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Material Perception in Virtual Environments: Impacts on Thermal Perception, Emotions, and Functionality in Industrial Renovation

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Abstract

Industrial building renovation is a sustainable strategy to preserve urban heritage while meeting modern needs. However, how interior material scenes affect users' emotions, thermal perception, and functional preferences remains underexplored in adaptive reuse contexts. This study used virtual reality (VR) to examine four common material scenes—wood, concrete, red brick, and white-painted surfaces—within industrial renovation settings. A total of 159 participants experienced four Lumion-rendered VR environments and rated them on thermal perception (visual warmth, thermal sensation, comfort), emotional response (arousal, pleasure, restoration), and functional preference. Data were analyzed using repeated measures ANOVA and Pearson correlation. Wood and red brick scenes were associated with warm visuals; wood scenes received the highest ratings for thermal comfort and pleasure, white-painted scenes for restoration and arousal, and concrete scenes, the lowest scores overall. Functional preferences varied by space: white-painted and concrete scenes were most preferred in study/work settings, wood in social spaces, wood and red brick in rest areas, and concrete in exhibition spaces. By isolating material variables in VR, this study offers a novel empirical approach and practical guidance for material selection in adaptive reuse to enhance user comfort, emotional well-being, and spatial functionality in industrial heritage renovations.

Keywords: industrial heritage preservation; virtual reality technology; thermal perception; emotional impact; material selection

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1. Introduction

With accelerating urbanization and the onset of the post-industrial era, cities face the dual pressures of industrial restructuring and limited land resources. Consequently, traditional industries and their associated buildings are gradually being phased out [1], creating an urgent need to renew existing industrial structures. In industrial building renovation, material selection is crucial for meeting modern functional requirements and enhancing user experience [2], as material properties directly shape the visual appearance of spaces and significantly influence users' emotions, thermal perceptions, and functional behavior preferences. Previous research has demonstrated that indoor environments have a major impact on occupants' well-being and health. However, systematic investigations into how the unique spatial features of industrial buildings—such as high ceilings, large exposed structures, and rough material textures—amplify material perception effects remain scarce [3–8]. As a result, comprehensive comparisons of common industrial materials, including wood, concrete, white paint, and red brick, across multiple perceptual dimensions are still noticeably lacking.

Notably, isolating material effects in real physical environments presents major methodological challenges. Environmental variables such as lighting and temperature often confound perceptual responses [9], and reconstructing the same industrial space with different materials is practically unfeasible. To overcome these limitations, this study employed static VR technology to establish a controlled experimental paradigm for material perception in industrial settings, enabling precise isolation of material variables while maintaining consistent environmental conditions. The VR approach offers several advantages: (1) It accurately replicates key features of industrial spaces, such as 4.2 m ceiling heights and exposed structures; (2) It allows systematic manipulation of material properties while tightly controlling other environmental factors; (3) It ensures high ecological validity through highly realistic three-dimensional environments [10–12].

This study established a unique experimental paradigm and, drawing on attention restoration theory (Kaplan), systematically compared four commonly used materials in terms of their effects on users' thermal perception, emotional responses, and functional preferences, addressing a key gap in material perception research within the context of industrial building renovation. It also introduces a material-driven, human-centered design approach, offering scientific evidence and practical guidance for material selection in the adaptive reuse of industrial heritage. The distinctive spatial characteristics of industrial buildings—such as high ceilings, exposed structures, and coarse textures—amplify the perceptual effects of materials, particularly in relation to thermal comfort and emotional experience [9]. These features fundamentally reshape how materials are perceived, positioning industrial renovation not only as a design application, but also as a foundation for this study's theoretical framework.

1.1. Material Perception in Industrial Renovation Contexts

In research on how materials affect thermal perception, the "warm color hypothesis" is one of the most frequently cited theories. This hypothesis suggests that materials closer to the red end of the visible spectrum are more likely to be perceived as warm [13]. Wood with reddish hues is therefore often regarded as a "warm material" [14]. Masuda et al. [15] found that red and yellow materials more readily evoke a sense of warmth, related to their higher infrared reflectance. Notably, this color-based perception is unrelated to the materials' actual thermal properties but has a significant impact on subjective thermal sensation. Further studies have shown that both the visual and tactile properties of materials influence thermal perception. Wastiels et al. [16] found that wood provides a stronger sense of warmth than steel, concrete, or white paint. This subjective thermal perception is closely linked to psychological states. Thoughtful material design can improve indoor comfort and functionality. The natural visual qualities of wood can evoke feelings of comfort and safety. Additionally, the warm appearance of wood can narrow the perceived thermal comfort range, especially during the heating season, helping to lower heating thresholds, improve thermal comfort, and achieve energy savings [17–20].

In research on the emotional impacts of materials, wood has been the most extensively studied, followed by some work on white materials, while systematic investigations on concrete and red brick are limited. Studies show that wood in indoor environments can produce positive emotional effects and significantly reduce stress [21–25]. According to the classic attention restoration theory (ART), natural elements help restore attention and promote relaxation. Materials such as wood provide "soft fascination", which helps users alleviate fatigue and enhances restoration [8]. Research also indicates that wooden spaces can effectively elicit feelings of pleasure, comfort, and connection to nature [26], and environments with wooden elements can lower stress levels [27]. The biophilia hypothesis suggests that humans have an innate preference for nature, and materials with natural attributes can stimulate positive emotions and improve comfort [28]. This explains why wooden and red brick environments in this study were associated with higher levels of pleasure and restoration. In contrast, materials such as white finishes, ceramics, and stone often induce discomfort or exacerbate depressive moods [29]. Sakuragawa et al. [30] also found that white steel walls, compared to wood, were more likely to provoke feelings of oppression and negative emotions.

