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Impact of Acoustic Characteristics on Authenticity in Historic Districts: Mechanisms and Parameter Optimization

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Abstract

Authenticity serves as a core criterion for evaluating cultural heritage, reflecting the capacity of historic districts to convey tangible and intangible narratives accurately. However, research on authenticity has predominantly focused on visual morphology, leaving the quantitative impact of acoustic characteristics relatively underdeveloped. This study employs audio-visual simulations and interactive experiments conducted via a custom-developed platform to investigate the commercial spaces of the Zhonghua Baroque Historic District in Harbin, China. The research identifies the distributional features of acoustic characteristics, reveals the correlation patterns between these features and perceived authenticity, and determines the optimal parameter ranges for authenticity enhancement. It was found that fidelity of dominant sound and equivalent sound pressure level (L_{Aeq}) are the primary predictors of authenticity perception ($r > 0.5$, $p < 0.01$). The results indicate a dynamic compensation mechanism: as background sound levels increase to 55–72 dB, the optimal dominant sound L_{Aeq} shifts to 60–65 dB and the required fidelity threshold increase to 35 dB to maintain historical character. In conclusion, this study establishes a scientific basis for the preservation of authenticity in historic urban environments.

Keywords: *soundscape, historic district, authenticity, sound environment, audio-visual perception.*

1. Introduction

Authenticity serves as a core criterion for evaluating cultural heritage, reflecting its capacity to convey historical and cultural narratives accurately [1]. Within historic districts, authenticity encompasses both tangible dimensions, such as urban grain and architectural character, and intangible elements, including folk customs and traditional lifestyles [2][3]. However, existing research has predominantly focused on visual aspects, such as spatial morphology and street scale, leaving the exploration of authenticity from an acoustic perspective relatively underdeveloped [4][5].

Acoustic characteristics form the foundation for authenticity perception and are instrumental in achieving the quantitative regulation of soundscapes [6]. Studies suggest that authenticity evaluation depends not only on the congruence between sound types and their spatial context [7] but also on the physical attributes of the sound itself [8]. Specifically, equivalent sound pressure level (L_{Aeq}) directly influences the perceived authenticity of a location's atmosphere [9]; for instance, higher L_{Aeq} is often regarded as a positive indicator of vitality in historic commercial spaces [10]. Furthermore, the tempo and event density of sound can shape the perception of spatio-temporal continuity by modulating psychological arousal [11]. Additionally,

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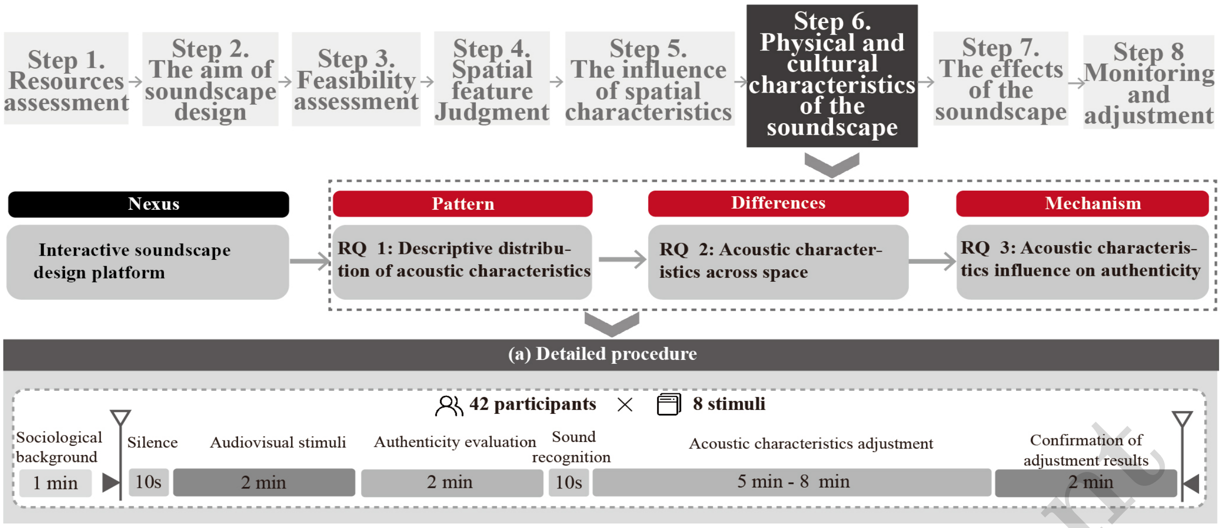

