heritage

MDPI

Article

Sensory Clustering of Traditional Building Materials: A Multimodal Framework for Material–Place Association

Manyouye Zhang [1], Miao Lu [1,*], Haixin Hu [2] and Xiang Wang [1]

[1] College of Arts, Jiang'an Campus, Sichuan University, Chengdu 610207, China; zhangmanyouye@stu.scu.edu.cn (M.Z.); wangxiang666@stu.scu.edu.cn (X.W.)
[2] School of Cyber Science and Engineering, Jiang'an Campus, Sichuan University, Chengdu 610207, China; huhaixin@stu.scu.edu.cn
* Correspondence: lumiao815@scu.edu.cn

Abstract

The relationship between the multimodal perceptual characteristics of traditional building materials and material-level place meaning remains unclear. Existing research largely focuses on the immediate perception of materials and lacks a framework for systematically analysing the association between multimodal perceptual characteristics and material-level place meaning. This study collected visual texture and material-related acoustic features from traditional tiles and wall bricks in the KuanZhai Alleyways, Chengdu. Combining eye-tracking and electroencephalography (EEG) experimental data, the k-means algorithm was employed to perform multimodal perceptual clustering, whilst a questionnaire survey was used to construct the Material Sense of Place Index (MSPI), in order to explore the associations between building material types, multimodal perceptual patterns and local significance at the material level. The study found that materials can be categorised into three multimodal perceptual patterns across the integrated dimensions of visual, auditory and physiological perception: brick materials are predominantly assigned to the texture-exploration cluster, whilst tile materials are predominantly assigned to the auditory-relaxation cluster; the overall MSPI of traditional bricks and tiles is generally higher than that of modern materials, and the material-related place identity dimension received the largest weight in the construction of the composite MSPI; the interaction between material category and sensory cluster was statistically significant, but the incremental explanatory power was small, indicating that material category is the primary distinguishing factor for MSPI differences, whilst sensory cluster provides only limited supplementary explanation. The framework proposed by the study—'multimodal perception data collection–cluster analysis–assessment of material–place association'—provides a research pathway and empirical reference for analysing the relationship between material types, multimodal perceptual patterns and material-level place meaning.

Keywords: traditional building materials; sensory clustering; multimodal perception; material–place association

Academic Editor: María Luisa Vázquez De Agredos Pascual

Received: 29 August 2026
Revised: 11 October 2026
Accepted: 14 October 2026
Published: 12 November 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Rapid urbanisation erodes local character and cultural identity, challenging sense of place and making it urgent to reconsider the built environment as a cultural vehicle. Tra-

ditional building materials serve as a key link between the physical environment and cultural memory; the techniques and craftsmanship behind these materials reflect the characteristics of their era, region and ethnic group [1], documenting social change and cultural heritage, and playing a vital role in shaping the historical and cultural atmosphere. In architectural practice, using locally sourced materials is a way of establishing a connection with the local area, and is more likely to gain psychological acceptance [2]; heritage conservation and urban planning authorities often tend to favour indigenous building materials that are symbolic, represent outstanding traditional craftsmanship, and are recognised by the local community; see, e.g., [3]. Although there is widespread emphasis in practice on the central role of local building materials in strengthening a sense of place, existing academic research on the relationship between building materials and local sentiment remains limited, with most studies confining themselves to qualitative discussions of the emotional memories associated with materials in specific regions [2,4]; the quantitative pathway linking the sensory characteristics of materials to indicators of urban sense of place remains unclear. In practice, material selection relies largely on experience because systematic information on the affective qualities of materials and suitable material databases are lacking.

In recent years, research into material perception has expanded from the analysis of a single sense to the integration of multi-channel information—including visual, auditory and tactile cues—focusing on how a material's texture, colour and acoustic properties work together to elicit emotional and behavioural responses in individuals. Research has included the cognitive evaluation of the intrinsic properties of materials [5] and studies on the connection between the perception of material properties and emotions [5,6]. In architecture, three trends are evident: (1) studies of material perception within spatial experience [7]; (2) studies linking sensory properties to emotions, material scale and preference, and user perception to physical material properties [8,9]; (3) neuroarchaeological interpretations of the cognitive significance of materials [10]. These studies have deepened our understanding of the multidimensional nature of material perception and its psychological and behavioural impacts; however, existing multimodal research has largely focused on common materials such as wood and metal, whilst the unique cultural perceptions associated with traditional building materials are often overlooked.

In light of the above issues, this study seeks to establish a clear 'material–perceptual–psychological' analytical framework linking research on material perception and local sentiment. Taking traditional Chinese bricks and roof tiles—which hold a prominent status as cultural symbols—as the subject, and using modern bricks and roof tiles as a comparative category, this study captures the visual textures and material-related acoustic characteristics of the materials through image and audio recording. By combining eye-tracking data with electroencephalographic (EEG) measures of relaxation, a multimodal perception index is constructed; k-means clustering is then applied to the materials to identify typical multimodal perception patterns. Building upon this, the Material Sense of Place Index (MSPI) is constructed based on three dimensions—historical memory association, material-related place identity and material-related place attachment—and the relationships between material categories, perceptual patterns and the MSPI are analysed. This paper defines the MSPI as the perceptual potential of materials to evoke place-related meanings at the micro-scale, rather than as a direct measurement of an individual's complete sense of place.

This study therefore aims to focus on three core themes:

(I) What typical multimodal clustering patterns do building material samples exhibit in terms of visual, auditory and physiological indicators?

(II) How is material-related sense of place characterized across the dimensions of history, identity, and attachment, and does the MSPI differ across material categories?

https://doi.org/10.3390/heritage9110477

(III) Within the MSPI assessment framework, how do different perceptual clustering patterns correlate with the MSPI levels of the materials?

The significance of this study lies in the following: In theory, by incorporating material perception and a sense of place within a single analytical framework, this study provides a material-scale research perspective for understanding how building materials contribute to the construction of local meaning through sensory cues and cultural contexts; In methods, by utilising MFCC, GLCM, eye-tracking, EEG, SEM and linear mixed models, the study establishes a multimodal quantitative pathway spanning from the physical and physiological perception of materials to their psychological and cultural evaluation, thereby providing a reference for interdisciplinary quantitative research in areas such as urban materials, public spaces and cultural heritage. In practice, the study's insights into the interactive relationship between a material's cultural context, sensory experience and a sense of place help to understand how materials contribute to the construction of local meaning against the backdrop of rapid urbanisation, thereby providing guidance for urban practices such as the regeneration of historic neighbourhoods and the selection of building materials.

2. Literature Review

2.1. Sense of Place and Material–Place Association

'Sense of place' provides a comprehensive theoretical framework for studying the relationship between people and place; it refers to the cognitive, emotional and behavioural connections formed by individuals or groups through ongoing interaction with a specific environment [11], and encompasses place attachment [12], place identity [13,14] and place dependence [15]. A sense of place is the result of a co-constructed relationship between individuals, communities and the place itself [16]; consequently, it is not only related to people's socio-cultural experiences, but the characteristics of the physical environment can also be linked to place attachment and satisfaction through the meanings people ascribe to the place [17]. The built environment shapes people's perception of a place's uniqueness and sense of belonging through spatial characteristics that are distinctive, continuous and evocative of memory [18]. When the scale is reduced to the material level, texture, colour, form and acoustic feedback constitute micro-clues for the perception of place, whilst local materials, construction techniques and traces of use carry specific historical and social significance [4]. Whilst building materials cannot, on their own, constitute a complete sense of place, they can serve as a micro-material medium that connects sensory experiences, historical memory and local significance. Existing research has discussed, for example, how the use of bamboo reflects the continuity of local resources and traditional building knowledge; how the sensory characteristics and local origins of clinker brick walls contribute to the formation of everyday heritage meaning; and how the choice of materials can also refer to the geographical and historical context in which a building is situated [19–21]. These studies primarily address the construction traditions, heritage value or symbolic significance of materials, whilst there is relatively little research on the relationship between multimodal perceptual measurement and individual evaluations of local significance. Accordingly, this paper refers to the link between the multimodal perceptual characteristics of materials and the evaluations of local significance they evoke as the 'material–place association'. This concept focuses on whether people can perceive a connection to a specific place through the sensory and cultural cues of materials, rather than implying that the materials themselves possess a sense of place.

The most commonly used frameworks for measuring a sense of place in contemporary environmental psychology typically assess the connection between an individual and a place through dimensions such as place identity, place attachment and place depend-

ence, focusing primarily on long-term relationships with a place. The objects of measurement are usually spatial units such as communities, neighbourhoods, parks or natural landscapes [11,22,23], and cannot be directly applied to individual materials. With regard to the evaluation of the sense of place evoked by materials, this paper takes into account: historical memory association, whereby urban architecture and material remains can serve as physical clues evoking a place's history, whilst the patina, wear and signs of use on a material's surface provide a tangible expression of the passage of time [24]; material-related place identity, whereby different building materials can convey culturally relative symbolic meanings, and traditional materials and façade elements can also contribute to the representation of regional identity and local character [20,25,26]; material-related place attachment, that is, participants' emotional inclinations towards the spaces created by materials, with existing research on place attachment providing a reference for the design of the study's items [22,23]. Consequently, the historical memory association, material-related place identity and material-related place attachment are adopted as the three dimensions for evaluating the local significance evoked by materials. All three are operationalised dimensions proposed in this paper based on the research subjects and objectives, rather than a direct adoption of a validated scale measuring the sense of place associated with materials.

In summary, given that the relationship between the multimodal perceptual characteristics of traditional building materials and local significance at the material level remains unclear, this paper focuses on exploring the 'material–place association', examining how the physical and cultural characteristics of materials contribute to the perception and evaluation of local significance. With regard to the evaluation of the sense of place evoked by materials, this paper integrates the history, identity and attachment into the 'Material Sense of Place Index' (MSPI), which is used to assess the potential of materials to carry and activate a sense of place. This paper analyses the visual and auditory characteristics of materials, as well as eye-tracking and electroencephalographic (EEG) responses, and then examines the relationship between material type, perception patterns and the MSPI. The experiments in this paper measure material-mediated associations rather than the complete experience of a place. The MSPI reflects the potential of materials to evoke a sense of place at the micro-scale; it is not equivalent to an individual's sense of place or cultural resilience in relation to a complete location. Its purpose is to serve as a material indicator for measuring the extent to which people perceive place-related meanings.

2.2. Material Perception Research

Sensory experiences are a key means by which individuals form a sense of place and emotional connections [27], and constitute an important component of place perception [28]. Building materials provide sensory stimuli for such emotional connections through their texture, colour, tactile roughness and acoustic properties. Research indicates that sensory channels such as sight and hearing can trigger emotional connections to specific places [29]. Sensory elements such as sound and smell can evoke a sense of spatial identity associated with ancestral rites and clan memories [30,31]. The texture, pattern, colour and brightness of building material surfaces can prolong the duration of gaze on focal points [2], and a close link has also been demonstrated between sensory stimulation from materials and emotional responses [32]. Experiments by Fleming [33] demonstrated a bidirectional relationship between perceived quality and material category, providing a cognitive basis for the clustering modelling of multimodal perceptual data in this study [34–36]. These studies examined the relationship between material properties and users' perception of their environment, enriching our understanding of the association between subjective perceptions of materials and their objective attributes.

Research focusing on a single sense or a single dimension struggles to capture the complexity of multimodal perception of materials. Fujisaki et al. [5,37] examined how conflicting visual and auditory cues affect material perception, pointing out that multimodal integration of material categories aligns more closely with a multiplicative model than with simple averaging; this provides important insights into the measurement of feature similarity when constructing multisensory material classification models. The multimodal frameworks proposed by Zheng [38] and Maleki [39], which integrate visual, tactile and auditory information, put forward an approach to multimodal recognition and 'sensory-guided sensory' sampling, emphasising that material cognition stems from the comprehensive integration of multiple senses, with different modalities exerting mutual guidance and synergy. With advances in sensor and bioengineering technologies, physiological measurements such as eye tracking, heart rate variability (HRV) and electroencephalography (EEG) have come to be widely used in research on environmental and material perception. By integrating subjective evaluations with objective physiological responses within a single framework, these methods provide the methodological foundation for the use of eye tracking and EEG to quantify material perception in this study [9,40,41].

In summary, research into material perception has expanded from examining the relationship between the objective properties of materials and subjective evaluations to encompassing multimodal integration and physiological responses. However, whilst most studies focus on the immediate physiological experiences associated with materials—such as emotions—there remains a lack of systematic quantitative research into how these multimodal perceptual characteristics contribute to the construction of local meaning, and how material types and perceptual patterns interact in the formation of a sense of place. Using separately collected visual texture, material-related acoustic features, eye-tracking and EEG data, this paper constructs an analytical-level multimodal perceptual representation and combines it with the MSPI to examine associations between material type, multimodal perceptual patterns and material–place meaning.

2.3. Application of the k-Means Clustering Method

k-means is a commonly used unsupervised clustering method suitable for continuous numerical variables; it identifies latent groupings based on the distances between samples and compares the feature combinations of different categories via cluster centres [42,43]. In recent years, clustering methods have been employed in research on the colour of historic buildings and psychological evaluation [44], whilst k-means has also been applied to the classification of material images [45], demonstrating its ability to bridge the gap between the computational analysis of material characteristics and perceptual evaluation.

The data in this study comprise physical measurement indicators of the materials, as well as psychological and physiological responses from participants (such as eye-tracking trajectories and EEG relaxation levels), forming a high-dimensional, multi-source dataset. Consequently, the multi-source indicators were standardised and incorporated into a unified feature space, and k-means clustering was employed to identify combinations of perceptual features of the materials. Given that this method is relatively sensitive to variable scales, the number of clusters and initial centres [42,43], this study determined the clustering scheme using Z-score standardisation, the elbow method, the silhouette coefficient [46] and Bootstrap stability assessment, whilst testing the robustness of the results through sensitivity analysis. The k-means cluster centres facilitate the comparison of features across different perceptual patterns and enable further analysis of the relationship between perceptual clusters and the evaluation of the local significance of materials. This method extends the classification of materials from physical form to a comprehensive

analysis of physical, behavioural and physiological indicators, thereby providing a quantitative basis for the multimodal perceptual classification of architectural heritage materials and the evaluation of their local significance.

2.4. Research Framework

The framework developed in this paper—'multimodal perception data collection–cluster analysis–assessment of material–place association'—comprises three phases.

Phase 1: Collection of visual and auditory data for tiles and bricks.