In studies on functional preferences, Proshansky et al. [31,32] argued that environmental cognition is closely related to environmental preference, with physical features such as materials and spatial layout shaping people's understanding of space functions and expected behaviors. Similarly, Gifford [33] noted in *Environmental Psychology* that perceived environmental characteristics can evoke functional associations—for example, "warm" or "open" spaces promote social interaction, while "closed" or "cold and rigid" environments encourage solitude or task-focused behavior. Zhang et al. [34] found that moderate wood use in offices reduces tension and fatigue, thereby extending productive work time. This suggests that material properties influence not only emotions but also spatial use. Nyrud et al. [21] further reported that moderate wood finishes enhance comfort in healthcare settings, whereas excessive or minimal use reduces relaxation. Thus, both material type and quantity shape users' perceptions of space and behavioral tendencies.

However, these conclusions are mainly based on conventional standardized spaces lacking distinctive structural features, making them difficult to generalize to industrial buildings. Industrial spaces have unique attributes, such as ceiling heights over 4 m, extensive exposed structural elements, and high material surface roughness. These characteristics can significantly modulate material perception by amplifying visual and tactile impressions and altering subjective emotional and thermal experiences [3]. This spatial mediation suggests that material effects observed in generic environments may not apply to industrial renovation contexts.

Existing research on environmental psychology theories—such as attention restoration theory and the biophilia hypothesis—has predominantly focused on conventional spatial settings characterized by standardized layouts, moderate scale, and stable formal attributes, including residential, office, or natural environments. These studies have largely overlooked spatial contexts with pronounced structural and material characteristics. In contrast, adaptive reuse of industrial buildings often involves environments with soaring ceilings, extensive exposed structural elements, and coarse-textured surfaces. Such spatial features may intensify users' visual and tactile impressions, significantly influencing their emotional states and thermal perceptions, and thereby altering material-related evaluations. However, it remains unclear whether these distinctive spatial attributes amplify, attenuate, or reshape the psychological effects predicted by existing theories, as systematic investigations in this context are still lacking. Moreover, while wood's positive emotional impacts—such as stress relief and increased pleasure—are well documented, there is a notable lack of systematic research on how other materials commonly used in industrial renovations, including concrete, red brick, and white paint, specifically affect emotional regulation (e.g., arousal, restoration) in industrial settings.

Therefore, this study systematically compares wood, concrete, red brick, and white paint material scenes in industrial building environments. It aims to reveal how these material scenes affect users' emotions and thermal perceptions in spaces with unique industrial features, providing scientific evidence for industrial renovation and offering new perspectives on human-centered material scenes selection and design. Importantly, industrial buildings are not just experimental sites in this research. Their distinctive attributes—high ceilings, large, exposed structures, and rough textures—form the theoretical foundation for amplifying material scenes perception effects. These features set industrial environments apart from traditional spaces and serve as the core basis for understanding material scenes perception in this study.

1.2. Virtual Reality for Material Perception Research

Comparing participants' perceptual differences toward four materials within an industrial architectural environment is constrained by limitations inherent to physical spaces. On one hand, studying materials within the same physical space restricts the range of materials that can be tested. On the other hand, using different physical spaces makes it difficult to isolate material effects from environmental variables that may influence outcomes. Additionally, factors such as lighting conditions and the relative positions of observers and materials are challenging to control precisely, yet these variables significantly impact the visual appearance and perceptual effects of materials [9]. Consequently, some studies have attempted to address these challenges by changing table colors [35], converting laboratory spaces into office-like environments [36], or using labs with different material finishes [37]. However, these studies often neglect potential interactive effects between the overall architectural space and color, with conclusions typically based on isolated environmental settings. Many studies, for example, only adjust the foreground or background colors of objects being evaluated (e.g., materials) [38–41], without considering the actual contextual relationships of these colors within specific architectural spaces.

Recent research increasingly uses virtual reality (VR) technology to create experimental settings, especially in indoor environment studies [10–12]. Virtual environments can simulate experiences similar to those in real physical spaces, producing perceptual effects comparable to actual environments. VR technology offers more realistic visual stimuli, enabling depth perception in three-dimensional scenes that surpasses traditional two-dimensional setups. It allows participants to naturally rotate their bodies and observe surroundings, enhancing realism [11,42]. Moreover, substantial research has demonstrated that VR environments are effective tools for studying perceptions of materials, lighting, and colors, as simulated spaces in VR can evoke psychological and physiological responses similar to those in real environments [43]. For example, VR has been successfully used to evaluate interventions for children with ADHD (Attention Deficit Hyperactivity Disorder) [10,11]. This is especially important for industrial spaces whose spatial properties cannot be physically replicated. VR simulations enable the systematic isolation of material effects within realistic industrial configurations, which is a methodological necessity in the context of this study. Additionally, VR allows precise control of environmental factors such as lighting and spatial layout through two-dimensional photographs [44], three-dimensional panoramic images [44–46], or digital models [47–50].

