equivalent to a traditional market arcade or qilou frontage, whose commercial noise can overpower cultural cues when the arcade is not deep enough or not acoustically treated.

Surface materials are central to the acoustics of vernacular Chinese architecture. The rammed-earth walls and dressed-stone bases typical of *siheyuan* (四合院) courtyards and *tulou* (土楼) walled compounds transmit the mid- and high-frequency human voice while blocking low-frequency traffic rumble, the spectral balance that the MSMI treats as culturally protective. Glazed tile roofs and masonry parapets reflect the human voice back down into the courtyard, sustaining audible social interaction, whereas wooden lattice screens (chuandou framing and lattice windows) diffract sound rather than reflecting it specularly, helping to preserve intelligibility without excessive reverberation. Bluestone or qingshi paving in lanes and courtyards strongly reflects footstep and ritual percussion, which historically reinforced procession and

craft sounds in marketplaces and along ritual routes. The MSMI does not measure these material properties directly, but its ranking of human- and natural-sound-dominant settings as culturally supportive is consistent with the acoustic role that these materials have historically played in vernacular Chinese architecture (Y. Li *et al.*, 2025; D. Zhang *et al.*, 2025).

### 4.3. Conservation and design implications

Table 10 summarizes the empirical results into a set of conservation and design recommendations organized by soundscape typology. Each row gives an acoustic condition, the associated sonic-memory risk, and a recommended architectural or planning intervention, cross-referenced to the vernacular architectural elements identified in Section 4.2.1.

The recommendations in Table 10 are applicable at the building, precinct, and district levels. At the building level, material and opening decisions will dictate whether or not sounds from the interior courtyard (voices, water, ritual activity) will still be heard over mechanical sounds. The balance between sonic memory and acoustic memory for an entire heritage area is controlled by the spatial organization, at the precinct scale, of the traffic lanes, commercial activities, and mechanical equipment with respect to culturally important gathering spaces. The source conditions that support cultural memory are contingent on the type of public space at the district level, defined by acoustic zoning, vegetation corridors, and traffic-management policies (X. Chen *et al.*, 2024). Complementary methods such as temporary sonic programming (seasonal ritual events, craft demonstrations, guided sound walks, performance in heritage courtyards, etc.) can enhance the human-sound presence without permanent structural interventions (Mao *et al.*, 2025).

### 4.4. Theoretical contribution

The theoretical value of this work is that it explicitly and repeatedly connects quantitative soundscape science and qualitative heritage interpretation. By combining units of standardized perceptual data collected by soundscape scientists with a rich interpretive context that soundscapes lack, the MSMI enables architectural researchers to discuss cultural sonic quality in the same units as soundscape scientists. The index is not meant to supplant ethnographic interpretation, participatory heritage assessment, or qualitative sound-walk approaches. Instead, it offers a quantitative initial clue on which spaces should be considered further and which spatial conditions require acoustic protection the most. In this regard, the MSMI sits methodologically between the condition indices employed in ecological studies as a clear and repeatable screening tool that should not be viewed as a replacement for the context-specific analysis of Mitchell *et al.* (2024).

### 4.5. Limitations and research roadmap

This research has several limitations. First, the ISD dataset is a public-space soundscape survey database, not a field study targeted at intangible heritage architecture; the sites under consideration are representative Chinese urban spaces but are not officially designated heritage sites, which limits the direct extrapolation of the findings to formal heritage-conservation settings. Second, the sound-source categories of the ISD questionnaire are four broad constructs (traffic noise, other noise, human sounds, natural sounds) that do not distinguish culturally specific sounds such as ritual chanting, market calls, craft sounds, tourist speech, or amplified commercial music. Third, of the 1,831 main records, only 450 could be analyzed on A-weighted acoustic variables, which is why the main analysis is perception-based and uses acoustic indicators as secondary evidence. Fourth, the Shenyang–Shenzhen sample is unbalanced (approximately 5.59:1); although the stratified-resample sensitivity check in Section 3.3 supports the city-level effect sizes, the city-level differences should be read as indicative rather than definitive. Fifth, the weights in **Equation 6** are theoretically motivated but provisional; the weight-sensitivity analysis in Section 3.5 shows that location rankings are robust to reasonable weight perturbations, but the weights themselves could be refined through expert consultation. Sixth, the analysis is purely quantitative, which would benefit from adding qualitative approaches, such as sound walks, ethnographic interviews, and participatory soundscape co-mapping, in order to further develop the cultural interpretation of the index.

The MSMI developed here is a pilot template, and the test on the ISD China subset is the first part of a long research program. The next step will be to gather primary field data at designated sites of intangible cultural heritage, with a focus on four typology families that are underrepresented in the existing data set: (i) siheyuan courtyards of northern Chinese cities where enclosure ratio and screen-wall placement structures the audibility of domestic and ritual life; (ii) Jiangnan garden enclosures and Qiantang gardens, where layered water and planted edges are central to cultural sonic identity; (iii) market arcades and qilou frontages in southern Chinese cities, where the commercial sound and the architectural depth interact; and (iv) ritual squares and temple courtyards where the timing and audibility of chanting and procession are constitutive of cultural meaning. The ISD protocol will be enriched with a culturally specific sound taxonomy that helps differentiate ritual, craft, commercial, tourist, and

amplified sources at each site, and MSMI weights will be re-estimated using a mixed-method protocol involving analytic hierarchy process consultations with heritage experts, sound walks with community stakeholders, and confirmatory structural equation modeling of the sound walks. The ultimate goal is to develop a validated heritage MSMI that can be applied by conservation officers, urban planners, and architects as a screening tool in the planning, sympathetic intervention, and post-occupancy assessment of public spaces in the conservation context.