For the visual modality, high-resolution images of the tiles and bricks were acquired; texture contrast features were extracted using Grey-Level Co-occurrence Matrix (GLCM); and the number of fixations was obtained through eye-tracking experiments to serve as an indicator of the level of visual exploration. For the auditory modality, material-related sound stimuli were recorded; sound features were extracted using Mel-frequency cepstral coefficients (MFCCs); and corresponding relaxation response indicators were obtained through auditory relaxation experiments.

Phase 2: Multimodal Perceptual Clustering.

The aforementioned multimodal features were fused, and the k-means clustering method was employed to identify material types and sensory patterns based on perceptual similarity. Visual and auditory stimuli are presented separately; multimodal integration occurs solely at the analytical level and does not imply synchronisation of audiovisual perception.

Phase 3: Evaluation and correlation of the Material Sense of Place Index (MSPI).

MSPI is constructed based on subjective scales to analyse the correlation between material categories, perceptual patterns and evaluations of local significance at the material level.

The research process described above is illustrated in Figure 1.

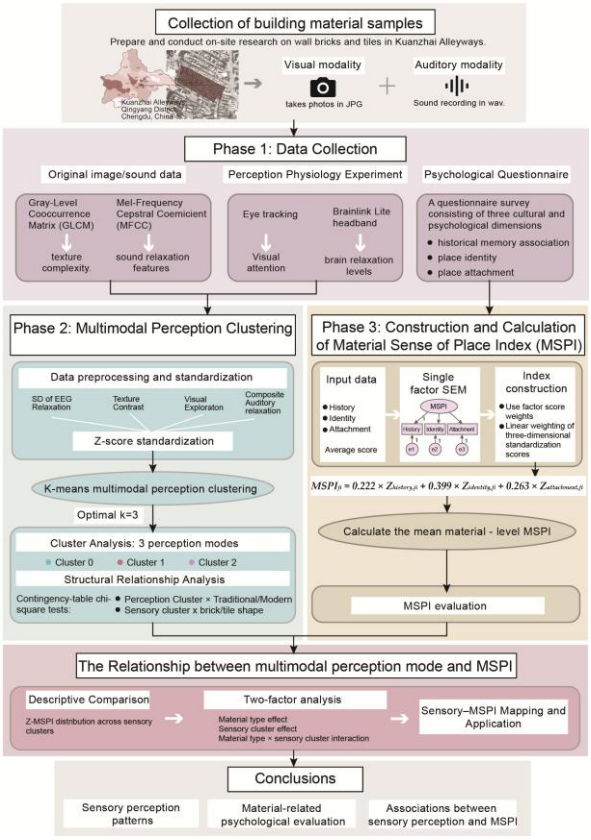


Figure 1. Research Framework.

3. Methods

3.1. Research Subjects

This study selected the KuanZhai Alleyways historic district in Qingyang District, Chengdu, Sichuan Province, China, as the area for data collection (see Figure 2). This area has preserved a relatively intact layout of Qing Dynasty courtyards and alleyways, as well as the architectural style of Western Sichuan dwellings. During modern regeneration, it has implemented a conservation strategy based on 'integrity— authenticity—diversity—sustainability' [47,48], thereby forming a mixed-use space that combines the historic built environment with contemporary commercial and leisure settings. This provides a stable contextual framework for comparing the textural characteristics and perceptual effects of traditional materials and modern materials within the same urban context.

Material		Specifications	Variety	Processes	Purpose
	B01	20x9.5x4	Face brick	Clay and sand mixed, high-fired, then water-quenched to greenish grey.	Public building
	B02	27x18x3	Face brick	Clay and sand mixed, high-fired, then water-quenched to greenish grey.	Public building
	B03	20x9.5x4	Rustic tile	Clay and sand mixed, high-fired, then water-quenched to greenish grey.	Cultural construction
	B04	24x18x11	Cement brick	Clay and sand molded, high-fired, air-cooled to red.	Public building
	B05	24x12x6	Rustic tile	Clay and sand mixed, high-fired, air-cooled to red.	Cultural construction
	B06	24x12x6	Cement brick	Cement hydrates with water, binding sand and stone.	Public building
	B07	40x19x10	Face brick	Local clay (Chengdu yellow soil) mixed with cinder/fine sand for hardness.	Public building
	B08	49x26x12	Cultural stone bricks	Sieved clay warmed, pressed, high-fired, water-quenched to greenish grey.	Public building
	B09	27x18x10.5	Cultural stone bricks	Clay and sand stamped, high-fired, water-quenched to greenish grey.	Cultural construction
	B10	40x19x10	Face brick	Local clay (Chengdu yellow soil) mixed with cinder.fine sand for hardness.	Commercial indoor space
	B11	28x19x3	Face brick	Clay and sand mixed, high-fired, water-quenched to greenish grey.	Public building
	B12	49x26x11.5	Face brick	Sieved clay warmed, pressed, high-fired, water-quenched to greenish grey.	Public building
	B13	33x16.5x3	Rustic tile	Sieved grey pottery, warmed, high-fired for hardness.	Cultural construction
	B14	33x15x3	Cement brick	Clay based, mixed with fine sand or rice husk ash, focusing on impermeability and partially mixed with lime powder.	Public building
	B15	33.5x16.8x4.8	Rustic tile	Clay based, mixed with fine sand or rice husk ash, fired to greenish grey or reddish brown.	Cultural construction
	B16	41x18x6	Cement brick	Clay (yellow/purple) mixed with sand/ash, high-fired.	Public building
	B17	60x40x10	Face brick	Pure yellow clay (low sand), high-fired.	Public building
	B18	None	Cultural stone bricks	Clay mixed with straw/fiber, fire-dried.	Public building
	B19	50x30x26.5	Cultural stone bricks	Clay and sand mixed, high-fired, air-cooled to red.	Cultural construction
	B20	24x12x6	Face brick	Local clay, reduction-fired to grey, hard and weather-resistant.	Commercial indoor space

Material		Specifications	Part	Ingredient	Purpose
	T01	20x20x4.5	Ban Wa (A curved, flat tile that forms the main roof pan to channel rainwater.)	Clay Tile	Dwellings
	T02	20x19x4		Clay Tile	Dwellings
	T03	19.8x19x5		Clay Tile	Memorial archway at the gate head
	T04	27x21x4.5		Clay Tile	Residential courtyards and temples
	T05	27x22x4.5		Clay Tile	Temple
	T06	27x21x5.5		Clay Tile	Widely used
	T07	28.2x21x5.7		Clay Tile	Public building
	T08	18x18x3.8		Clay Tile	City Wall
	T09	23x13x6.5	Tong Wa (A semi-cylindrical tile placed over the seams between rows of flat tiles to weather-proof the	Clay Tile	City Wall
	T10	20x10.5x5.6		Clay Tile	Dwellings
	T11	22x11x6		Clay Tile	Dwellings
	T12	22.5x11x5.8		Clay Tile	City Wall
	T13	24x11x8.4	Wa Dang (An eaves tile end, often decorated, that caps the end of a cylindrical tile to protect rafters and as ornamentation.)	Mud Gray Pottery	Road
	T14	23x11x11		Mud Gray Pottery	Waterway
	T15	11x11x7.5		Clay Tile	City Wall
	T16	23x 12.8x13		Clay Tile	Public building
	T17	21x18x0.6	Di Shui (A drip tile with a pointed tip attached to the end of a flat tile to guide water away from the wall.)	Mud Gray Pottery	Sacrifice
	T18	29x19x7		Clay Tile	Early Palace
	T19	21x18x7.4		Mud Gray Pottery	Decoration
	T20	28x15x8.8		Clay Tile	Monument

Material	Specifications	Variety	Processes	Purpose	Material	Specifications	Part	Ingredient	Purpose
MB01	20x10x6	Face brick	Resin, processed via 3D printing, etc.	Public building	MT01	17.8x16.6x3	Ban Wa (Same as above)	Clay Tile	Public building
MB02	20x10x6	Face brick	Cement, aggregate, and pigment molded and cured.	Public building	MT02	18x16x4.5		Clay Tile	Public building
MB03	22.5x10x5	Rustic tile	Cement, aggregate (e.g., construction waste), and pigment pressed under high pressure and steam-cured.	Cultural construction	MT03	20x10x5	Tong Wa (Same as above)	Clay Tile	Temporary decoration
MB04	24x10x6	Cement brick	Cement, aggregate (e.g., construction waste), and pigment pressed under high pressure and steam-cured.	Public building	MT04	8x12x8	Wa Dang (Same as above)	Resin	Tempo-rary decora-tion
MB05	22.5x10x5	Rustic tile	Clay fired with surface texturing.	Cultural construction	MT05	18x9x5		Clay Tile	Widely used
MB06	23x11x5	Cement brick	Cement, aggregate (e.g., construction waste), and pigment pressed under high pressure and steam-cured.	Public building	MT06	10x7x7		Resin	Widely used
MB07	20x6	Face brick	Clay, quartz, feldspar, etc. pressed, high-fired, and surface-polished.	Public building	MT07	16x15x6.5	Di Shui (Same as above)	Clay Tile	Widely used
MB08	24x6x1	Cultural stone bricks	Cement and natural stone scraps proportionally mixed, vibratory compact-ed in molds, sandblasted, and colored.	Public building	MT08	15x15x6		Clay Tile	Widely used
MB09	30x10	Cultural stone bricks	Cement, quartz sand, etc, molded by pressing/vibra-tion, then sandblasted and colored.	Cultural construction	MT09	9x10x7		Resin	Temporary decoration
MB10	24x0.8x6	Face brick	Clay, quartz sand, feldspar, etc. dry-pressed into shape.	Commercial indoor space	MT10	9x10x7		Resin	Tempo-rary decora-tion

Figure 2. Overview of the material samples.

The study focuses on bricks and roof tiles used in typical building envelope components within the region, covering both 'traditional building materials' and 'modern imitative materials'. The criteria for sample inclusion are: ① the samples must include external walls and pitched roofs of streets and alleys; ② the surfaces must be free from extensive secondary coatings or coverings, so as to reflect the intrinsic texture of the materials; ③ the samples must be intact and visible, facilitating standardised sampling and recording; ④ for modern imitative materials, components that have been replaced or newly added during recent renovations were selected. These modern antique-style samples serve as a category for comparison rather than as a control group. They were chosen because such samples have been widely used in recent renovation projects within the study area. A total of 60 sets of material samples were ultimately selected (see Figure 2). The unequal sample size reflects the actual availability of materials in the study area. Traditional bricks and tiles were the main target of this study and were relatively abundant. In contrast, fewer modern replacement or newly added components met the inclusion criteria—namely, intact and visible surfaces without extensive secondary coatings—during the sampling period. The modern samples therefore serve as a comparison category rather than a balanced control group, and the smaller modern sample size may limit statistical power for comparisons involving modern subtypes.

(1) Traditional wall bricks (20 sets) and traditional roof tiles (20 sets): These consist primarily of blue bricks and blue roof tiles, which were in use from the Ming and Qing dynasties through to the Republic of China period. The materials are made from clay or earthenware as the basic raw materials, produced through traditional processes such as clay preparation, moulding, drying and firing [49]. The types of roof tiles covered include common components such as flat tiles, curved tiles, eaves tiles and tile finials; their surfaces generally exhibit varying degrees of weathering, dust accumulation and biocoating (such as lichen and moss), reflecting the characteristics of long-term use.

(2) Modern bricks (10 sets) and modern tiles (10 sets): These consist primarily of ceramic roof tiles and resin-based modern tile. Resin-based modern tiles use polyvinyl chloride (PVC) resin and modifiers as their base materials; they are formed through extrusion

or compression moulding, with 'aged' embossing applied to simulate traditional textures. Antique-style wall tiles are typically produced by moulding to replicate traditional masonry textures, followed by surface colouring or ageing treatments [50]. In this study, modern materials designed to resemble antique ones were used as a category for comparison, rather than as a control group in the strict sense.

3.2. Building Material Sample Data Collection

3.2.1. Visual Texture Features

Sixty sets of material images were collected. Photography was carried out using a SONY SELP1650 lens paired with a camera body with a resolution of ≥24 million pixels. Brick samples were collected from KuanZhai Alleyways in Chengdu on a sunny day with low levels of atmospheric particulate matter; tile samples were collected from KuanZhai Alleyways and photographed under a D65 standard light source in the laboratory to ensure stability in colour temperature and illuminance. The distance between the camera and the sample surface was uniformly set at 50 cm, with the camera positioned directly opposite the sample (90°). All photographs (see Figure 3) were post-processed in Adobe Photoshop to a size of 2000 × 2000 pixels to standardise image dimensions [51].



Figure 3. Sample images.

Texture features were extracted using the GLCM method. In this study, conducted within the Python 3.13.5 environment using OpenCV 4.12.0 (cv2) and scikit-image 0.25.2, images were quantised to L = 256 grey levels. The GLCM was calculated at a pixel spacing of d = 1 and for directions $\theta \in \{0°, 45°, 90°, 135°\}$, and the results for each direction were averaged to obtain direction-invariant statistics. Based on the results of preliminary experiments and relevant research, this study selected contrast as the core texture metric to describe the clarity, intensity of undulation and visual distinctiveness of material textures, and thus employed it for subsequent cluster analysis [51]. Whilst this metric provides a unified quantitative comparison across different materials, the GLCM metric alone cannot encompass all the characteristics of material textures.

3.2.2. Sound Characteristics Associated with Materials

To capture the sounds produced by the interaction between building materials and environmental factors, this study recorded two types of scenarios: (1) a uniform wind speed of 2 m/s blowing against a brick wall, recording the sound of 'wind passing through wall cracks'; (2) under natural rainfall conditions, recording the sound of 'rain striking roof tiles'. These scenarios were selected because Chengdu has a rainy climate, brick walls and tiled roofs are typical building-envelope interfaces in the KuanZhai Alleyways, and wind and rain are common everyday environmental sounds in the area; nevertheless, they represent only a limited subset of material-related auditory conditions. Recordings were

made using a ZOOM H5 digital recorder mounted on a tripod, employing mono close-miking to maximise the proportion of direct sound. The recording specifications were 48 kHz/24-bit WAV, with a dynamic range of ≥110 dB [52]. The input level was controlled within the range of −12 to −6 dB peak to avoid clipping and ensure consistency in subsequent feature comparisons. At the same location and during the same time period, low and stable background noise was ensured. Each group of building materials corresponded to one material-related sound stimulus, totalling 60 audio clips. As the recordings were made using mono close-range pickup and had undergone noise reduction, amplitude normalisation and clip extraction, they were referred to in the experiment as 'material-related sound stimuli' rather than 'soundscapes' containing complete spatial and contextual information. Furthermore, whilst brick materials were recorded as wind passing through wall joints and roof tiles as rain striking the tile surface, material form was confounded with the type of material-related sound stimulus; the auditory results merely reflect correlations under the specified recording conditions and should not be interpreted as causal effects inherent to the materials themselves.