Finally, VR reduces the artificiality of experimental setups. People often change their behavior in the presence of others [51], and since participants cannot see the experimental setup or the experimenter in VR, this helps control personal factors that might influence results. VR enables accurate simulation of real spaces under controlled experimental conditions, providing a more scientific and rigorous environment for research. This facilitates deeper and more systematic investigations into the impact of industrial architectural materials on human perception. However, the application of VR technology in material perception research remains relatively limited, particularly in design optimization based on participant responses.

1.3. Research Objectives

Although the effects of building materials on thermal perception and emotional responses have been widely studied, research in the context of industrial renovation remains limited. Unique spatial characteristics—such as high ceilings and exposed structures—may amplify material perception, yet this interaction has not been fully explored. This study employs static virtual reality (VR) to systematically compare four commonly used materials in industrial settings—wood, concrete, red brick, and white paint—while retaining key architectural features of industrial buildings and controlling for external variables. It investigates how these materials influence users' thermal perception, emotional responses, and functional preferences in adaptive reuse scenarios. Guided by existing theories and empirical findings, this study addresses the following key questions:

1. Are there significant differences in users' thermal sensation and comfort associated with different materials in the context of industrial building renovation?
2. Are different materials linked to varying emotional responses in adaptive reuse settings of industrial buildings?
3. Are users' functional preferences (e.g., study, socializing, rest, exhibition) associated with materials in renovated industrial buildings?

Based on these questions, the following hypotheses are proposed:

Hypothesis 1 (H1): *Users' thermal sensation and thermal comfort are expected to differ across the four material conditions within the context of industrial building renovation.*

Hypothesis 2 (H2): *Emotional responses (e.g., arousal, pleasure, restoration) may vary across material types in adaptive reuse environments of repurposed industrial buildings.*

Hypothesis 3 (H3): *Functional preferences (e.g., for studying, socializing, resting, or exhibiting) may be associated with different materials used in renovated industrial spaces.*

This study aims to provide systematic empirical evidence to guide material selection in industrial renovations, establish a VR-based framework for material perception research, and propose design guidelines that align material choices with the functional and emotional goals of adaptive reuse projects. These contributions seek to improve user comfort, emotional well-being, and spatial adaptability.

2. Materials and Methods

This study employed a within-subject experimental design using virtual reality (VR) technology to evaluate perceptual differences elicited by four commonly used industrial renovation materials—wood, concrete, red brick, and white paint—within a virtual learning and working space based on an industrial heritage setting (dimensions: 30,000 × 12,000 × 4200 mm). By creating four distinct VR environments with different materials, the experiment aimed to quantify participants' differences in thermal perception, emotional responses, and functional preferences under each material condition. The research framework included experimental design, participant recruitment, data collection, and data analysis.

2.1. Experimental Design

This study employed a within-subject experimental design, focusing on floor and wall materials categorized into four types: concrete, wood, white paint, and red brick. The advantage of this design lies in its use of repeated measures, ensuring that each participant experienced all four material variations, thereby effectively eliminating individual differences [52].

The experiment was conducted in virtual rooms with four different material settings. The room was modeled in SketchUp 2023, rendered in Lumion 12.0, and enhanced with realistic object textures, natural daylight, and shadow effects, before being displayed through a VR eye-tracking system. The virtual room prototype represented a learning and working space (30,000 mm × 12,000 mm × 4200 mm) within a renovated industrial heritage building. The interior walls and floors of this space served as visual environmental variables, showcasing four material scenarios commonly used in industrial renovations: concrete, wood, white paint, and red brick. Figure 1a illustrates the four interior wall material scenes. The same material was applied to both the floor and wall surfaces to enhance the perceptual impact of each material and to realistically simulate industrial renovation scenarios, where consistent material use is often adopted to achieve spatial coherence.