Figure 1. Experimental framework design

pitch and fidelity are capable of conveying the spatial volume and materiality of historic structures [12].

Despite these insights, a systematic investigation into the quantitative correlations between acoustic characteristics and authenticity perception in historical districts remains limited. In particular, precise physical parameter regulation criteria are still lacking for complex acoustic environments.

To address these gaps, this study employs audio-visual simulations and interactive experiments. The research seeks to: First, identify the distribution patterns of acoustic characteristics from an authenticity perspective; Second, reveal the correlations between these acoustic characteristics and authenticity perception; Finally, determine the optimal acoustic parameter intervals for enhancing authenticity.

2. Method

2.1 Experimental design

2.1.1 Experimental framework overview

The technical framework of this study builds upon a previously established stepwise framework for soundscape design in historical districts (Fig. 1), specifically focusing on Step 6, 'Physical characteristics of the soundscape' [13]. At the quantitative level, a weighted formula for authenticity evaluation—comprising 14 descriptive indicators derived from prior research—was proposed [14]. Through this formula, three spatial categories (commercial, cultural, and residential) were classified, and the optimal dominant sounds for each were identified. Based on these foundations, this research focuses on commercial spaces to systematically quantify the correlation between acoustic characteristics and authenticity perception, ultimately establishing optimal parameter intervals to support heritage soundscape design.

A priori power analysis using G*Power 3.1 indicated a minimum sample size of 30 for a medium effect size ($f = 0.3$), $\alpha = 0.05$, and power = 0.80. Accordingly, 42 valid participants were recruited, each evaluating and adjusting eight audio-visual stimulus samples. Regarding data collection, objective metrics included acoustic characteristics (equivalent continuous sound pressure level (L_{Aeq}), tempo, pitch, and fidelity), while subjective data comprised the perceptual identification of sound types and scores for authenticity-related adjectives (rated on a scale of 0–10). The specific experimental procedure is illustrated in Fig. 1(a). Following a socio-demographic survey and a resting period, participants underwent four stages: perceptual scoring, source identification, interactive adjustment, and result validation. During the core adjustment phase (5–8 minutes), participants performed real-time adjustments to the sample's acoustic characteristics based on their perception of authenticity. The samples were generated based on the adjusted results of preceding participants. Each sample evaluation lasted approximately 15–17 minutes, including scoring, interactive adjustment, and validation. The eight audio-visual stimuli were presented in random order, with short breaks and optional pauses between samples to reduce order and fatigue effects; therefore, the total duration of approximately 160 minutes refers to the full experimental procedure rather than continuous rating.

2.1.2 Case site

The Zhonghua Baroque Historic District in Harbin was selected as the source for the experimental materials (Fig. 2). The district covers an area of 12.33 ha and was chosen for its exceptional representativeness and spatial diversity: From the perspective of tangible heritage, the district integrates a variety of functional spaces, including commercial, residential, and cultural spaces; From the perspective of intangible heritage, the cultural activities it hosts contribute to a unique and complex soundscape. This multifaceted character provides a rich repository of stimuli for the audio-visual simulation experiment.