All audio files underwent standardised pre-processing in Adobe Audition CC 2023, during which invalid segments and sections containing obvious ambient noise were removed, the amplitude was normalised to −12 dBFS, and the files were trimmed to 10-s valid segments. MFCC were used as the audio features; these simulate the frequency resolution characteristics of the human ear and can effectively capture perceptual dimensions related to timbre and texture [52,53]. Empirical studies on MFCCs have further demonstrated that these features can significantly predict perceptual dimensions of soundscapes such as relaxation, dynamism and communicativeness, with overall predictive performance superior to that of commonly used ecoacoustic indicators [54]. In a Python/librosa 0.11.0 environment, the parameters were set to a sampling rate of 48,000 Hz, a frame length of 1,024 samples (≈21 ms) and a frame shift of 512 samples, to extract 13-dimensional MFCCs (including MFCC0). Combining existing soundscape research with the scale design of this study, the V1 metric within the MFCC features—which is associated with the degree of relaxation induced by sound [54]—was included in the main analysis.

3.3. Multisensory Experiment

3.3.1. Physiological Indicators

Physiological data were recorded in real time using eye-tracking metrics and electroencephalography (EEG) equipment. The eye-tracking experiment utilised a Tobii Pro Fusion desktop eye-tracker with a sampling rate of 250 Hz. All participants completed a standard nine-point calibration prior to the formal experiment; those who failed to achieve the accuracy recommended by the equipment were excluded from the analysis. Eye-tracking data were recorded and processed using Tobii Pro Lab, and the number of fixations was selected to characterise the frequency of visual sampling by participants on the surface of the material. The number of fixations reflects the degree to which the gaze is concentrated or dispersed across the surface of the material and the difficulty of identifying elements, but does not directly indicate the degree of emotional association.

The auditory relaxation experiment utilised the Brainlink Lite portable EEG headband. The three dry electrodes on the forehead of the device correspond to F7–Fp1, with a sampling rate of 512 Hz [55]. The headband employs the NeuroSky ThinkGear ASIC module to calculate the power spectral density (PSD) values from the raw EEG data every second [56], and outputs one meditation score (0–100) per second based on the eSense algorithm; a higher score indicates that the participant is in a more relaxed state. Previous research has shown that this type of device and its eSense parameters possess acceptable validity for monitoring emotional and attentional states [57]. In this study, the sequence

of meditation values recorded for each audio segment was averaged to serve as an indicator of EEG relaxation in response to the corresponding material-related sound stimuli.

3.3.2. Questionnaire Survey

To evaluate the local significance evoked by the materials, this paper designed the Material Sense of Place Questionnaire (MSPQ) based on the three dimensions identified in Section 2.1—historical, identity and attachment—in conjunction with a material-stimulus task. Three items were devised for each dimension, making a total of nine questions (see Appendix A, Table A1). The items were designed to focus on the materials themselves and the spaces they might evoke, and experts in relevant fields were consulted to review the relevance of the items to the research subjects and the clarity of their wording. Participants rated each item on a seven-point Likert scale based on their own perceptions (1 = strongly disagree, 7 = strongly agree).

3.3.3. Experimental Procedure

Forty volunteers (aged 20–40, comprising 20 men and 20 women) were recruited online and in person, including three groups: current students at universities in Sichuan (n = 21), visitors to Sichuan (n = 9) and local residents (n = 10). All participants had visited KuanZhai Alleyways within the past two years and had some understanding of traditional Sichuan residential architecture. They were unaware of the purpose of the study and were all right-handed individuals with normal or corrected vision and hearing.

The experiment was conducted in a laboratory at the School of Arts, Sichuan University, China. It began on 10 October 2025 and lasted for seven days. Throughout the experiment, the room was kept quiet, the ambient temperature was maintained at approximately 24 °C, and non-essential electronic devices were switched off to minimise the impact of ambient noise and electromagnetic interference on the acquisition of physiological signals. Prior to the start of the experiment, a multifunctional sound level meter, a temperature and humidity meter, and a lux meter were used to confirm that the environmental parameters were stable. The subject maintained a viewing distance of approximately 60 cm from the monitor, and the seat height was adjusted so that their line of sight was roughly level with the centre of the screen.

The experimental session lasted approximately 50 min, with the time taken to complete the questionnaire counted separately (see Figure 4). During the preparatory phase, participants first signed an informed consent form, provided their basic details, and sat quietly for 3 min to relax. A multifunctional sound level metre, along with temperature, humidity and illuminance meters, was used to confirm that the environmental parameters were stable. For the visual experiment (see Figure 4), participants wore an eye tracker and underwent calibration. The image materials were presented in blocks, divided into 'brick' and 'tile' groups, with randomised presentation within each block. Each image was displayed for 8 s, with a 3-s inter-stimulus interval. To minimise strategic differences arising from free viewing, participants were uniformly instructed to perform two tasks: Task A—Emotional Evaluation: 'Please rate how "familiar" this material makes you feel on a scale of 1 to 7; press the button to respond after viewing.' Task B—Historical Judgement: 'Please judge whether this material appears "traditional" or "modern", and indicate your level of confidence.' Participants were instructed to focus naturally on the texture, structure and overall impression of the material's surface. For the auditory experiment, participants wore an EEG headband and rested in a quiet environment for 3 min [58]. The corresponding material-related sound stimuli were then played; the brick and tile groups were presented sequentially, with randomised order within each group. Each audio clip lasted 10 s. During the experiment, participants were asked to remain quiet and listen attentively.

Upon completion of the experiment, participants completed the Material Sense of Place Questionnaire (MSPQ).

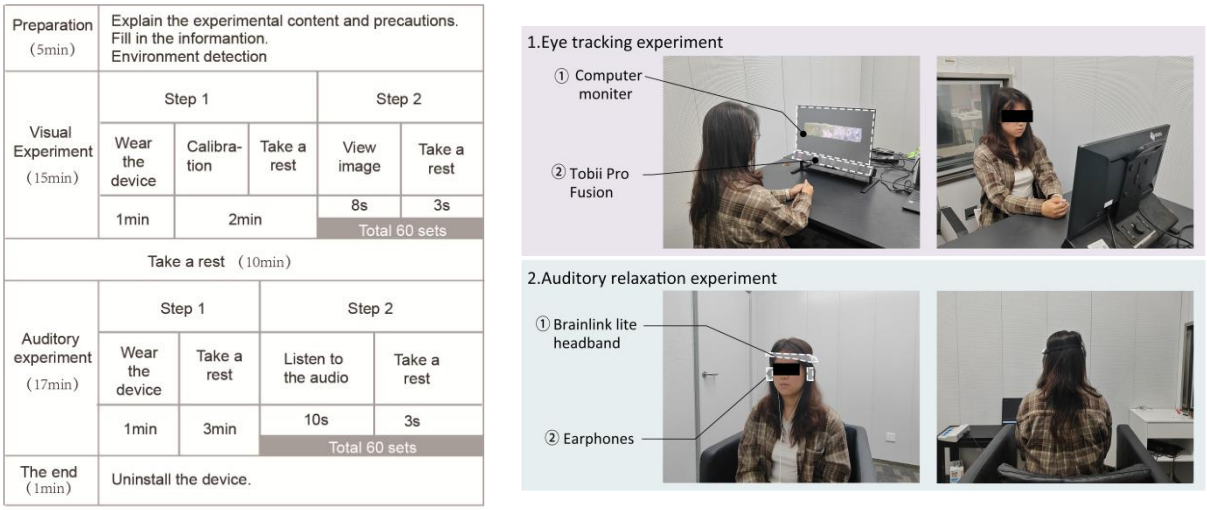


Figure 4. Physiological Experiment Procedure and Experimental scenarios.

3.4. Data Processing and Algorithm Design

3.4.1. Data Preprocessing

In terms of auditory–physiological responses, the BrainLink Lite device records the relaxation state of participants whilst they listen to material-related sound stimuli at a rate of one eSense meditation value per second. First, the mean and standard deviation of the meditation values for each participant within a 10-s stimulus window for a single material were calculated; these were then averaged across all 40 participants to obtain the mean EEG relaxation level and EEG relaxation variability (within-stimulus SD) at the material level, representing the overall relaxation level and short-term fluctuations under material-related sound stimuli, respectively. The Pearson correlation coefficient between MFCC V1 and the average EEG relaxation level was r = 0.346, indicating a limited degree of correlation between the two. The two indicators reflect two complementary aspects. The limited correlation and complementary information provided by the two indicators support their equal weighting in the composite auditory relaxation index.

$$AVR_i = (Z(MFCCV1_i) + Z(RelaxMean_i))/2$$

In the processing of eye-tracking data, this study operationalised the number of fixations as a measure of visual exploration, to reflect the frequency and overall extent of visual sampling by observers across the surface of the material. This metric emphasises the frequency of visual search behaviour rather than the intensity of attentional resource allocation or the spatial extent of fixations. To ensure the quality of the eye-tracking data, trials with a tracking rate below 80 per cent were excluded. Given that bricks and tiles may exhibit systematic differences in geometric shape, image composition and screen coverage, this study constructed a linear regression model with material type (brick/tile) as the independent variable and number of fixations as the dependent variable. The residuals of the number of fixations from this regression were then used as an indicator of visual exploration in subsequent analyses, in order to mitigate the potential influence of material type differences on the eye-tracking results. This procedure also eliminated the average difference in fixations between bricks and tiles; however, as this difference may itself carry perceptual significance, the relevant results should be interpreted with caution.

Prior to cluster analysis, the four features listed in Table 1 were standardised using Z-scores [59] to minimise the impact of differing units of measurement and numerical

ranges on the calculation of Euclidean distances in k-means clustering. The standardised data were used for subsequent k-means clustering and stability tests; the resulting clusters represent only descriptive patterns derived from the combination of multimodal indicators and are not interpreted causally.

Table 1. Clustering characteristics and data sources.

Variables	Concept	Basis	Data Sources
EEG relaxation variability	Short-term fluctuations in the relaxation response within the 10-s stimulation window	Complements the overall level and reflects reaction stability	BrainLink Lite data; the average was calculated for 40 people after computing the individual standard deviations
Texture contrast (GLCM contrast)	Local variations in grey scale and texture intensity on the surface of materials	Characterisation of the visual textural properties of materials	Mean GLCM contrast across directions
Visual exploration level (adjusted fixation count)	Visual sampling frequency on the surface of materials	Reflecting visual search behaviour and mitigating the impact of variations in brick and tile morphology	Residuals from the regression of eye-tracking fixations on material form
Composite auditory relaxation index	The overall level of acoustic characteristics and physiological relaxation responses	Exploratory integration of two types of auditory information	Standardised MFCC V1 and the average EEG relaxation level, weighted equally

3.4.2. K-Means Clustering Algorithm

To investigate the natural grouping of multimodal features at the perception level, k-means clustering was performed using the four standardised features mentioned above as input. Using Euclidean distance as the metric, the silhouette coefficient and intra-cluster and inter-cluster differences were calculated for K = 2–10. The optimal K value was selected by comprehensively evaluating cluster compactness, separation and interpretability, and the characteristic performance of each class in terms of material properties and subjective evaluation was recorded for the construction of multimodal perception types. This study does not introduce any additional weight adjustments or improved algorithms; it merely examines the impact of different feature combinations on the robustness of the clustering when necessary. To investigate the influence of the construction method of auditory indicators on the clustering results, this study conducted sensitivity analyses by substituting the composite auditory relaxation index with MFCC V1, the average EEG relaxation level, and the first principal component (PCA) of both, respectively. The results are presented in Section 5.

3.4.3. Construction and Calculation of the Material Sense of Place Index (MSPI)

In order to quantify participants' evaluations of the material-level place meaning, this study constructed the Material Sense of Place Index (MSPI) based on three dimensions: historical memory association, material-related place identity and material-related place attachment. All three dimensions were measured using a seven-point Likert scale, with each dimension comprising three items. The data were initially organised at the 'participant–material' level, meaning that each record corresponded to one participant's evalua-

tion of one material. The average was calculated for the three items within the same dimension in each record, yielding scores for the 'history', 'identity' and 'attachment' dimensions respectively.

A three-indicator single-factor model was estimated using AMOS 27.0 based on the history, identity, and attachment dimension scores to derive weights for the composite MSPI (see Appendix A, Figure A1). Because this model was just-identified (df = 0), its global fit indices were not interpreted as evidence of unidimensionality. The model specified MSPI as a latent factor reflected by the history, identity and attachment dimensions, with no additional covariance paths among the three dimensions. Questionnaire reliability, standardised factor loadings and factor score weights are reported in Section 4.3.. To calculate MSPI scores, the 'participant–material' level scores for history, identity and attachment were first standardised using Z-scores; the MSPI at the participant–material level was then derived by applying the factor score weights provided by AMOS as linear combination coefficients. The formula for calculating the MSPI of the jth participant for the ith material is as follows:

$$MSPI_{ji} = 0.222 \times Z_{history,ji} + 0.399 \times Z_{identity,ji} + 0.263 \times Z_{attachment,ji}$$

To examine whether the three dimensions are better represented by a single factor, we conducted item-level confirmatory factor analyses using the nine items. Four types of models were compared: (1) a one-factor model with all items loading on MSPI; (2) a three-factor model with history, identity, and attachment as correlated factors; (3) three two-factor models combining two dimensions and separating the third; and (4) a second-order factor model with three first-order dimensions loading on MSPI. Model fit was evaluated using robust χ^2, df, χ^2/df, CFI, TLI, RMSEA, SRMR, AIC, and BIC. The results are reported in Table 2.

Table 2. Comparison of confirmatory factor analysis models for MSPI.

Model	Robust χ^2	df	χ^2/df	CFI	TLI	RMSEA	RMSEA 90% CI	SRMR	AIC	BIC
One-factor	567.319	27	21.012	0.938	0.918	0.101	[0.094, 0.108]	0.039	71,128.35	71,284.5
Three-factor correlated	400.482	24	16.687	0.958	0.937	0.088	[0.081, 0.096]	0.033	70,917.81	71,091.3
Two-factor H + I / A	459.477	26	17.672	0.951	0.932	0.092	[0.085, 0.099]	0.037	70,996.12	71,158.05
Two-factor H + A / I	569.943	26	21.921	0.939	0.915	0.102	[0.095, 0.110]	0.038	71,124.37	71,286.3
Two-factor I + A / H	453.166	26	17.429	0.951	0.933	0.091	[0.084, 0.099]	0.035	70,987.9	71,149.83
Second-order	400.482	24	16.687	0.958	0.937	0.088	[0.081, 0.096]	0.033	70,917.81	71,091.3

Note: H = history, I = identity, A = attachment. The second-order model reproduced the fit of the three-factor correlated model because the higher-order portion with only three first-order factors was just-identified. However, it yielded an improper solution (a standardised loading exceeding 1 and a negative residual variance), indicating that the higher-order factor was not empirically tenable. It was therefore not interpreted as evidence for a general higher-order MSPI factor.