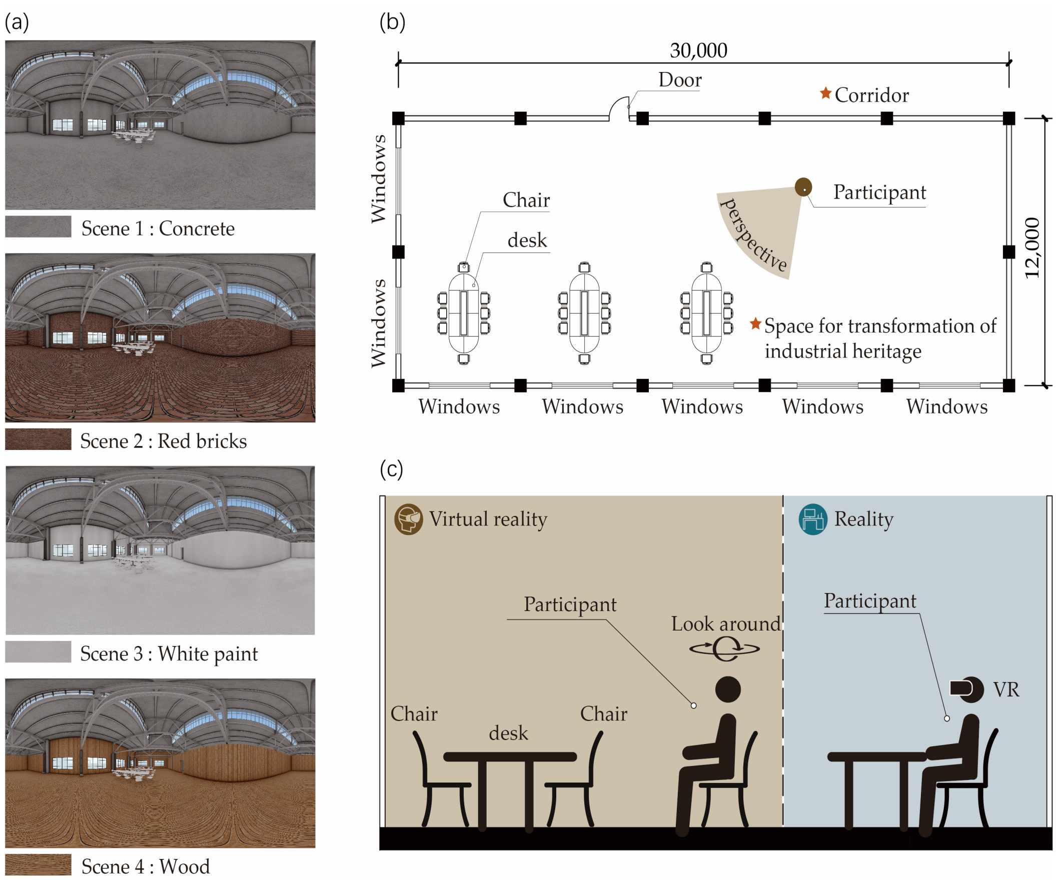

Figure 1. (**a**) VR scene (360°); (**b**) Experimental scene layout; (**c**) Experimental schematic.

Given the industrial building context, the material atmosphere was designed to realistically reproduce industrial spaces, ensuring the reliability of the evaluation results. We acknowledge that such environments contain inherent historical and spatial cues that may influence participants' perceptions. However, this choice was intentional and closely aligned with the study's goal of investigating material effects within authentic industrial renovation settings. To minimize unintended biases, we kept all factors consistent across scenes except for the interior wall and floor materials, including finishes, layout, furniture, lighting, and natural daylight conditions. Identical desks and chairs for learning and working were provided in each room. Additionally, to avoid obvious thermal cues, the virtual scenes excluded elements that could trigger temperature associations, such as sunlight, rain, or snow. During the experiment, the order in which each participant experienced the scenes was randomized to control for order effects.

The scene was set at 10:00 AM in early May, representing a bright and sunny summer morning. Panoramic images of the virtual space were generated using Lumion 12.0's built-in functions. To ensure the realism of material perception, Lumion 12.0's physically based rendering (PBR) material system was used, allowing materials to maintain realistic color, texture, and gloss under various lighting conditions. Scene lighting relied entirely on natural sky illumination provided by Lumion 12.0's Real Skies, without artificial indoor lighting. By enabling global illumination from the sky and selecting a soft ambient HDRI sky, we reduced direct sunlight and harsh shadows. The sun's brightness and angle were adjusted to block direct light, resulting in evenly diffused natural lighting with minimal shadows. To further eliminate noticeable shadows, sun brightness was set to zero, and both the OmniShadow and Fine Detail Shadows sliders were set to 0, significantly reducing subtle shadows while maintaining natural depth. Key surfaces, such as floors and glass, used Planar Reflections combined with reflection effects to enhance the accuracy of material reflections. This ensured that reflective materials, like polished wood, displayed realistic highlights and environmental mapping even without strong direct light. Finally, Lumion 12.0's color correction tools were used to fine-tune exposure values, ensuring indoor lighting was bright yet not overexposed, with material textures and colors clearly visible. This setup ensured simplified shadow visualization did not compromise the accurate perception of materials during the VR experiment.

The observation point in the scenes was set at a height of 1.2 m, matching the average eye level of seated participants. Panoramic images of the virtual space were integrated into the 3D Unity 2021 platform and presented through a Tobii Pro VR eye-tracking device (Beijing Kingfar Technology Co., Ltd., Beijing, China) to create the required virtual environment. This device features a resolution of 2160 × 1200 pixels, a refresh rate of 90 Hz, and a 110° field of view, enabling static 360° panoramic renderings from a fixed seated position to standardize material exposure and reduce movement-related interference [11]. Participants could freely observe the virtual scenes. Although this design limited interactivity, it ensured consistency in material evaluation across participants, a method validated in previous visual perception studies [43]. The Tobii VR eye-tracking system was used primarily to align participant gaze with the virtual environments and to improve the realism of stimulus presentation.

2.2. Participants

Table 1 displays the characteristics of the participants. The required sample size for this study was calculated using GPower 3.1 software [53,54], with an effect size set to 0.25 and α set to 0.05. The results indicated that 24 participants were needed to achieve a statistical power of 0.8. This study ultimately recruited 159 participants, meeting the effect size requirements. Among them, 50.9% were female, and 49.1% were male. Additionally, 84.3% of the participants were aged between 18 and 25. During recruitment, volunteers were required to be in good health, free from serious illnesses such as colds, fevers, or color blindness, and to have uncorrected or corrected visual acuity of 1.0 or higher to avoid visual discrepancies affecting the results. Furthermore, the number of participants was balanced across genders and between professional and non-professional backgrounds to ensure sample homogeneity [55]. When asked whether they had prior experience with VR before the experiment, 60% reported having such experience. Prior to the formal experiment, a test segment was conducted to identify and exclude participants who exhibited symptoms such as dizziness, nausea, or an inability to adapt to the virtual reality environment. To eliminate subjective preconceptions, participants were only briefly informed about the experimental procedure during recruitment, and the purpose of the experiment was kept confidential. All participants volunteered for the study and confirmed that they had no history of drug or alcohol addiction. They were also instructed to maintain regular dietary and sleep patterns during the experiment to ensure physical and mental well-being [55]. This study was approved by the Ethics Committee of the School of Architecture at Inner Mongolia University of Technology (approval number: 20240915-MS-E02, approval date: 15 September 2024) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all individual participants included in the study.