## 5. Conclusion

Based on the concept of materialized sonic memory, this article has designed and tested a pilot analytical framework for interpreting the soundscape characteristics of Chinese urban public space and their relationship to cultural construction, operationalized through the MSMI. When applied to 1,831 cleaned records from eight sites in Shenyang and Shenzhen, the MSMI indicates significant differences in soundscape quality between locations (one-way ANOVA $F = 26.91$, $p < 0.001$) and that soundscape typologies that are human-sound-dominant and natural-sound-dominant consistently yield higher sonic-memory values while pleasantness alone is insufficient to assess cultural supportiveness. Plausible analytical choices do not seem to affect the MSMI ordering of locations, as shown through diagnostic checks (weight-sensitivity testing, stratified resampling for comparison at the city level, location-stratified regression, and VIF). The MSMI combines affective appraisal, sound-source composition, and mechanical disturbance in one transparent, reproducible measure, and the typological extension of the MSMI reveals that a space can be pleasant, vibrant, and well rated on the ISO coordinates, yet be acoustically weak as a carrier of heritage cultural meaning. The work provides a computational framework for soundscape analysis and interpretation of Chinese architectural heritage that is reproducible and extensible; a series of testable conservation and design recommendations by soundscape typology and linked to vernacular architectural elements; and a demonstration of the presence and importance of sound as a constitutive dimension of heritage conservation, rather than a secondary acoustic concern. Since none of the sampled sites is an officially designated heritage site, the results are best read as a methodological proof-of-concept that motivates the heritage-site fieldwork outlined in the research roadmap.

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## Conflict of interest

The authors declare no financial, professional, or personal interests in the content, findings, or conclusions of this manuscript.

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All authors have read and approved the final manuscript.

## Ethics approval and consent to participate

Not applicable. This study used publicly available secondary data. No new human-subject data were collected by the authors. The original data collection was conducted under appropriate ethical approval as documented in the source dataset record.

## Consent for publication

Not applicable.

## Availability of data

The data analyzed in this study were drawn from the publicly available, open-access International Soundscape Database, available at https://zenodo.org/records/10672568.

## Use of artificial intelligence

During the preparation of this manuscript, the authors used AI-assisted tools for language editing and readability improvement. The authors confirm that (a) all citations have been independently verified against the original sources, (b) all statistical results derive from the authors' own analysis, and (c) the conceptual framework,

methodological choices, results, and analytical decisions are the authors' own. The authors take full responsibility for the content of the published article.

## References

Aletta, F., Oberman, T., Mitchell, A., Erfanian, M., & Kang, J. (2023). Soundscape experience of public spaces in different world regions: A comparison between the European and Chinese contexts via a large-scale on-site survey. *Journal of the Acoustical Society of America*, *154*(3), 1710–1734.

https://doi.org/10.1121/10.0020842

Chen, X., Aletta, F., Moshona, C. C., Fiebig, A., Henze, H., Kang, J., Mitchell, A., Oberman, T., Schulte-Fortkamp, B., & Tong, H. (2024). Developing a taxonomy of soundscape interventions from a catalogue of real-world examples. *Acta Acustica*, *8,* 29.

https://doi.org/10.1051/aacus/2024027

Chen, Z., Jin, M., Zuo, Y., Ding, P., & Shi, X. (2024). The effect of soundscape on sense of place for residential historical and cultural areas: A case study of Taiyuan, China. *Buildings*, *14*(5), 1394.

https://doi.org/10.3390/buildings14051394

Deacon, T., Frohlich, D., & Plumbley, M. D. (2026). Soundscape experience activities and mapping. *npj Acoustics*, *2,* 7.

https://doi.org/10.1038/s44384-025-00041-6

Fang, X., Aletta, F., Mitchell, A., Oberman, T., & Kang, J. (2024). Determining factors for the appropriateness of soundscapes: A cross-sectional large-sample study in London (UK). *Journal of the Acoustical Society of America*, *156*(5), 3588–3607.

https://doi.org/10.1121/10.0034418

Hedfors, P., Thomsen, R. T., & Ruiz Arana, U. (2026). Soundscape Characterisation Tool (SCT): Semantic assessment of sound quality in landscape projects. *Landscape Research*, *51*(2), 277–294.

https://doi.org/10.1080/01426397.2025.2562865

Hu, W., Li, M., Chi, X., Wang, X., & Khan, A. U. (2024). Intangible cultural heritage research in China from the perspective of intellectual property rights based on bibliometrics and knowledge mapping. *Humanities and Social Sciences Communications*, *11,* 836.