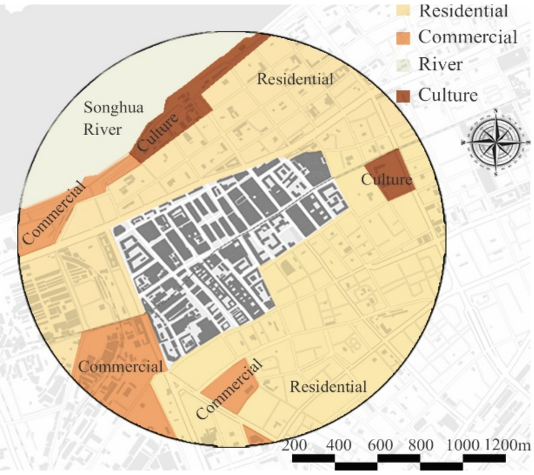

Figure 2. Site context and surrounding land use

2.1.3 Audio-visual stimuli

To effectively control variables, acoustic characteristics were classified into interactive parameters and controlled attribute levels. The equivalent continuous L_{Aeq} of both dominant and background sounds, along with the tempo of the dominant sound, were defined as interactive variables that could be adjusted by participants in real time. In contrast, pitch and fidelity were treated as controlled attribute levels rather than continuously adjustable parameters, because continuous manipulation could alter the naturalness, recognisability, and contextual meaning of the original sound sources. Therefore, pitch and fidelity were pre-set before the formal experiment, each with two levels (high and low). As illustrated in Fig. 3, an experimental matrix comprising two sound combinations and four acoustic characteristic sets, nested according to pitch and fidelity levels, resulted in eight standardised audio-visual samples.

Dominant sounds were sourced from high-quality archives, while background sounds were recorded on-site using a HEAD Acoustics SQobold binaural system (44,1 kHz, 24-bit). Recording points were 1.5 m high and more than 3.5 m from structures to ensure field stability. Simultaneously, an Insta360 ONE X2 captured panoramic video to ensure precise audio-visual spatial mapping.

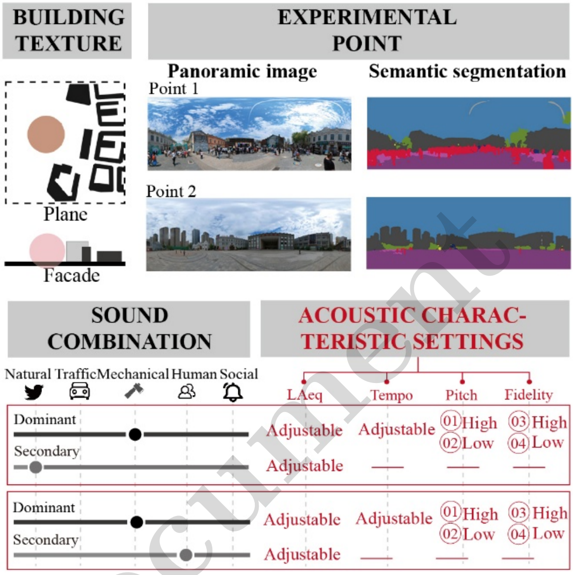

Figure 3. Construction of audio-visual stimulus samples and experimental parameter settings

2.2 Interactive experimental platform and parameter settings

To ensure standardisation, reproducibility, and scalability of data collection, an interactive soundscape design application (app) was developed using Glide, with real-time cloud storage managed via Google Sheets. The App integrates six core functions (Fig. 4): (1) collection of demographic information; (2) presentation of audio-visual stimuli; (3) identification of primary and secondary dominant sound sources; (4) evaluation of a 14-item authenticity scale; (5) real-time adjustment of acoustic parameters (including L_{Aeq} and tempo of dominant sounds); and (6) final verification of the adjusted audio-visual output.

During the interactive adjustment phase, participants continuously modified selected acoustic characteristics within predefined ranges: 40–80 dB(A) for dominant sounds, 35–75 dB(A) for background sounds, and 30–130 BPM for tempo.