Table 1. Descriptive statistics of participant characteristics.

Category		Frequency (Percentage/%)	Category		Frequency (Percentage/%)
Gender	Male	78 (49.1)	Education	Short-cycle Courses	10 (6.3)
	Female	81 (50.9)		Normal Courses	74 (46.5)
Age	18~25 years old	134 (84.3)		Master's Degree	74 (46.5)
	26~30 years old	20 (12.6)		Doctor's Degree	1 (0.6)
	31~40 years old	5 (3.1)	Hours of work-study at the Architecture Hall	No or occasionally	77 (48.4)
College	Architecture	73 (45.9)		Less than 3 years	72 (45.3)
	Non-Architecture	86 (54.1)		3 years and above	10 (6.3)

2.3. Data Collection

2.3.1. Questionnaire Design

This experiment used a questionnaire to assess participants' thermal perception, emotions, and functional preferences (see Table 2). The thermal perception scale consisted of three dimensions: thermal sensation, visual sensation, and overall thermal comfort, each measured with one question. The scale was adapted from Chinazzo et al. [56] and based on the EN ISO standard [57], which addresses thermal sensation and comfort [58]. Results were analyzed using quantitative statistics. The visual sensation section was developed based on studies of temperature–color interactions [48], covering perceptions of material warmth and coolness. For overall thermal comfort, participants were asked to evaluate the comfort and acceptability of the space, assuming an extended stay. The thermal perception scale demonstrated good reliability ($\alpha > 0.7$) across all four material conditions.

The emotion scale consisted of three dimensions—Arousal, Pleasure, and Restoration—with 12 items in total (see Table 2). Each was measured using a five-point Likert-type semantic differential scale, based on the Positive and Negative Affect Schedule. Items used bipolar adjectives such as "calm (1)–excited (5)", "boring (1)–stimulating (5)", and "constrained (1)–at ease (5)", to capture emotional responses in virtual material environments. Reliability analysis showed good internal consistency for each dimension under all four material conditions, with Cronbach's α values exceeding 0.7, confirming that the scale effectively captured emotional variations across different material scenarios.

Functional preferences were assessed using a qualitative classification questionnaire (see Table 2). Participants were asked to select the function they considered most suitable for each of the four environments, with options including "study/work", "communication/socializing", "rest", "exhibition", and "other". This classification was based on common functions found in industrial renovation projects [59]. Additionally, participants could choose "other" and freely describe alternative functions they deemed appropriate. To minimize the influence of cultural or semantic associations on functional judgments, two design controls were implemented. First, all activity options were labeled using neutral, non-material-specific terms to reduce semantic priming. Second, participants received contextual anchoring instructions that explicitly guided them to base their responses solely on the visual perception of each VR scene, imagining they were encountering the space for the first time. These measures aimed to reduce reliance on prior knowledge or learned associations and ensure that responses reflected perceptual impressions rather than pre-existing functional stereotypes. This section aimed to explore how different material environments influenced participants' functional preferences.

Table 2. Questionnaire for Thermal Perception, Emotions, and Functional Preferences.

Variable	Subjective Perception	Question	Response Scale
Thermal Perception	Visual sense	How do the wall and floor materials appear to you visually	Cold (1)–Hot (5)
	Thermal sensation	How would you rate your thermal sensation in this scene?	Cold (1)–Hot (5)
	Thermal comfort	How would you rate your thermal comfort in this scene?	Very uncomfortable (1)–Very comfortable (5)
Emotion	Arousal	Do you feel aroused in this scene?	Calm (1)–Excited (5)
		Do you feel excited in this scene?	Peaceful (1)–Excited (5)
		Do you feel stimulated in this scene?	Bored (1)–Stimulated (5)
		Do you feel surprised in this scene?	Disappointed (1)–Surprised (5)
	Pleasure	Do you feel happy in this scene?	Sad (1)–Happy (5)
		Do you feel relaxed in this scene?	Tense (1)–Relaxed (5)
		Do you feel satisfied in this scene?	Dissatisfied (1)–Satisfied (5)
		Do you like this scene?	Dislike (1)–Like (5)
	Restoration	Do you feel calm in this scene?	Anxious (1)–Calm (5)
		Do you feel at ease in this scene?	Restrained (1)–At ease (5)
		Do you feel comfortable in this scene?	Uneasy (1)–Comfortable (5)
		Do you feel relaxed in this scene?	Tense (1)–Relaxed (5)
Functional Preference		What type of activity do you think this scene is most suitable for?	Studying and Working, Socializing, Resting, Exhibiting, Other

2.3.2. Experimental Arrangements and Procedures

The experiment was conducted from 28 June 2024, over eight non-consecutive days, from 9:00 AM to 5:00 PM each day. The laboratory was a 20 m^2 enclosed, windowless space designed to eliminate visual distractions and included an adjacent waiting room. The air conditioning system precisely controlled indoor temperature and humidity, which were continuously monitored using an Elitech BT-3 digital hygrothermograph (Elitech Technology, Inc., San Jose, CA, USA). During each session, the average air temperature was maintained at 26.5 °C, with fluctuations within ±1 °C. Relative humidity was kept between 20% and 30%, and airspeed remained below 0.1 m/s, all aligning with optimal conditions for human neural activity [58].