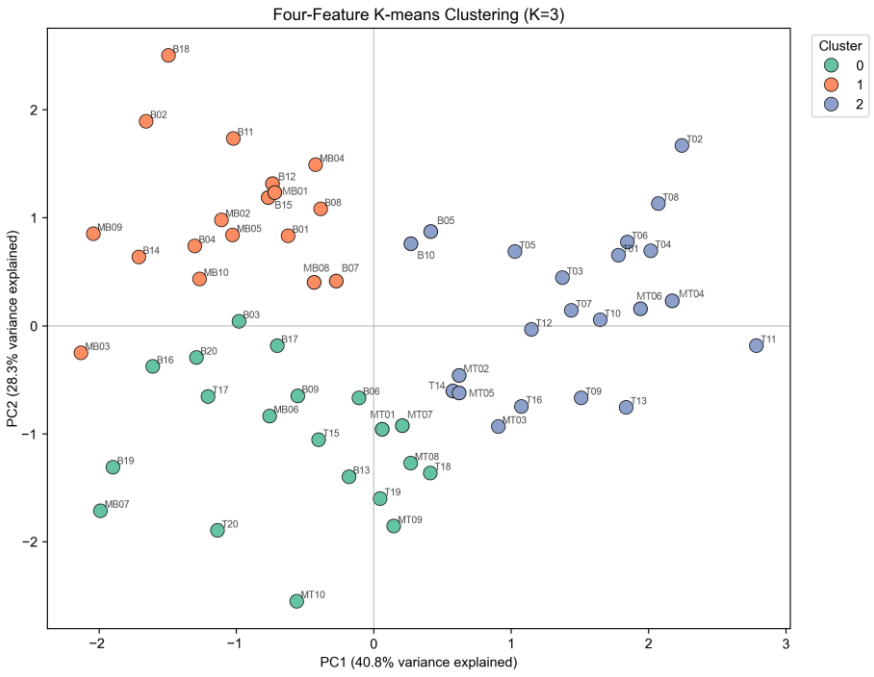
At the material level, the MSPI scores for the 40 participants corresponding to each material were further averaged to obtain the mean material-level MSPI scores for each of the 60 materials; these were used for descriptive comparisons between materials, bar chart presentations and the ranking of materials. The participant–material-level MSPI scores

were used in linear mixed-model analyses to preserve individual evaluation differences. This hierarchical structure prevents the conflation of aggregated material scores with individual evaluation scores.

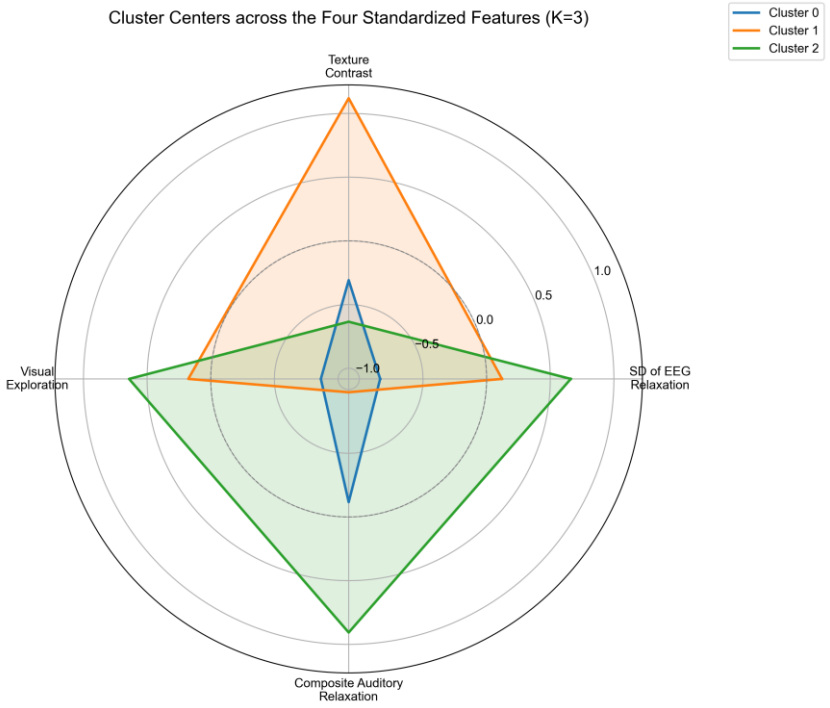
4. Results

4.1. Multimodal Perception Clustering Results

Taking into account the results of the silhouette coefficient, the elbow method and the Bootstrap stability assessment, K = 3 (mean adjusted Rand index (ARI) = 0.729) exhibited the highest clustering stability whilst yielding silhouette coefficients comparable to those of K = 2 (mean ARI = 0.627) and K = 4 (mean ARI = 0.621), and was able to form three distinct and interpretable perception patterns; therefore, K = 3 was ultimately selected (see Appendix A, Table A2). Based on four standardised features—EEG relaxation variability, texture contrast, visual exploration level (adjusted fixation count) and composite auditory relaxation index—k-means clustering divided the 60 material samples into three clusters. The three clusters exhibited distinct response patterns in terms of their multimodal feature combinations; the results of a one-way analysis of variance (ANOVA) indicated significant differences between the three clusters, and Tukey's honestly significant difference (HSD) test was subsequently employed for pairwise comparisons (see Figures 5 and 6).



(**a**)



(**b**)

Figure 5. Cluster Analysis Results: (**a**) PCA projection of the four-feature K-means clustering results (K = 3); (**b**) standardised feature profiles of the three cluster centres..

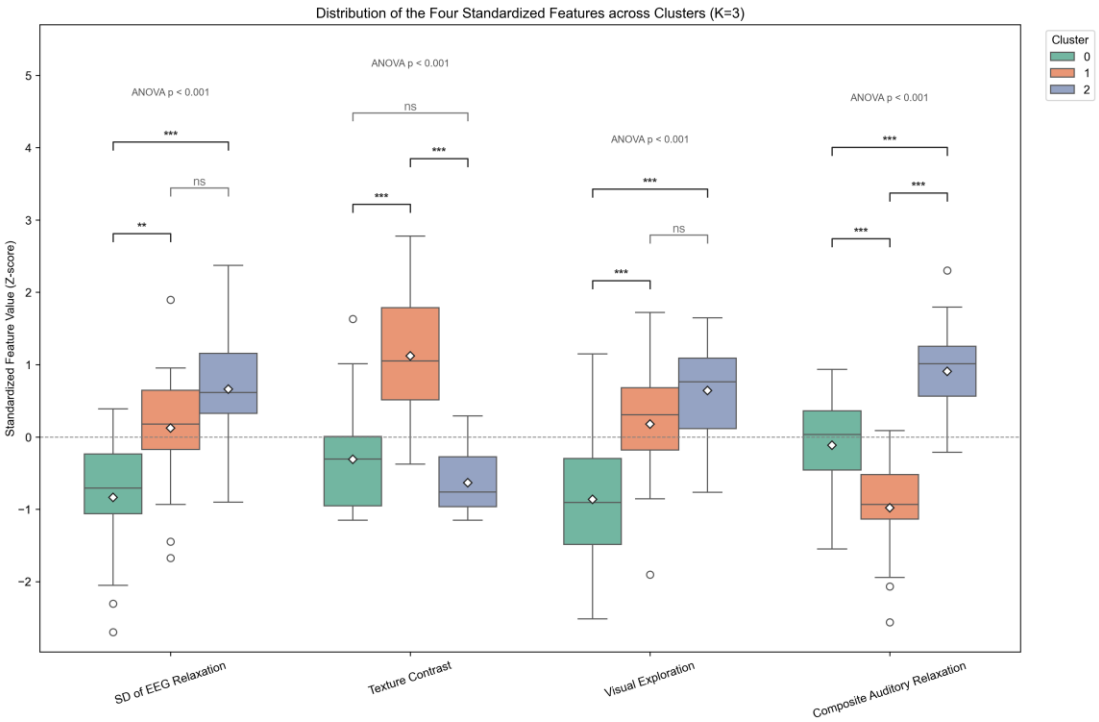


Figure 6. Box plots of the one-way ANOVA results for the clustering features: Pairwise brackets show Tukey HSD adjusted comparisons: ** $p < 0.01$, *** $p < 0.001$; ns = not significant. Diamonds indicate means.

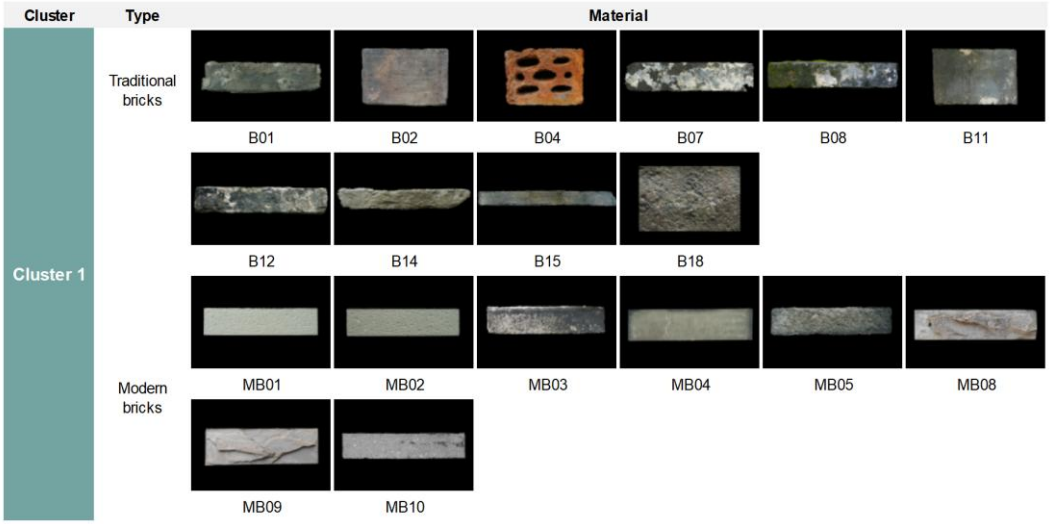
(1) **Cluster 0: Cue-focused cluster(n = 20)**

Cluster 0 exhibited the lowest level of visual exploration, significantly lower than that of Cluster 1 and Cluster 2 (both $p < 0.001$); texture contrast and EEG relaxation variability

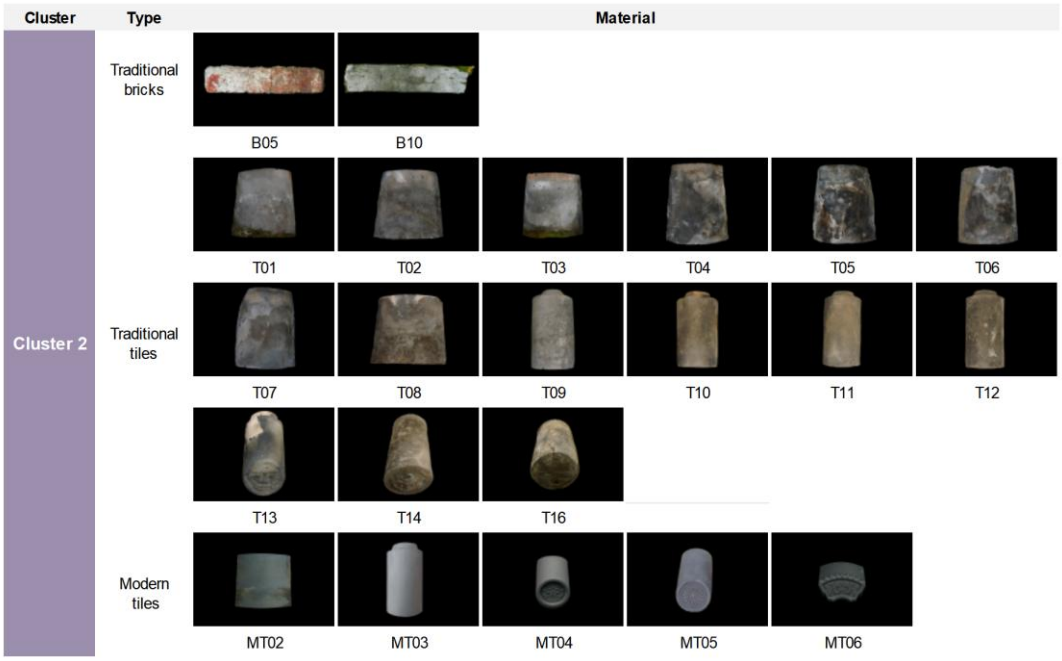
were also relatively low, whilst composite auditory relaxation index was close to the mean for the entire sample. This cluster comprised four types of material, with traditional bricks being slightly more prevalent, followed by traditional tiles and modern tiles, and a few modern bricks; the composition of materials was relatively diverse (see Figure 7).



(**a**)



(**b**)



(**c**)

Figure 7. Material composition of the three clusters: (**a**) Cluster 0, cue-focused; (**b**) Cluster 1, texture-exploration; (**c**) Cluster 2, auditory-relaxation.

This cluster comprises a large number (n = 12) of materials with distinct traditional patterns or structural features at their ends. This phenomenon appears to contradict the relatively low level of visual exploration; however, when considered in conjunction with the distribution of hotspots (see Figure 8), it is evident that observers' gaze was primarily concentrated on the localised areas where these patterns and structural features were located. This suggests that distinctive local cues may have focused visual sampling on a few key areas rather than prompting frequent scanning across the whole surface. A small number of unpatterned materials (n = 8), on the other hand, may have attracted fewer fixations due to the absence of prominent visual anchors and information conducive to sustained exploration on their surfaces. It should be noted that a lower number of fixations here merely indicates a lower volume of visual sampling; it cannot be directly interpreted as low attention, rapid recognition or a lack of interest. Its specific psychological implications should be assessed in conjunction with the distribution of hotspots and the characteristics of the materials. Overall, this cluster can be summarised as 'cue-focused cluster'.