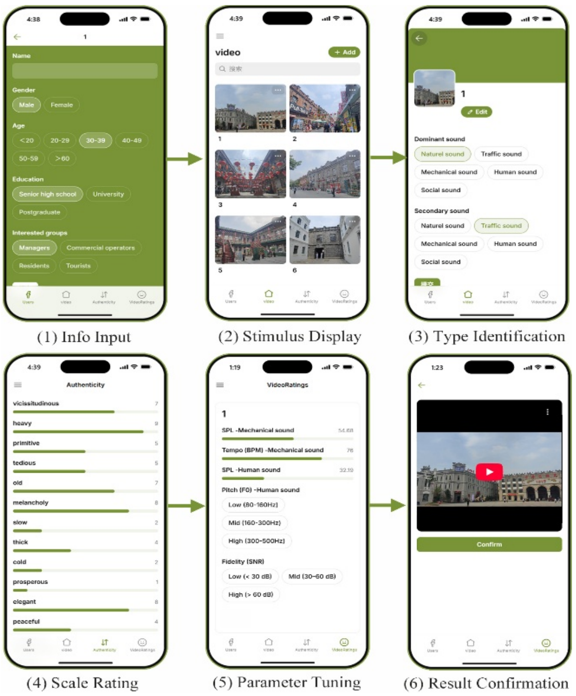

Figure 4. Stepwise workflow of the APP for soundscape assessment

2.3 Data analysis

The system encompasses four key acoustic characteristic indicators: equivalent continuous sound pressure level (L_{Aeq}), tempo, pitch, and signal-to-noise ratio (SNR). The definitions and calculation formulae for each indicator are as follows:

$$L_{Aeq} = 10log_{10}\left(\frac{1}{T}\int_0^T \frac{p_a^2(t)}{p_0^2}dt\right) \quad (1)$$

Where T is the measurement duration (s); $pa\ (t)$ is the A-weighted instantaneous sound pressure（Pa）; p_0 is the reference sound pressure (2×10^{-5}Pa).

$$Tempo = \frac{N}{T} \quad (2)$$

Where N is the number of identifiable sound events per unit time; T is the statistical duration (s).

$$F_0 = \frac{1}{T_0} \quad (3)$$

Where T_0 is the fundamental frequency period of the sound signal (s).

$$SNR = 10log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) \quad (4)$$

Where P_{signal} is the average power of the dominant sound; P_{noise} is the average power of the background noise.

3. Results

3.1 Descriptive distribution of acoustic characteristics related to authenticity

Figure 5 presents raincloud plots combined with box plots to illustrate the data density and statistical features of the recorded parameters. Both background and dominant sounds exhibit relatively high intensity, with median L_{Aeq} values of 63.2 dB and 65.2 dB, respectively. Notably, both parameters display significant multimodal distributions: the background sound levels show peaks at 73.1 dB and 52.6 dB, while the dominant sound shows multimodal characteristics with peaks at 76.4 dB and 52.2 dB. Regarding the temporal dimension, the distribution of dominant sound tempo is notably discrete, with a median of 86.5 BPM (IQR: 61.3–113.4 BPM). The observed multimodal distribution of tempo underscores the complex and dynamic temporal patterns of sound events within these commercial spaces.