The experiment was divided into four parts, with each participant completing the entire process, which lasted approximately 65 min. Upon entering the laboratory, participants were asked to remove excess clothing, such as hats, jackets, and masks, and to wear lightweight attire, such as short sleeves, shorts, or skirts, to control the insulation value of their clothing [55], as illustrated in Figure 2. During the experiment, the laboratory remained closed to prevent entry by outside individuals and avoid potential distractions.

To reduce demand characteristics, participants were not informed of the study's hypotheses, and the questionnaires used neutral wording to minimize leading responses.

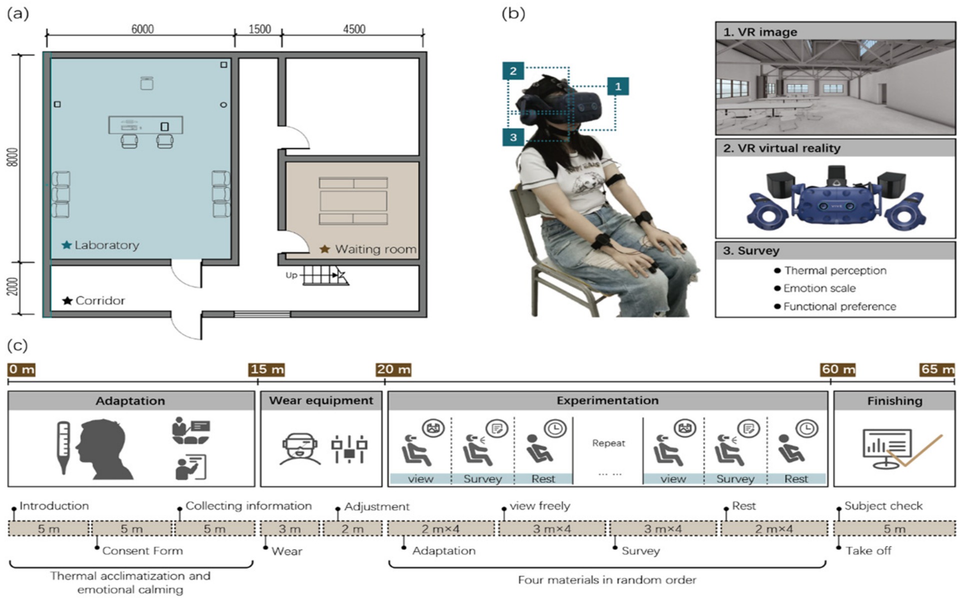

Figure 2. (**a**) Laboratory equipment; (**b**) Experimental equipment; (**c**) Experimental procedure.

The first part was the adaptation phase, which lasted approximately 15 min. Participants were briefly introduced to the experimental procedures, requirements, and potential risks. They were then asked if they were willing to participate and to sign a written informed consent form. After consent was obtained, basic information was collected, including age, gender, major, educational background, and health status. During this period, participants were instructed to remain still to allow for thermal adaptation and emotional stabilization, ensuring a stable baseline state.

The second part was the equipment setup phase, which lasted approximately 5 min. Researchers guided participants in wearing the VR device and explained safety precautions. The device was then calibrated, including interpupillary distance adjustment and eye-tracking checks, to ensure proper functioning throughout the experiment. After calibration, a test segment was played to confirm that participants did not experience discomfort, such as dizziness.

The third part was the experimental phase, which lasted approximately 40 min. Participants completed the experiment while seated on armless stools. Based on previous research [60–62], the adaptation time for each virtual scene was set at 2 min to ensure all participants experienced each scene for the same duration. This approach minimized fatigue from prolonged exposure and maintained participant comfort and experimental accuracy. During the resting adaptation period, participants were instructed to sit quietly with their eyes closed and to refrain from talking. During the experiment, the four material scenarios were presented in random order to avoid sequence effects. Participants first explored each scene freely and informed the researcher when they were ready. They then answered questionnaire items verbally to report their perceptual impressions while the visual scene remained unchanged. Brief rest periods were provided between scenes.

The fourth part was the conclusion phase, which lasted approximately 5 min. After participants removed the VR device, researchers confirmed that all data had been successfully collected. Participants then received compensation and exited the laboratory.

2.4. Data Analysis

This study analyzed significant differences and correlations in thermal perception, emotions, and functional preferences across four indoor material conditions. Data analysis was performed using IBM SPSS Statistics 27. Reliability and validity tests indicated good data quality (Cronbach's $\alpha > 0.7$; KMO value > 0.8). The specific analysis steps were as follows: First, the data were grouped by material, and the mean and standard deviation for each group were calculated [63]. Repeated measures ANOVA was then used to examine within-subject differences in subjective thermal perception, emotions, and functional preferences across materials. Based on the central limit theorem, the data were assumed to follow a normal distribution. Additionally, both Pearson and Spearman rank correlation analyses were conducted to explore relationships between thermal perception dimensions and emotions, ensuring robustness against potential violations of the interval scale and linearity assumptions of Likert-scale data. Finally, to investigate potential gender effects on thermal perception across materials, the Wilcoxon rank-sum test was used to examine significant differences in thermal perception ratings by gender.

3. Results

3.1. Thermal Sensing

Table 3 presents the results of the RM ANOVA, which examined significant differences in subjective thermal perception (visual sensation, thermal sensation, and thermal comfort) across different indoor materials. The p-values for visual sensation, thermal sensation, and thermal comfort were all below 0.05, indicating statistically significant differences based on the selected indoor materials.