(2) **Cluster 1: Texture-exploration cluster (n = 18)**

Cluster 1 exhibited the highest texture contrast, significantly higher than that of Cluster 0 and Cluster 2 ($p < 0.001$). The level of visual exploration was not significantly different from that of Cluster 2, falling within the upper-middle range, but was significantly higher than that of Cluster 0 ($p < 0.001$). The EEG relaxation variability was at an intermediate level, whilst the composite auditory relaxation index score was the lowest across all three clusters. This cluster consists entirely of brick materials, comprising 10 traditional bricks and 8 modern bricks (see Figure 7).

The surfaces of the materials in this cluster often feature variations in colour, signs of historical weathering, patterns, moss or artificial ageing treatments, creating dense and diverse textural information. The high textural contrast provides observers with a greater amount of distinguishable visual information, prompting them to sample the scene more frequently and engage in sustained observation; at the same time, this cluster exhibits a

lower overall level of auditory relaxation under specified material-related sound stimuli. Consequently, this cluster can be summarised as the 'texture-exploration cluster'.

(3) **Cluster 2: Auditory-relaxation cluster (*n* = 22)**

Cluster 2 exhibited the highest levels of composite auditory relaxation index (all $p < 0.001$), whilst also displaying high levels of visual exploration; however, it had the lowest texture contrast, which was significantly lower than that of Cluster 1 ($p < 0.001$). This cluster consisted predominantly of roof tiles, including 15 traditional tiles and a small number of modern tiles and traditional bricks (see Figure 7).

The materials in this cluster predominantly exhibit relatively gentle surface textures and variations in grey scale; their visual exploration does not rely on high-contrast textures, but rather stems more from details such as colour, form, contour and temporal aspects. Under the specified condition of 'rain striking roof tiles', this cluster exhibits a high level of composite auditory relaxation index; naturally, this result cannot be separated from the influence of the sound of rain itself and the shape of the roof. The predominant tile type is the concave drip tile. The instantaneous reflection and resonance of sounds such as raindrops on the ceramic tile surface produce a clear, percussive sound with transient peaks. Based on its overall characteristics, this cluster can be summarised as the auditory-relaxation cluster; this designation merely describes the auditory–physiological correlation under the recording conditions and does not imply that the tile material possesses an independent relaxing effect.

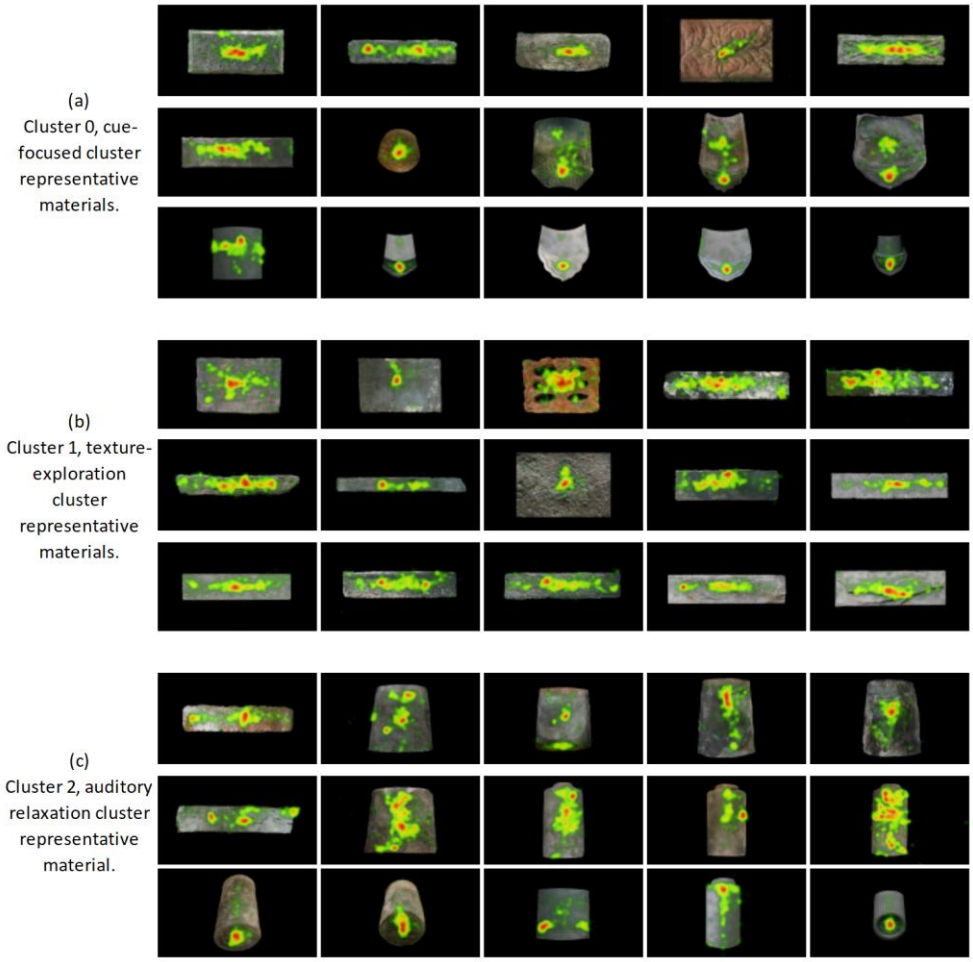


Figure 8. Eye-tracking heat maps for representative materials: (**a**) Cluster 0, cue-focused cluster representative materials; (**b**) Cluster 1, texture-exploration cluster representative materials; (**c**) Cluster 2, auditory-relaxation cluster representative materials..

4.2. The Relationship Between Multimodal Perception Clusters and Material Types

To examine the relationship between sensory clusters and material types, this study conducted tests of independence using contingency tables for 'sensory cluster × material type (traditional/modern)' and 'sensory cluster × material form (brick/tile)'. The results of the former analysis showed that there were no significant differences in the distribution of traditional and modern materials across the clusters ($\chi^2(2) = 2.139$, $p = 0.343$, Cramér's V = 0.189), and the adjusted residuals for each cell did not exceed ±2. This indicates that, within this sample, traditional/modern material type was not significantly associated with sensory-cluster membership.

By contrast, sensory cluster was significantly associated with material form (brick/tile) ($\chi^2(2) = 32.727$, $p < 0.001$, Cramér's V = 0.739), indicating a strong association between sensory pattern and brick/tile form. Brick material was significantly over-represented in Cluster 1 (+5.071), whilst tile material was significantly over-represented in Cluster 2 (+4.822); the composition of bricks and tiles in Cluster 0 did not deviate significantly from the overall expectation. It can thus be seen that brick materials are predominantly clustered in the texture-exploration cluster, characterised by high contrast and strong texture, such as Cluster 1, whilst tile materials are predominantly clustered in the auditory-relaxation cluster, such as Cluster 2. However, this distribution is simultaneously influenced by both material morphology and the type of material-related sound stimulus and should be understood as a statistical association under the specific experimental conditions.

4.3. Analysis of the Results of the Questionnaire and the MSPI Assessment

The item-level CFA comparison showed that the three-factor correlated model fitted the data better than the one-factor model (CFI = 0.958 vs. 0.938; RMSEA = 0.088 vs. 0.101; SRMR = 0.033 vs. 0.039). It also fitted significantly better than the one-factor model, scaled $\Delta\chi^2(3) = 146.647$, $p < 0.001$, and all three two-factor alternatives, scaled $\Delta\chi^2(2) = 48.832$–150.957, all $p < 0.001$. The second-order model reproduced the three-factor fit but yielded an improper solution and was not interpreted. Thus, history, identity, and attachment are highly correlated but empirically distinguishable dimensions. MSPI was therefore retained as a theoretically defined composite index for subsequent analyses, rather than as a validated unidimensional or higher-order latent construct. In the original three-indicator AMOS model used to derive weights for the composite MSPI, identity received the largest standardised loading ($\beta = 0.880$), followed by attachment ($\beta = 0.836$) and history ($\beta = 0.812$) (see Table 3 and Figure 9). The small differences indicate that no single dimension should be regarded as uniquely dominant; these coefficients are weighting-model parameters, not causal contributions to MSPI.

Table 3. Questionnaire reliability and results of the MSPI measurement model.

Dimension	Items	Cronbach's α	Corrected Item–Total Correlation Range	Standardised Factor Loading	Factor Score Weights
History	3	0.792	0.564–0.676	0.812	0.222
Identity	3	0.738	0.493–0.615	0.880	0.399
Attachment	3	0.779	0.523–0.693	0.836	0.263

Note: The composite reliability (CR) of the overall MSPI is 0.881, and the average variance extracted (AVE) is 0.711. CR and AVE were calculated based on the standardised factor loadings of the three dimensions. Cronbach's α and the corrected item–total correlations were calculated based on 2400 'participant–material' evaluation records.

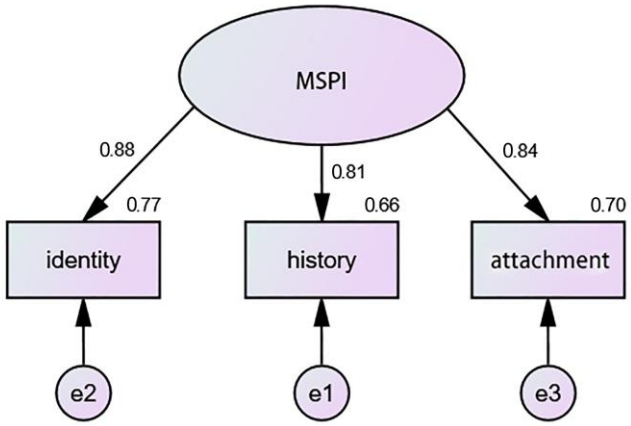


Figure 9. Standardised Factor Loadings and Squared Multiple Correlations from the Three-Indicator AMOS Model.

Following the method described in Section 3.4.3, the MSPI values for the 2400 'participant–material' records were first calculated; subsequently, the ratings of the 40 participants were averaged by material to obtain 60 material-level MSPI mean values. The results show that the material-level mean MSPI values ranged from approximately −0.92 to 0.75 (see Figure 10). As the three dimensions were standardised prior to weighting, positive values indicate a higher level relative to the overall level of the study sample, whilst negative values indicate a lower level; these do not constitute an absolute threshold for the presence or absence of a sense of place. In terms of material distribution, traditional bricks and traditional roof tiles were predominantly found in the positive range, whilst modern bricks and modern roof tiles were predominantly found in the negative range. This indicates that there are certain differences in the MSPI distributions between traditional materials and modern materials; the statistical significance of these differences will be further tested in the linear mixed model in Section 4.4.1.

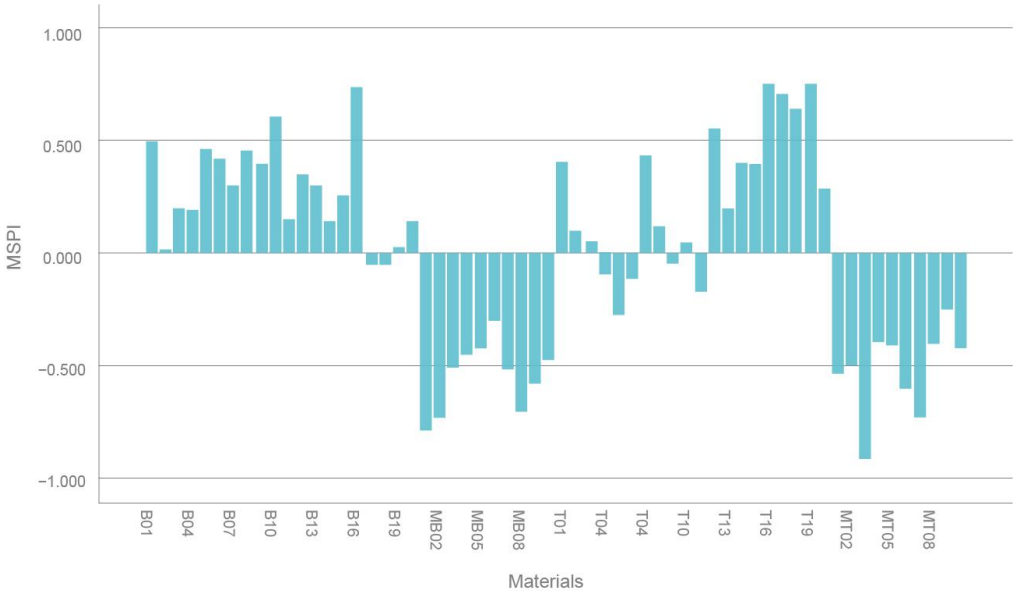


Figure 10. Material-level MSPI Bar Chart.

4.4. The Relationship Between Multimodal Perceptual Patterns and MSPI

4.4.1. Joint Effects of Material Type and Sensory Cluster on MSPI

MSPI distributions overlapped substantially across the three clusters (see Figure 11). This suggests that there may be a certain correlation between sensory clusters and the sense of place associated with the materials, but differences in MSPI scores cannot be fully explained by the materials' cluster affiliation alone. To further test the effect of sensory clusters whilst simultaneously controlling for material type and differences at both the participant and material levels, this study retained 2400 'participant–material' hierarchical records comprising 40 participants × 60 materials, and fitted a linear mixed-effects model (LMM) using the lme4 and lmerTest packages in R. The model took MSPI as the dependent variable, with material type (traditional bricks, traditional tiles, modern bricks and modern tiles), sensory cluster and their interaction term set as fixed effects, whilst subject ID and material ID were set as random intercepts; the overall significance of the fixed effects was assessed using the nested model likelihood ratio test under maximum likelihood estimation.

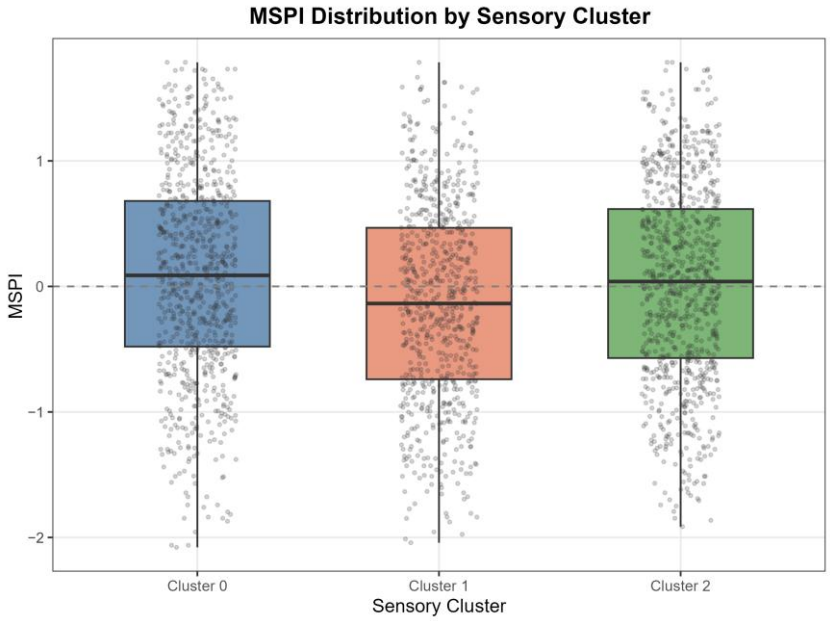


Figure 11. MSPI distribution across different sensory clusters: Each semi-transparent grey point represents an individual participant–material Z-MSPI observation and is horizontally jittered to reduce overlap; darker areas indicate overlapping observations.