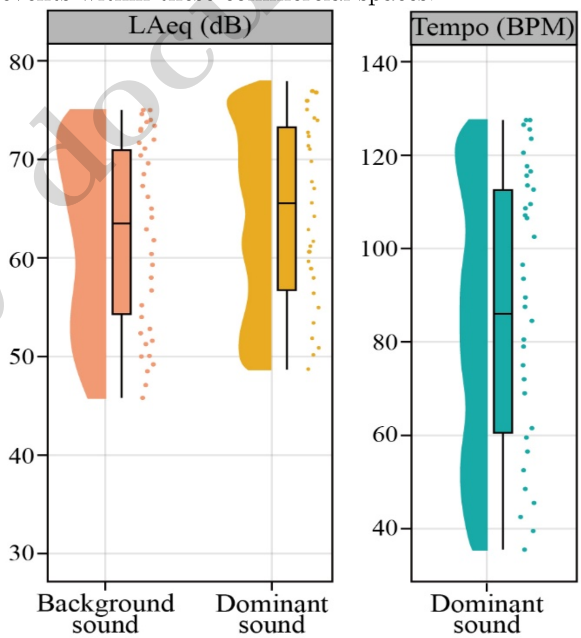

Figure 5. Distribution characteristics of acoustic characteristics

3.2 Correlation patterns between acoustic characteristics and authenticity

The results of the Spearman correlation analysis are presented in Fig. 6. Taylor diagrams were employed to illustrate the correlation patterns between acoustic characteristics and perceived authenticity. The azimuthal angle represents the Spearman correlation coefficient (r), the radial distance denotes the standard deviation (SD) of the acoustic characteristics, and the radius of the observation point corresponds to the SD

of the observed authenticity data. The distance between the model points and the observation point reflects the root mean square error (*RMSE*); correlation coefficients are presented in absolute values.

The results indicate that dominant sound fidelity (r = 0.63, p = 0.007) and dominant sound L_{Aeq} (r = 0.51, p = 0.009) exhibit the strongest positive correlations and the highest fitting precision. This suggests that the fidelity and L_{Aeq} of the dominant sound are core elements in shaping perceived authenticity. In contrast, the effects of dominant sound tempo (r = -0.36, p = 0.03) and background sound L_{Aeq} (r = 0.28, p = 0.04) are less pronounced, while dominant sound pitch shows no significant correlation (r = 0.09, p = 0.21). The Taylor diagram further confirms that the data points representing fidelity and L_{Aeq} are situated closest to the observation point (*SD* = 2.38, *RMSE* = 2.05), demonstrating substantial predictive value for perception. Conversely, while tempo and background L_{Aeq} reach statistical significance, they contribute less to the variance in authenticity evaluation.

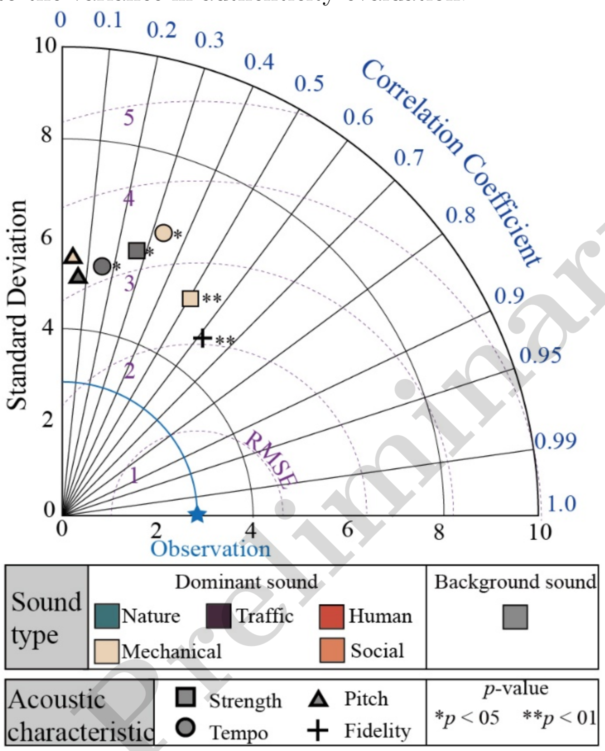

Figure 6. Correlation characteristics between acoustic characteristics and authenticity perception