Table 3. Results of RM ANOVA for subjective thermal perception.

Source	Measure	SS	df	MS	F	Sig.	η^2
Material	visual sense	317.72	2.67	119.05	73.85	<0.001	0.32
	thermal sensation	336.18	2.70	135.85	92.20	<0.001	0.37
	thermal comfort	163.86	2.88	56.92	41.98	<0.001	0.21
Error	visual sense	679.78	421.68	1.43			
	thermal sensation	627.49	425.88	1.47			
	thermal comfort	616.76	454.87	1.36			

Figure 3 illustrates differences in visual sensation, thermal sensation, and thermal comfort among the four materials commonly used in industrial buildings: concrete, wood, white paint, and red brick.

For visual sensation, participants rated the four material scenes as follows: concrete (M = 1.96, SD = 1.06), wood (M = 3.71, SD = 1.19), white paint (M = 2.27, SD = 1.22), and red brick (M = 3.22, SD = 1.35). The Greenhouse–Geisser corrected estimate of sphericity deviation was $\omega = 0.89$. Results showed significant differences in visual sensation among the four scenes, F (2.67, 421.68) = 73.85, $p < 0.001$, partial $\eta^2 = 0.32$. Bonferroni-corrected post hoc comparisons indicated significant differences between all material scenes ($p < 0.05$). Specifically, visual sensation ratings for the concrete scene were significantly lower than those for wood (t(474) = −13.54, $p < 0.001$, 95% CI [−2.11, −1.40]), white paint (t(474) = −2.78, $p < 0.05$, 95% CI [−0.62, −0.01]), and red brick (t(474) = −9.36, $p < 0.001$, 95% CI [−1.62, −0.90]). The wood scene was rated significantly higher than white paint (t(474) = 9.79, $p < 0.001$, 95% CI [0.82, 1.05]) and red brick (t(474) = 3.96, $p < 0.001$, 95% CI [0.16, 0.82]). The white paint scene was rated significantly lower than red brick (t(474) = −6.25, $p < 0.001$, 95% CI [−1.36, −0.54]). Overall, participants perceived wood as the warmest material and concrete as the coldest, with the warmth ranking: wood > red brick > white paint > concrete.

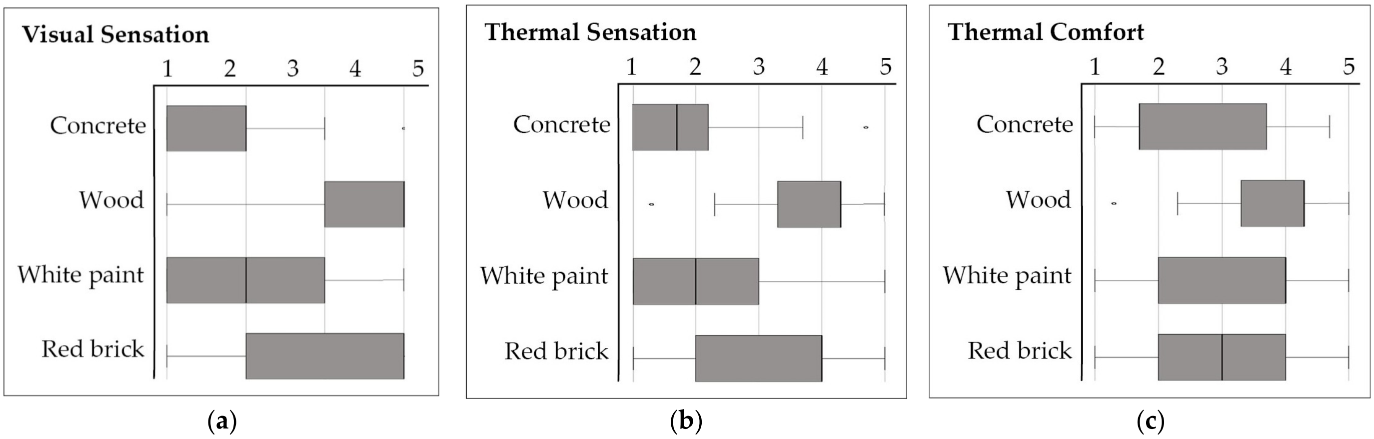

Figure 3. Changes in subjective thermal perception across different materials: (**a**) Visual sensation; (**b**) Thermal sensation; (**c**) Thermal comfort.

For thermal perception, ratings were as follows: concrete (M = 1.78, SD = 1.06), wood (M = 3.76, SD = 1.21), white paint (M = 2.35, SD = 1.24), and red brick (M = 3.19, SD = 1.29). The Greenhouse–Geisser corrected estimate was $\omega = 0.89$. Results showed significant differences among the four scenes, F (2.70, 425.88) = 92.20, $p < 0.001$, partial $\eta^2 = 0.37$. Bonferroni-corrected post hoc comparisons confirmed significant differences between all materials ($p < 0.05$). Concrete was rated significantly lower than wood (t(474) = −14.81, $p < 0.001$, 95% CI [−2.33, −1.62]), white paint (t(474) = −4.31, $p < 0.001$, 95% CI [−0.85, −0.26]), and red brick (t(474) = −8.58, $p < 0.001$, 95% CI [−1.75, −1.06]). Wood was rated significantly higher than white paint (t(474) = 10.09, $p < 0.001$, 95% CI [1.04, 1.79]) and red brick (t(474) = 4.82, $p < 0.001$, 95% CI [0.25, 0.85]). White paint was rated significantly lower than red brick (t(474) = −5.98, $p < 0.001$, 95% CI [−1.23, −0.47]). Overall, participants perceived wood as the warmest and concrete as the coldest material, with the warmth ranking: wood > red brick > white paint > concrete, showing a trend similar to the visual sensation results.