The results indicate that the main effect of material type on MSPI was significant, $\chi^2(3) = 78.093$, $p < 0.001$; the main effect of sensory cluster was not significant, $\chi^2(2) = 5.696$, $p = 0.058$; and the interaction between material type and sensory cluster was significant, $\chi^2(3) = 10.742$, $p = 0.013$ (see Table 4). Following the inclusion of the interaction term, the marginal R^2 increased from 0.232 to 0.246, representing an increase of approximately 1.4 percentage points in the proportion of variance explained by fixed effects; the final model had a marginal R^2 of 0.246 and a conditional R^2 of 0.411. Material type, sensory clusters and their interaction jointly explained approximately 24.6% of the variance in MSPI; after accounting for random variations between participants and specific materials, the model's overall explanatory power was approximately 41.1%. Consequently, material type constitutes the primary distinguishing dimension for MSPI differences; whilst sensory clusters did not exhibit a significant independent main effect, their combined relationship with material type was statistically significant. Given the small actual increase in explanatory

power attributed to the interaction term, this result should not be interpreted as indicating a strong interaction or a decisive moderating effect.

Table 4. Likelihood ratio tests of fixed effects in linear mixed-effects models.

Model	Effect	χ^2	df	*p*	Sig	Marginal R^2	Conditional R^2
Additive model	Material_Type Main Effect	78.093	3	<0.001	***	0.232	0.411
	Cluster Main Effect	5.696	2	0.058			
Interaction model	Material_Type × Cluster Interaction	10.742	3	0.013	*	0.246	0.411

Note: The additive model includes two fixed effects—material category and sensory cluster—whilst the interaction model further includes the interaction term between the two; in both models, participant ID and material ID are set as random intercepts. The χ^2 values are based on a nested likelihood ratio test under maximum likelihood estimation. Marginal R^2 for the additive model = 0.232; marginal R^2 for the interaction model = 0.246; conditional R^2 = 0.411. * $p < 0.05$, *** $p < 0.001$.

The estimated marginal means (see Figure 12) show that, within the actual observed data set, the mean MSPI for traditional materials is generally positive, whilst that for modern materials is generally negative, indicating that the traditional–modern nature of the materials constitutes the primary dividing line in the MSPI evaluation. Comparing inter-cluster variations within the same material type, the differences between clusters for traditional bricks and traditional tiles are relatively pronounced, whilst the variations for modern bricks and modern tiles are more gradual. This suggests that, in this sample, the association between sensory clusters and the MSPI of traditional materials may be more pronounced. Among these, only the single interaction coefficient for 'traditional roof tiles × Cluster 2' reached statistical significance; the remaining interaction coefficients were not significant, indicating that this interaction primarily reflects differences in specific material combinations rather than a universal moderating effect across all material types.

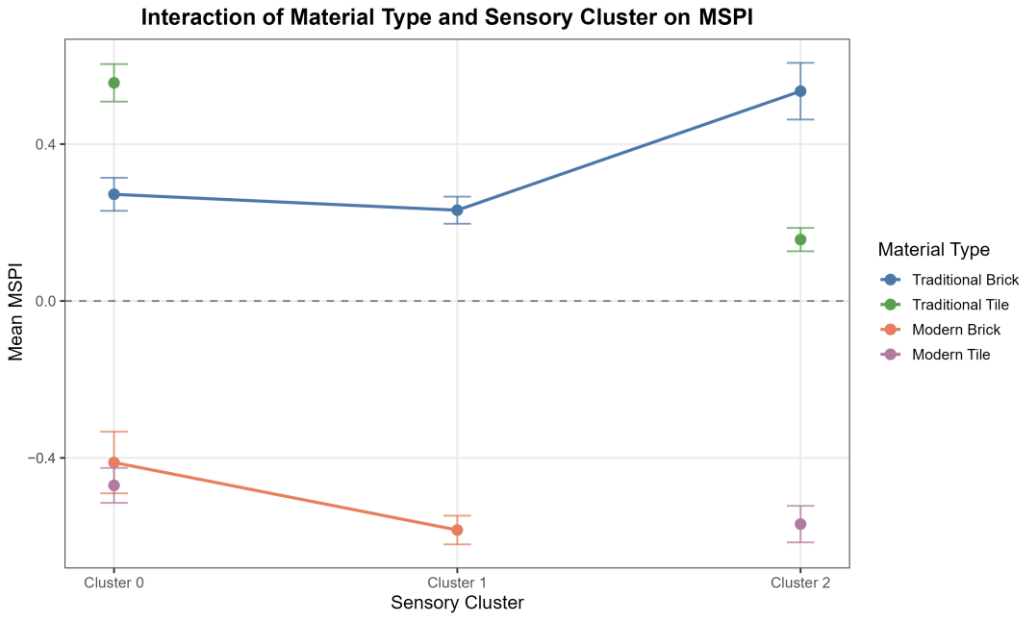


Figure 12. Type × Cluster–MSPI Interaction Line Chart.

It should be noted that the sample lacks the three combinations: 'traditional roof tiles–Cluster 1', 'modern bricks–Cluster 2' and 'modern roof tiles–Cluster 1'. Consequently, Figure 12 and the interpretation of the interactions apply only to the material combinations actually observed; it is not appropriate to extrapolate findings to the missing combinations.

4.4.2. Associations Between Multimodal Perceptual Patterns and the MSPI and Their Application

Combining the aforementioned clustering characteristics with the LMM results, material type emerges as the primary distinguishing dimension for MSPI differences, whilst multimodal perception patterns provide a supplementary explanation. By integrating the perceptual characteristics of each cluster, a preliminary 'sensory–MSPI' composite map can be constructed, providing a reference for urban material assessment and design strategies (see Figure 13). Materials with positive MSPI values are distributed across three sensory clusters and different PCA sensory regions, and are not concentrated in any single fixed perceptual mode; modern bricks and tiles with more negative MSPI values are similarly distributed across clusters. Therefore, sensory clusters alone cannot independently determine MSPI levels; in this sample, higher MSPI values are more commonly observed in combinations where traditional materials co-occur with specific sensory characteristics.

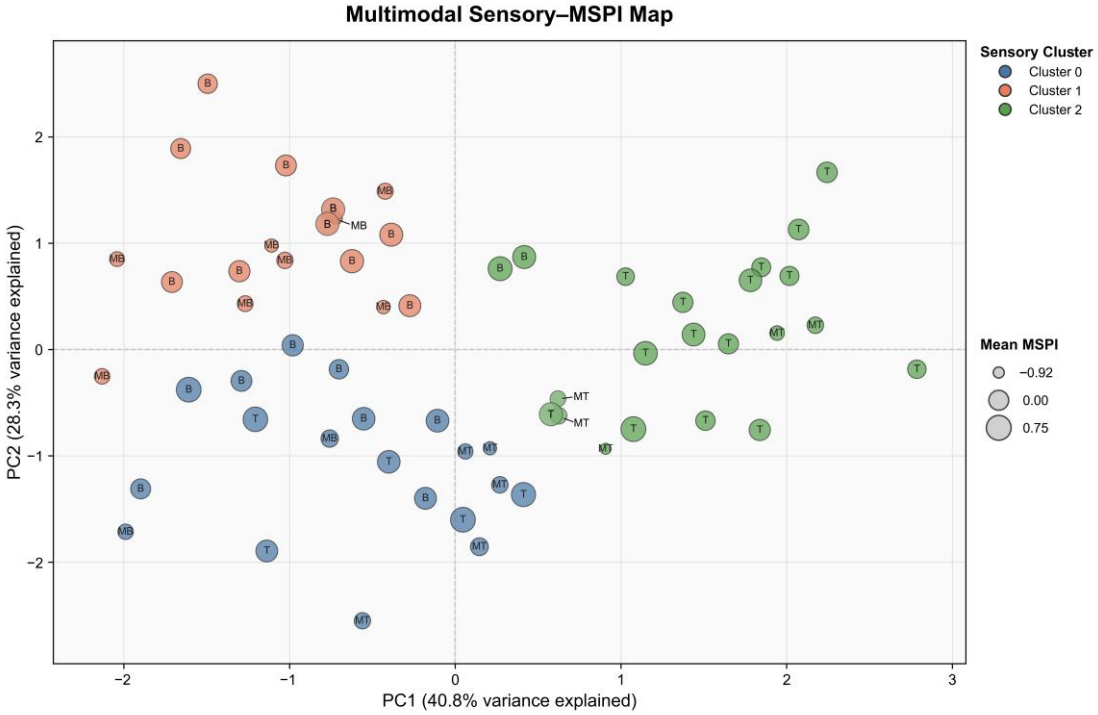


Figure 13. Two-dimensional Sensory—MSPI Map (PCA Scatter Plot): Material codes: B = Traditional Brick, MB = Modern Brick, T = Traditional Tile, MT = Modern Tile; Bubble size is linearly scaled: larger bubbles indicate higher mean MSPI.

Looking at specific combinations, under the rain-striking-tile-surface conditions examined in this study, some traditional clay tiles exhibited higher composite auditory relaxation index levels and MSPI; however, this co-occurrence cannot be attributed entirely to the tile material itself. Some traditional bricks and tiles featuring patterns, eave-end ornaments or distinct signs of ageing also exhibited high MSPI values, suggesting that these localised characteristics may serve as visual cues associated with historical, cultural

and social contexts; their effect does not stem solely from the intensity of visual stimulation, but may be linked to the memory cues and sense of time embodied by the materials.

Conversely, whilst some modern bricks in Cluster 1 exhibit high textural contrast, their mechanically aged or disordered, rough textures were associated with more visual sampling and do not necessarily correspond to higher ratings for history or identity. Although some bricks and tiles in Cluster 0 feature patterns or localised visual anchors, their relatively low MSPI may reflect less distinctive material cues or historical associations. Although some modern roof tiles in Cluster 2 exhibited a high level of composite auditory relaxation index under the specified material-related sound stimuli, they still displayed a low MSPI. The above results indicate that high textural complexity, distinct visual cues or high auditory relaxation indices do not necessarily correspond to higher evaluations of a material's sense of place.

In the context of urban spatial design, this sensory–MSPI spectrum can serve as an auxiliary tool for material evaluation. In traditional neighbourhoods, historic settings and general urban public spaces, a higher MSPI value can be used in conjunction with a material's visual and auditory characteristics as a supplementary reference; when combined with the material's texture, signs of wear and the acoustic experience within its environment, this approach allows for consideration of how visual cues and everyday sounds collectively contribute to the expression of a place. For example, the relationship between roof tiles, eaves and rainfall can be incorporated into design considerations regarding local acoustic experiences; however, as this study does not conclude that roof tiles are materials with an independent relaxing effect, verification in practice must take into account the actual rainfall, structural and acoustic conditions of the specific space. For urban spaces characterised by narrative, commemorative or formal qualities, materials with a high MSPI and cue-focused properties may be considered, with particular attention paid to patterns, traces of craftsmanship and other easily recognisable cues that carry symbolic significance; for newly developed spaces—such as new urban streets, commercial districts and public spaces within residential areas—it is inadvisable to rely solely on surface-level imitation of traditional materials to establish a connection with the place; instead, consideration should also be given to the origin of the materials, their construction methods and their relationship to contemporary contexts of use.

5. Discussion

Based on the results of cluster analysis, MSPI measurements and linear mixed models, the discussion below focuses on three aspects: the sensory pathways in material perception, the psychological representations of material sense of place, and the associations between perceptual characteristics and evaluations of material-level place meaning:

(1) Sensory Pathways in Material Perception

The results of sensory clustering indicate that material samples can be categorised into three sensory clusters: cue-focused, texture-exploration and auditory-relaxation. In contrast to the intuitive understanding that the texture, pattern, colour and brightness of building material surfaces prolong gaze duration [2], this study found that there is not a simple linear relationship between visual texture and the number of fixations. When considered in conjunction with the distribution of eye-tracking hotspots, some materials with distinct patterns or structural features, although receiving fewer fixations, exhibited relatively concentrated fixation locations. This suggests that local cues may reduce extensive, repetitive visual sampling. Of course, a lower number of fixations merely indicates a lower volume of visual sampling and cannot be interpreted in isolation as low attention, rapid recognition or a lack of interest. On the other hand, higher texture contrast can increase the amount of information available for observation and promote texture sampling, but

this does not necessarily translate into positive preferences or associations. Therefore, material design should not merely pursue visual stimulation, but should strike a balance between visual richness, comprehensibility and cultural significance. The material composition of sensory clusters indicates that bricks are more frequently categorised under the 'textural-exploration' type, whilst roof tiles are more commonly classified under the 'auditory relaxation' type. The wear, moss growth and variations in colour tones on the surface of bricks provide visual cues for identifying signs of material use. Within the context of Chengdu's rainy climate and the architectural landscape of western Sichuan—characterised by traditional dwellings with eaves and tiles—the sound of rain striking the tiles and the echoes beneath the eaves constitute everyday auditory experiences associated with roof tiles. Consequently, material design in urban spaces should not only consider visual characteristics such as texture and colour but also focus on the relationship between materials, architectural structure and environmental sounds, thereby enabling multiple sensory cues to collectively contribute to the expression of place meaning.

Sensitivity analysis further indicates that, whilst keeping the number of clusters, the standardisation method and the remaining input features constant, re-clustering was performed using MFCC V1, average EEG relaxation, and the first principal component (PCA) of both, respectively, in place of the composite auditory relaxation index. Compared with the baseline approach, the ARI values for the three alternative methods were 0.805, 0.734 and 1.000, respectively, whilst the silhouette coefficients were 0.269, 0.262 and 0.299. The results indicate that the clustering structure retains a high degree of consistency even when a single auditory metric is employed; as the first principal component of PCA is mathematically equivalent to the equally weighted average metric after standardisation, it yields completely consistent clustering results.