3.3 Optimal acoustic characteristics ranges for authenticity

The results of the Wilcoxon signed-rank test are presented in Fig. 7. These results reveal that the optimal parameter intervals for enhancing authenticity exhibit a dynamic compensation mechanism in response to background sound levels. Under low background sound conditions (45–55 dB), authenticity scores were significantly highest when the dominant sound L_{Aeq} was maintained between 58–62 dB (p < 0.01), suggesting that a moderate loudness advantage of the dominant sound facilitates authenticity perception. The optimal tempo was identified at 60–75 BPM (p < 0.01), indicating that a moderate-to-fast tempo is conducive to atmospheric arousal. Furthermore, signal-to-noise ratio (SNR) must exceed 30 dB to ensure the perceived realism of acoustic details (p < 0.01). As background sound levels increase to 55–72 dB, the thresholds for all parameters shift upwards accordingly. The optimal L_{Aeq} interval for dominant sounds shifts to 60–65 dB (p < 0.01) to maintain the identifiability of historical and cultural features. The suitable tempo range broadens to 35–85 BPM, with the 70–85 BPM interval showing the highest significance (p < 0.01). Additionally, the fidelity threshold must reach at least 35 dB (p < 0.01). In summary, high-background-sound environments impose more stringent requirements on the L_{Aeq}, tempo, and fidelity of dominant sounds to sustain authenticity.

4. Conclusion

This study investigated the quantitative relationship between authenticity and physical acoustic characteristics in historic districts. Through the application of an interactive soundscape design platform, the real-time adjustment of acoustic parameters was implemented. The primary conclusions are as follows:

Firstly, the distributional features of acoustic characteristics were identified. Both background and dominant sound L_{Aeq} are characterised by high intensity and multimodal distribution patterns. Secondly, within commercial spaces, dominant sound fidelity and L_{Aeq} were identified as the core factors influencing authenticity perception, demonstrating significant predictive value. Finally, the research identified the optimal parameter intervals for authenticity perception. It was found that the acoustic intervals required to enhance authenticity exhibit a dynamic compensation mechanism as background sound intensifies. In high-background-sound environments, it is necessary to simultaneously increase the thresholds for dominant sound L_{Aeq}, tempo, and fidelity to enhance authenticity. In summary, this research provides a quantitative basis for the refined design and preservation of soundscapes in historic districts.

5. Acknowledgments

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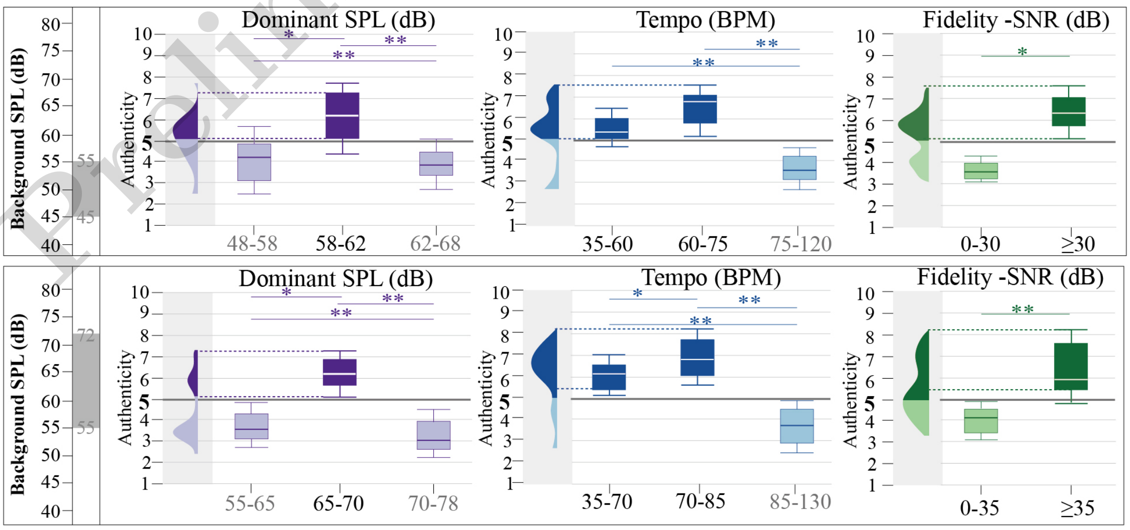

Figure 7. Optimal parameter intervals for acoustic characteristics based on Signed-Rank Test