https://doi.org/10.1057/s41599-024-03314-9

Kang, J. (2023). Soundscape in city and built environment: Current developments and design potentials. *City and Built Environment*, *1*(1), 1.

https://doi.org/10.1007/s44213-022-00005-6

Li, N., Wang, H., & Fan, J. (2025). How soundscape perception enhances the well-being of elderly recreational visitors in urban parks: A case study of Zhengzhou People's Park. *Scientific Reports*, *15,* 16652.

https://doi.org/10.1038/s41598-025-98125-6

Li, Y., Li, X., & Gao, M. (2025). Soundscapes and emotional experiences in World Heritage temples: Implications for religious architectural design. *Buildings*, *15*(15), 2681.

https://doi.org/10.3390/buildings15152681

Liu, Y., Chen, M., & Tian, Y. (2022). Temporal and spatial patterns and influencing factors of intangible cultural heritage: Ancient Qin–Shu roads, Western China. *Heritage Science*, *10,* 201.

https://doi.org/10.1186/s40494-022-00840-0

Mao, L., Hou, H., Xia, Z., & Zhang, X. (2025). Soundscape preferences and cultural ecosystem services in the Grand Canal National Cultural Park: A case study of Tongzhou Forest Park. *Buildings*, *15*(13), 2360.

https://doi.org/10.3390/buildings15132360

Mitchell, A., Aletta, F., & Kang, J. (2022). How to analyse and represent quantitative soundscape data. *JASA Express Letters*, *2*(3), 037201.

https://doi.org/10.1121/10.0009794

Mitchell, A., Aletta, F., Oberman, T., & Kang, J. (2024). Soundscape perception indices: Developing context-dependent single-value scores of multidimensional soundscape perceptual quality. *Journal of the Acoustical Society of America*, *156*(6), 3694–3706.

https://doi.org/10.1121/10.0034417

Ozturk, Z. S., Kang, J., & Aletta, F. (2025). Soundscape research in streets: A scoping review. *Sustainability*, *17*(8), 3329.

https://doi.org/10.3390/su17083329

Pang, L., & Wu, L. (2023). Distribution characteristics and influencing factors of intangible cultural heritage in Beijing-Tianjin-Hebei. *Heritage Science*, *11*(1), 19.

https://doi.org/10.1186/s40494-023-00862-2

Sun, L., Li, J., Wang, Z., Liu, W., Zhang, S., & Wu, J. (2024). Research on the redesign of China's intangible cultural heritage based on sustainable livelihood: The case of Luanzhou Shadow Play empowering its rural development. *Sustainability*, *16*(11), 4555.

https://doi.org/10.3390/su16114555

Tian, L., Winterbottom, D., & Liu, J. (2023). Soundscape optimization strategies based on landscape elements in urban parks: A case study of Greenlake Park in Kunming. *Sustainability*, *15*(13), 10155.

https://doi.org/10.3390/su151310155

Yang, L., Liu, J., Albert, C., & Guo, X. (2024). Exploring the effects of soundscape perception on place attachment: A comparative study of residents and tourists. *Applied Acoustics*, *222,* 110048.

https://doi.org/10.1016/j.apacoust.2024.110048

Zhang, C., Zeng, Y., Wu, W., & Xiao, L. (2025). Spatial distribution patterns and influencing factors of intangible cultural heritage in China. *Sustainability*, *17*(23), 10594.

https://doi.org/10.3390/su172310594

Zhang, D., Chen, H., Zhang, X., & Tan, L. (2025). Evaluation of landscapes and soundscapes in traditional villages in the Hakka region of Guangdong Province based on audio-visual interactions. *Buildings*, *15*(2), 259.

https://doi.org/10.3390/buildings15020259

Zhang, R., Ma, H., Wang, C., Zhang, Y., & Kang, J. (2025). Soundscape and its context: A framework based on a systematic review. *Journal of the Acoustical Society of America*, *157*(6), 4417–4436.

https://doi.org/10.1121/10.0036882

Zhang, S., Zhang, X., & Liu, J. (2024). Spatial distribution and pedigree age of intangible cultural heritage along the Grand Canal of China. *Heritage Science*, *12,* 246.

https://doi.org/10.1186/s40494-024-01357-4

Zhang, Z., Li, Q., & Hu, S. (2022). Intangible cultural heritage in the Yellow River Basin: Its spatial-temporal distribution characteristics and differentiation causes. *Sustainability*, *14*(17), 11073.

https://doi.org/10.3390/su141711073

Zhang, Z., Cui, Z., Fan, T., Ruan, S., & Wu, J. (2024). Spatial distribution of intangible cultural heritage resources in China and its influencing factors. *Scientific Reports*, *14*(1), 4960.

https://doi.org/10.1038/s41598-024-55454-2

Zhu, X., Liu, F., Kang, J., Liu, S., Wu, Y., Zhao, W., Xue, Y., & Wang, C. (2024). Assessing the audio-visual environment at the Great Wall of China: Impacts on visitor satisfaction and restoration. *Applied Acoustics*, *218,* 109905.

https://doi.org/10.1016/j.apacoust.2024.109905