(2) Psychological Representations of Material-Level Place Meaning

The CFA results indicate that history, identity, and attachment are highly correlated but empirically distinguishable components of material-level place meaning. The relative importance of material-related place identity within the MSPI measurement framework suggests that people's evaluation of materials is not based solely on their age, but also on whether they are considered local, whether they align with their perception of the city, and whether they can represent a shared identity. History, identity and attachment thus collectively constitute different manifestations of a material's sense of place, rather than forming a definitive, unidirectional causal chain. The research findings also show that traditional materials with an authentic historical context generally achieved higher MSPI scores, whilst modern materials that merely imitate traditional styles in form scored relatively lower. Yalçın [60] distinguishes between 'existing authenticity' and 'perceived authenticity', noting that spatial authenticity is not only determined by the existing physical environment but is also continuously interpreted and constructed within local memory, social narratives and cultural contexts. Whilst his research did not directly measure perceived responses to building materials, this perspective provides an important frame of reference for understanding the material differences identified in this study. The historical traces, continuity of use and connections to local culture inherent in traditional materials may make them more readily recognisable as material cues of local authenticity, thereby contributing to the formation of local meaning. Consequently, the higher MSPI scores for traditional materials should not be simply attributed to the age of the materials; rather, they are more likely to reflect the interplay between the materials' physical characteristics, historical continuity and local cultural memory. Accordingly, future research could examine whether these three dimensions show differential predictive validity across material types.

In contrast, the historical role of ancient towns within cities has shifted from architectural spaces primarily serving residential functions to tourist resources with development potential; whilst modern materials, period-style finishes and staged events may replicate the visual imagery of a specific era or region, they risk severing the continuity of authentic lived experience. As Relph discusses in his work on 'placelessness', when spaces are primarily shaped by technical planning and commercial logic, and are detached from the continuity of real-life experience, people may consume a certain 'impression of place' within them, but may not necessarily establish a stable sense of place with them [61]. From this perspective, the cultural psychology revealed by this study carries certain practical implications—the 'authenticity' of materials relates not only to their age, craftsmanship and physical form, but also depends on whether they continue to play a part in residents' daily lives and remain connected to concrete experiences of use and social relationships. Materials are therefore not merely decorative or stylistic symbols; they may also serve as material mediators linking past experiences, present life and future imaginings.

(3) Associations between Perceptual Characteristics and Evaluations of Material-Level Place Meaning

The sensory properties of a material cannot directly predict its performance on the MSPI; however, the two are not entirely unrelated, but may be linked to sensory characteristics, material type and environmental context. The results indicate that material type constitutes the primary distinguishing dimension for MSPI differences, whilst sensory patterns provide only limited supplementary explanation; similar sensory characteristics may correspond to different MSPI values because the role of sensory cues is influenced by the material's historical and cultural context. The patterns, sounds and signs of ageing in traditional materials can establish connections with existing local knowledge and lived memories, thereby contributing to the formation of cultural meaning; even if modern materials imitating traditional ones possess similar textures or sounds, their sensory characteristics may remain confined to the level of recognition if they lack a history of use and social connections. Therefore, the relationship between multimodal perception and the material sense of place can be understood as a process of sensory translation grounded in cultural context. Stedman [17] argues that the built environment does not directly generate a sense of place, but rather functions through the meanings people ascribe to it. Raymond et al. [62] further point out that local meaning is formed through the combined influence of the built environment, individual experience and socio-cultural processes. This study provides additional insight from the material scale, demonstrating that textures, signs of ageing and associated auditory experiences can constitute sensory cues for local meaning; however, their role depends on the historical and cultural context in which the materials are situated. Sensory characteristics alone cannot adequately compensate for deficiencies in the cultural context, and historical value may prove difficult for observers to recognise if it lacks perceptible expression.

In today's highly mobile society, the duration of people's stays and the trajectories of their lives are becoming increasingly fragmented; the pre-modern foundation of 'long-term residence in one place' is being steadily eroded, and the pathways through which a sense of place is formed are facing reconstruction. In this context, multisensory design—through the careful consideration of materials' textures, colours, soundscapes and tactile qualities—may help people to grasp clues linked to the city's character and local memories even during brief stays. In urban regeneration and design practice, we should avoid design that prioritises technology over all else, and instead focus on harmonising sensory characteristics with the specific meanings of the local context. Modern materials and a contemporary aesthetic are not inherently at odds with a sense of place; for cities such as Chengdu, where cultural traditions and urban development are continuously intertwined,

the key to fostering a sense of place lies in balancing the relationship between historical authenticity, contemporary life and diverse aesthetic sensibilities.

Based on the above analysis, material strategies can be developed in at least three directions: firstly, in the selection and use of building materials, we must avoid reducing tradition to a mere replication of history. We should emphasise the structural logic, traces of craftsmanship and history of use of materials, whilst avoiding the substitution of local significance with increased textural complexity or surfaces imitating antiquity. Secondly, materials should be situated within the context of residents' everyday use, rather than being confined to display spaces intended solely for tourists, ensuring that material choices remain connected to residents' actual perceptions and experiences of use. Thirdly, building materials should be situated within a longer-term local narrative. A sense of place concerns not only memories of the past, but also the present situation and visions of the future. Material strategies should align with residents' expectations regarding future lifestyles, place identity and the character of the city.

This study has several limitations. Firstly, visual and auditory stimuli were presented separately; thus, 'multimodal' refers to the integration of indicators at the analytical level, while the effects of simultaneous multisensory stimulation remain unexamined. Furthermore, the close-up images of materials and audio recordings did not fully capture the spatial context and everyday activities of real streets and alleys, thereby limiting their ecological validity. Future research should employ field studies or conduct more comprehensive multimodal experiments that combine virtual reality (VR), physical materials and interactive environments. Secondly, as brick materials correspond to wind sounds and tile materials to rain sounds, there is a confounding relationship between material form and the type of material-related sound stimulus; consequently, the auditory results cannot be interpreted as independent effects of the materials themselves. Subsequent studies should compare materials under standardised stimulus conditions, whilst taking into account practical environmental factors such as background noise, rainfall and building construction. Thirdly, the sample consisted predominantly of young adults, with insufficient representation of residents aged 60 and over; differences in local experiences among residents, tourists and students may also affect the interpretation of the MSPI. Future research could expand the age range, analyse groups such as local residents separately, and incorporate familiarity with the local area. Fourthly, as this study employed a cross-sectional design, it can only demonstrate associations between variables and cannot determine the direction of causality. Future research could involve longitudinal intervention studies. Fifthly, the material samples were limited to bricks and roof tiles, which may restrict the generalisability of the findings to other traditional building materials, such as timber, stone or rammed earth. The smaller number of modern samples may also reduce the precision of comparisons involving modern materials. Future research could expand the range of material types and geographical samples, while adopting a more balanced sampling design.

6. Conclusions

This study focuses on the brick and tile materials found in the KuanZhai Alleyways, integrating image and audio features, eye-tracking and EEG data to identify sensory patterns of the materials using k-means clustering; simultaneously, it constructs a Material Sense of Place Index (MSPI) based on three dimensions—history, identity and attachment—to analyse the relationship between material type, sensory patterns and evaluations of local significance. The study reached three conclusions:

Firstly, the material samples formed three sensory clusters—cue-focused, texture-exploration and auditory-relaxation—reflecting the combination of perceptual characteristics of the materials under the selected indicators and predetermined stimulus conditions, as well as differences in the distribution of sensory clusters across different material types.

Secondly, history, identity, and attachment collectively reflect material-related sense of place; among these, identity exhibited the highest standardised factor loading. The overall MSPI score for traditional materials was higher than that for modern materials imitating antique styles, suggesting that the historical traces of the materials, their continuity of use and their connection to local culture all contribute to the evaluation of their local significance.

Thirdly, material type is the primary distinguishing dimension for differences in MSPI, whilst sensory clusters provide a supplementary explanation; although the interaction between the two can be statistically detected, its actual explanatory power is limited, indicating that the sensory characteristics of materials need to be understood in conjunction with their material type and cultural context.

It should also be noted that this study integrates separately collected visual, auditory and physiological indicators at the analytical level; the MSPI reflects the perceptual potential of materials to evoke place-related meanings at the micro-scale. Consequently, the research findings cannot be interpreted as a direct measurement of the complete sense of place or causal mechanisms.

Author Contributions: M.Z.: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualization, Writing. M.L.: Conceptualization, Resources, Funding Acquisition, Supervision. H.H.: Conceptualization, Data Curation, Methodology. X.W.: Conceptualization, Investigation, Software. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical approval for this study was obtained from the Ethics Committee of the College of Arts, Sichuan University (Approval No. K2026003). The study design and implementation adhered to established ethical principles for research involving human participants, including the Declaration of Helsinki and relevant institutional guidelines of Sichuan University. This study was classified as non-invasive, minimal-risk research within the field of humanities and social sciences. All procedures were conducted in accordance with the approved research protocol.

Informed Consent Statement: All participants voluntarily took part in the study and provided written informed consent prior to their participation. The consent procedure was administered by the research team, and written consent was obtained directly from all individual participants. The research protocol implemented during data collection fully complies with the submitted ethics application. This study constitutes non-invasive, low-risk social science research. The procedure adheres to established institutional and international ethical principles. Before signing the consent form, participants were clearly informed of the study purpose, procedures, data usage, anonymity protection, and their right to withdraw from the study at any time. All image data of research participants featured in this paper have been obtained with the participants' written informed consent, which explicitly includes authorisation for the use of their images in academic publications. Prior to signing the informed consent form, all participants were fully informed of the potential public display of their images in academic publications and the associated risks. During the image processing, the study has taken reasonable measures to protect participants' privacy and anonymity. No identifiable personal sensitive information has been disclosed, except where explicit authorisation has been obtained.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy and ethical restrictions. The dataset contains participant-level eye-tracking, EEG, and questionnaire data. Any shared dataset will be de-identified to protect participant privacy.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Equation A1 presents the contrast formula employed in this paper:

$$\text{Contrast} = \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} (i-j)^2 \cdot p(i, j; d, \theta) \quad \text{(A1)}$$

Table A1. Material Sense of Place Questionnaire (MSPQ).

	Label	Indicator Explanation	Score (1 = Strongly Disagree, 7 = Strongly Agree)						
HISTORY	HISTORY1	I believe this material can represent the cultural characteristics of the local region (Sichuan).	1	2	3	4	5	6	7
	HISTORY2	This material conveys a sense of temporal continuity (a connection from past to present).	1	2	3	4	5	6	7
	HISTORY3	The material evokes associations with Sichuan culture, history and architecture.	1	2	3	4	5	6	7
IDENTITY	IDENTITY1	This material (visual and auditory) evokes positive emotions in me.	1	2	3	4	5	6	7
	IDENTITY2	This material strengthens my sense of belonging to the local Sichuan region.	1	2	3	4	5	6	7
	IDENTITY3	I am more inclined to favour this material for use in urban development and cultural enhancement.	1	2	3	4	5	6	7
ATTACHMENT	ATTACHMENT1	I enjoy moving about and lingering in the urban spaces created by this material.	1	2	3	4	5	6	7
	ATTACHMENT2	The environment created by this material is an integral part of experiencing the charm of spaces such as KuanZhai Alleyways.	1	2	3	4	5	6	7
	ATTACHMENT3	If such spaces created from these materials were to diminish in our cities, I would find it regrettable.	1	2	3	4	5	6	7

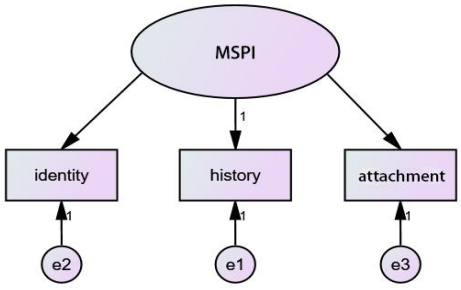


Figure A1. Three-Indicator AMOS Path Diagram for MSPI Construction: The values of 1 indicate coefficients fixed for model identification..

Table A2. Evaluation of K-means cluster solutions based on silhouette coefficients and bootstrap stability.

K	Silhouette	Bootstrap ARI Mean	SD	Min–Max	Cluster Sizes
2	0.275	0.627	0.246	−0.017–1.000	28/32
3	0.299	0.729	0.158	0.280–1.000	20/18/22
4	0.281	0.621	0.115	0.311–1.000	19/12/13/16

Note: Bootstrap repeated 1000 times.

References

1. Li, Z. *Forms and Construction Techniques of Traditional Chinese Architecture*; Tongji University Press, Shanghai, China, 2015. (In Chinese)
2. Gao, L. Material Perception—A Study of Material Experience in Architectural Space. Master's Thesis, Dalian University of Technology, Dalian, China, 2009. Available online: https://kns.cnki.net/kcms2/article/abstract?v=fvaKTeWl6eIb7HUZb-blEF_Pm2YV9eXYVi0gRhyYK4kyf0T0QHHtlvwqFBy1RYCt73jayTsGRv8eYqMlefyc_PxjnOv1ol8lIXWL73dNks-nDqlPTb9vph7JcD5NIrstiMMQ1ls-HUbb0dEnPJd0wwFLTMT28Uj55DhXS50RwrLQGIweutDKm3w==&uniplatform=NZKPT&language=CHS (accessed on 13 October 2026). (In Chinese)
3. Standing Committee of the Guangdong Provincial People's Congress. Regulations of Guangdong Province on the Protection of Famous Historical and Cultural Cities, Towns, and Villages (Announcement No. 51), 25 March 2025; Effective 1 May 2025. Available online: https://zfcxjst.gd.gov.cn/xxgk/wjtz/content/post_4687101.html (accessed on 30 September 2026). (In Chinese)
4. Zou, M.; Bahauddin, A. The creation of "sacred place" through the "sense of place" of the Daci'en wooden Buddhist temple, Xi'an, China. *Buildings* **2024**, *14*, 481. https://doi.org/10.3390/buildings14020481.
5. Fujisaki, W.; Goda, N.; Motoyoshi, I.; Komatsu, H.; Nishida, S. Audiovisual integration in the human perception of materials. *J. Vis.* **2014**, *14*, 12. https://doi.org/10.1167/14.4.12.
6. Kanaya, S.; Kariya, K.; Fujisaki, W. Cross-modal correspondence among vision, audition, and touch in natural objects: An investigation of the perceptual properties of wood. *Perception* **2016**, *45*, 1099–1114. https://doi.org/10.1177/0301006616652018.
7. Chen, X.; Xiong, J. Material perception: Experience design of construction material. *Adv. Mater. Res.* **2013**, *689*, 290–293. https://doi.org/10.4028/www.scientific.net/AMR.689.290.
8. Chen, X.; Duan, W.; Liu, Y.; Li, S.; Song, G. The influence of material and spatial size on indoor environment preference evaluation. *J. Asian Archit. Build. Eng.* **2025**, *24*, 1112–1122. https://doi.org/10.1080/13467581.2023.2278447.
9. Zhou, Y.; Zhao, X.; Feng, Y.; Xuan, C.; Yang, C.; Jia, X. Effects of visual perception of building materials on human emotional states and cognitive functioning in a physical learning environment. *Buildings* **2025**, *15*, 1163. https://doi.org/10.3390/buildings15071163.
10. Lorenzon, M. Brick by brick: Illuminating the cognitive landscape of the past through sensory archaeology. *Time Mind* **2024**, *17*, 55–76. https://doi.org/10.1080/1751696X.2024.2352383.
11. Jorgensen, B.S.; Stedman, R.C. A comparative analysis of predictors of sense of place dimensions: Attachment to, dependence on, and identification with lakeshore properties. *J. Environ. Manag.* **2006**, *79*, 316–327. https://doi.org/10.1016/j.jenvman.2005.08.003.
12. Low, S.M.; Altman, I. Place attachment: A conceptual inquiry. In *Place Attachment*; Altman, I., Low, S.M., Eds.; Springer: Boston, MA, USA, 1992; Volume 12, pp. 1–12. https://doi.org/10.1007/978-1-4684-8753-4_1.
13. Proshansky, H.M. The city and self-identity. *Environ. Behav.* **1978**, *10*, 147–169.
14. Proshansky, H.M.; Fabian, A.K.; Kaminoff, R. Place-identity: Physical world socialization of the self. *J. Environ. Psychol.* **1983**, *3*, 57–83. https://doi.org/10.1016/S0272-4944(83)80021-8.
15. Stokols, D.; Shumaker, S.A. People and places: A transactional view of settings. In *Cognition, Social Behavior and the Environment*; Harvey, J.H., Ed.; Erlbaum: Hillsdale, NJ, USA, 1981; pp. 441–488.
16. Erfani, G. Reconceptualising sense of place: Towards a conceptual framework for investigating individual-community-place interrelationships. *J. Plan. Lit.* **2022**, *37*, 452–466. https://doi.org/10.1177/08854122221081109.
17. Stedman, R.C. Is it really just a social construction? The contribution of the physical environment to sense of place. *Soc. Nat. Resour.* **2003**, *16*, 671–685. https://doi.org/10.1080/08941920309189.
18. Shamsuddin, S.; Ujang, N. Making places: The role of attachment in creating the sense of place for traditional streets in Malaysia. *Habitat Int.* **2008**, *32*, 399–409. https://doi.org/10.1016/j.habitatint.2008.01.004.
19. Thinnakorn, W.; Noonsuk, W.; Srimuang, K. Cultural identity, local wisdom and sustainability of bamboo in forming vernacular architecture: A case study of Bang Chak and Khlong Noi communities, Mueang District, Nakhon Si Thammarat Province. *Cogent Arts Humanit.* **2026**, *13*, 2603722. https://doi.org/10.1080/23311983.2025.2603722.
20. Edensor, T.; Cullen, B. A sense of place and everyday heritage: The clinker brick walls of suburban London. *J. Place Manag. Dev.* **2025**, *18*, 348–365. https://doi.org/10.1108/JPMD-10-2024-0116.
21. Dilaveroglu, B. Matter, form and meaning in architecture: A cross-cultural reading of parliament buildings. *Archnet-IJAR Int. J. Archit. Res.* **2026**, *20*, 501–521. https://doi.org/10.1108/ARCH-11-2024-0469.
22. Jorgensen, B.S.; Stedman, R.C. Sense of place as an attitude: Lakeshore owners' attitudes toward their properties. *J. Environ. Psychol.* **2001**, *21*, 233–248. https://doi.org/10.1006/jevp.2001.0226.

23. Williams, D.R.; Vaske, J.J. The measurement of place attachment: Validity and generalizability of a psychometric approach. *For. Sci.* **2003**, *49*, 830–840.
24. Wells, J.C. How are old places different from new places? A psychological investigation of the correlation between patina, spontaneous fantasies, and place attachment. *Int. J. Herit. Stud.* **2017**, *23*, 445–469. https://doi.org/10.1080/13527258.2017.1286607.
25. Sadalla, E.K.; Sheets, V.L. Symbolism in building materials: Self-presentational and cognitive components. *Environ. Behav.* **1993**, *25*, 155–180. https://doi.org/10.1177/0013916593252001.
26. Atalan, O. Continuity of regional identity: A case study of facade elements in traditional Çeşme houses. *A/Z ITU J. Fac. Archit.* **2016**, *13*, 121–131. https://doi.org/10.5505/itujfa.2016.49368.
27. Cross, J.E. Processes of place attachment: An interactional framework. *Symb. Interact.* **2015**, *38*, 493–520. https://doi.org/10.1002/symb.198.
28. Vanclay, F.H.; Higgins, M.; Blackshaw, A. *Making Sense of Place: Exploring Concepts and Expressions of Place Through Different Senses and Lenses*; National Museum of Australia Press: Canberra, ACT, Australia, 2008.
29. Ariannia, N.; Naseri, N.; Yeganeh, M. Cognitive-emotional feasibility of the effect of visual quality of building form on promoting the sense of place attachment (Case study: Cultural iconic buildings of Iran's contemporary architecture). *Front. Archit. Res.* **2024**, *13*, 37–56. https://doi.org/10.1016/j.foar.2023.10.002.
30. Liu, J.; Yang, L.; Xiong, Y.; Yang, Y. Effects of soundscape perception on visiting experience in a renovated historical block. *Build. Environ.* **2019**, *165*, 106375. https://doi.org/10.1016/j.buildenv.2019.106375.
31. Feng, J.; Bahauddin, A.; Miao, J. Sense of place and sacred places: A phenomenological study of ancestral hall spatial narratives—The Shike Ancestral Hall, En Village, Guangdong. *Buildings* **2025**, *15*, 470. https://doi.org/10.3390/buildings15030470.
32. Bertheaux, C.; Zimmermann, E.; Gazel, M.; Delanoy, J.; Raimbaud, P.; Lavoué, G. Effect of material properties on emotion: A virtual reality study. *Front. Hum. Neurosci.* **2024**, *17*, 1301891. https://doi.org/10.3389/fnhum.2023.1301891.
33. Fleming, R.W.; Wiebel, C.; Gegenfurtner, K. Perceptual qualities and material classes. *J. Vis.* **2013**, *13*, 9. https://doi.org/10.1167/13.8.9.
34. Wastiels, L.; Schifferstein, H.N.J.; Heylighen, A.; Wouters, I. Relating material experience to technical parameters: A case study on visual and tactile warmth perception of indoor wall materials. *Build. Environ.* **2012**, *49*, 359–367. https://doi.org/10.1016/j.buildenv.2011.08.009.
35. Strobel, K.; Nyrud, A.Q.; Bysheim, K. Interior wood use: Linking user perceptions to physical properties. *Scand. J. For. Res.* **2017**, *32*, 798–806. https://doi.org/10.1080/02827581.2017.1287299.
36. Coşgun, B.; Yıldırım, K.; Hidayetoglu, M.L. Effect of wall covering materials on the perception of cafe environments. *Facilities* **2022**, *40*, 214–232. https://doi.org/10.1108/F-07-2021-0060.
37. Fujisaki, W.; Tokita, M.; Kariya, K. Perception of the material properties of wood based on vision, audition, and touch. *Vis. Res.* **2015**, *109*, 185–200. https://doi.org/10.1016/j.visres.2014.11.020.
38. Zheng, H.; Fang, L.; Ji, M.; Strese, M.; Özer, Y.; Steinbach, E. Deep learning for surface material classification using haptic and visual information. *IEEE Trans. Multimed.* **2016**, *18*, 2407–2416. https://doi.org/10.1109/TMM.2016.2598140.
39. Maleki, M.; Rouhafzay, G.; Cretu, A.-M. Multimodal material classification using visual attention. *Sensors* **2024**, *24*, 7664. https://doi.org/10.3390/s24237664.
40. Zhang, R.S.; Yan, X.Y.; Wang, C.; Chen, J.T. Multimodal Data-Driven Research on Affective Interaction between People and the Built Environment—A Case Study of the Wudaokou Section of the Beijing–Zhangjiakou Railway Heritage Park. *Urban Dev. Stud.* **2022**, *29*, 55–66. (In Chinese)
41. Mao, Y.; Li, P.; Hao, P. The effects of wooden furniture color, floor material, and age on design evaluation, visual attention, and emotions in office environments. *Buildings* **2024**, *14*, 1498. https://doi.org/10.3390/buildings14061498.
42. Steinley, D. K-means clustering: A half-century synthesis. *Br. J. Math. Stat. Psychol.* **2006**, *59*, 1–34. https://doi.org/10.1348/000711005X48266.
43. Jain, A.K. Data clustering: 50 years beyond K-means. *Pattern Recognit. Lett.* **2010**, *31*, 651–666. https://doi.org/10.1016/j.patrec.2009.09.011.
44. Fan, T.; Tang, X.; Li, K. Image clustering algorithm and psychological perception in historical building colour rating research: A case study of Guangzhou, China. *Front. Archit. Res.* **2025**, *14*, 1415–1435. https://doi.org/10.1016/j.foar.2025.01.003.
45. Gunawan, P.H.; Fathurahman, T. Parallel algorithm for K-means clustering in wood species classification. In *Intelligent Algorithms in Software Engineering*; Silhavy, R., Ed.; Springer: Cham, Switzerland, 2020; Volume 1224, pp. 474–483. https://doi.org/10.1007/978-3-030-51965-0_41.

46. Rousseeuw, P.J. Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *J. Comput. Appl. Math.* **1987**, *20*, 53–65. https://doi.org/10.1016/0377-0427(87)90125-7.
47. Architectural History Society of China; School of Civil Engineering and Architecture, Henan University; Henan Provincial Institute of Ancient Architecture Conservation. (Eds.) *Architectural History and Theory*; Selected Papers from the 2008 Academic Symposium; China Science and Technology Press: Beijing, China, 2008; Volume 9. (In Chinese)
48. Chen, K. Research on the "de-scenification" renewal of historic conservation districts under the urban catalyst: A case study of the Kuanzhai Xiangzi area in Chengdu. *Archit. Cult.* **2024**, *9*, 181–183. (In Chinese) https://doi.org/10.19875/j.cnki.jzywh.2024.09.056.
49. An, P.J.; Yang, R. *Yingzao (The Art of Building)*; Hua, J.M., Li, J.L., Eds.; Elephant Press: Zhengzhou, China, 2016. (In Chinese)
50. Suzhou Urban and Rural Construction Archives. (Ed.) *Memories in Brick: Interpreting the History of Brick from an Urban Construction Perspective*; Suzhou Gu Wu Xuan Publishing House: Suzhou, China, 2017. (In Chinese)
51. Zhao, X.; Xu, F. Asphalt pavement segregation detection method based on LBP-GLCM. In Proceedings of the 2020 IEEE 18th International Conference on Industrial Informatics (INDIN), Warwick, UK, 20–23 July 2020; pp. 765–770. https://doi.org/10.1109/INDIN45582.2020.9442087.
52. Wang, T.R.; Bao, Q.Y.; Qin, P.L. Environmental sound classification method based on Mel-frequency cepstral coefficient, deep convolution and Bagging. *J. Comput. Appl.* **2019**, *39*, 3515–3521.
53. Terasawa, H.; Slaney, M.; Berger, J. The thirteen colors of timbre. In Proceedings of the 2005 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics, New Paltz, NY, USA, 16–19 October 2005; pp. 323–326. https://doi.org/10.1109/ASPAA.2005.1540234.
54. Noviyanti, A.; Sudarsono, A.S.; Kusumaningrum, D. Urban soundscape prediction based on acoustic ecology and MFCC parameters. *AIP Conf. Proc.* **2019**, *2187*, 050005. https://doi.org/10.1063/1.5138335.
55. Japaridze, G.; Loeckx, D.; Buckinx, T.; Armand Larsen, S.; Proost, R.; Jansen, K.; MacMullin, P.; Paiva, N.; Kasradze, S.; Rotenberg, A.; et al. Automated detection of absence seizures using a wearable electroencephalographic device: A phase 3 validation study and feasibility of automated behavioral testing. *Epilepsia* **2023**, *64*, S40–S46. https://doi.org/10.1111/epi.17200.
56. Yang, S.; Li, M.; Wang, J.; Shi, Z.; He, B.; Xie, J.; Xu, G. A low-cost and portable wrist exoskeleton using EEG-sEMG combined strategy for prolonged active rehabilitation. *Front. Neurorobot.* **2023**, *17*, 1161187. https://doi.org/10.3389/fnbot.2023.1161187.
57. Rieiro, H.; Diaz-Piedra, C.; Morales, J.M.; Catena, A.; Romero, S.; Roca-Gonzalez, J.; Fuentes, L.J.; Di Stasi, L.L. Validation of electroencephalographic recordings obtained with a consumer-grade, single dry electrode, low-cost device: A comparative study. *Sensors* **2019**, *19*, 2808. https://doi.org/10.3390/s19122808.
58. Yang, Z.; Zhao, X.; Zhu, L.; Xia, Y.; Ma, Y.; Wu, J.; Xiong, X.; Yang, N.; Lu, M. Research on the healing potential of urban parks from the perspective of audio-visual integration: A case study of five urban parks in Chengdu. *Land* **2023**, *12*, 1317. https://doi.org/10.3390/land12071317.
59. Diti, I.; Tassinari, P.; Torreggiani, D. The agri-environmental footprint: A method for the identification and classification of peri-urban areas. *J. Environ. Manag.* **2015**, *162*, 250–262. https://doi.org/10.1016/j.jenvman.2015.07.058.
60. Yalçın, B. One place two stories: The reproduction of the "authentic" in Beyoğlu. *Megaron* **2023**, *18*, 231–245. https://doi.org/10.14744/megaron.2023.23355.
61. Relph, E.C. *Place and Placelessness*; Pion: London, UK, 1976.
62. Raymond, C.M.; Kyttä, M.; Stedman, R. Sense of place, fast and slow: The potential contributions of affordance theory to sense of place. *Front. Psychol.* **2017**, *8*, 1674. https://doi.org/10.3389/fpsyg.2017.01674.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.