A Pearson correlation analysis was conducted to examine the relationship between visual sensation and thermal perception, as both showed similar trends (see Figure 4). Normality and linearity assumptions were assessed through descriptive statistics (skewness and kurtosis within ±1) and visual inspection of scatterplots. To account for the ordinal nature of Likert-scale data, a Spearman rank correlation analysis was also performed, yielding results consistent with the Pearson analysis. Visual sensation and thermal perception were significantly positively correlated (r(636) = 0.722, $p < 0.001$).

For thermal comfort, participants rated the four scenes as follows: concrete (M = 2.30, SD = 1.22), wood (M = 3.69, SD = 1.15), white paint (M = 3.21, SD = 1.23), and red brick (M = 2.84, SD = 1.27). The Greenhouse–Geisser corrected estimate was $\omega = 0.96$. Significant differences in thermal comfort were observed among the scenes, F(2.88, 454.87) = 41.98, $p < 0.001$, partial $\eta^2 = 0.21$. Bonferroni-corrected post hoc comparisons indicated significant differences between all materials ($p < 0.05$). Concrete was rated significantly lower than wood (t(474) = −10.58, $p < 0.001$, 95% CI [−1.74, −1.03]), white paint (t(474) = −7.58, $p < 0.001$, 95% CI [−1.24, −0.59]), and red brick (t(474) = −3.96, $p < 0.001$, 95% CI [−0.91, −0.18]). Wood was rated significantly higher than white paint (t(474) = 3.84, $p < 0.001$, 95% CI [0.14, 0.81]) and red brick (t(474) = 7.24, $p < 0.001$, 95% CI [0.59, 1.24]). White paint was rated significantly higher than red brick (t(474) = 2.73, $p < 0.05$, 95% CI [0.08, 0.74]). Overall, participants perceived wood as providing the highest comfort and concrete the lowest, with the comfort ranking: wood > white paint > red brick > concrete. These results suggest that although red brick produced a stronger sensation of warmth than white paint, white paint offered better overall comfort.

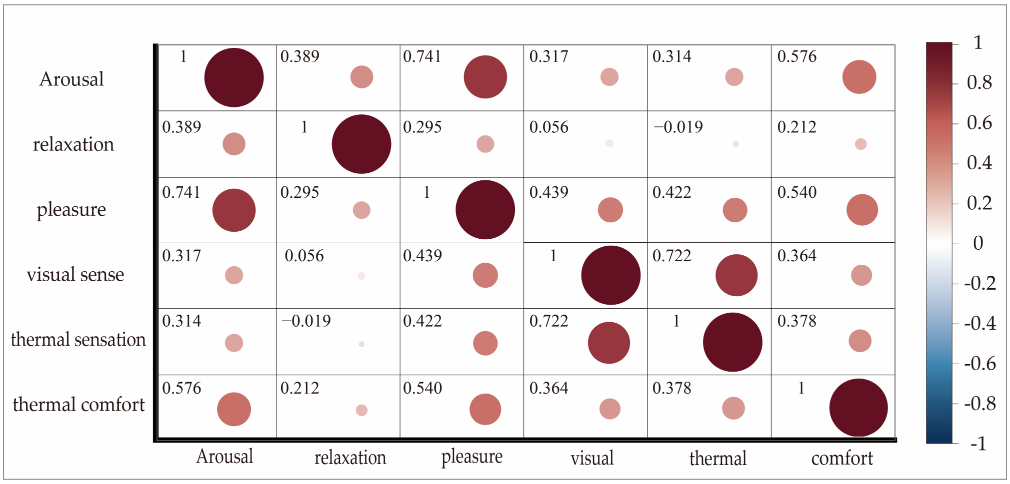

Figure 4. Correlation analysis between subjective thermal sensation and emotions.

Finally, the Mann–Whitney U test was used to examine potential gender differences in subjective thermal perception across materials. Results showed that female participants generally gave lower ratings than male participants (see Table 4), with lower scores in visual sensation, thermal sensation, and thermal comfort. However, these differences did not reach statistical significance (see Table 5).

Table 4. Thermal perception ratings of female and male participants.

	Gender	Mean	Median	Standard Deviation
visual sense	F	2.70	2.00	1.40
	M	2.87	3.00	1.39
thermal sensation	F	2.69	2.00	1.37
	M	2.85	3.00	1.28
thermal comfort	F	2.92	3.00	1.34
	M	3.10	3.00	1.17

Table 5. Statistical analysis results of gender groups.

	Visual Sensation	Thermal Sensation	Thermal Comfort
Mann–Whitney U test	46,873.50	46,753.00	46,703.00
Wilcoxon W	95,701.50	95,581.00	95,531.00
Z	−1.63	−1.68	−1.71
Asymp. Sig. (2-tailed)	0.10	0.09	0.09

3.2. Subjective Emotion

Table 6 presents the results of the repeated measures ANOVA, which examined significant differences in subjective emotions (arousal, pleasure, and restoration) across different indoor materials. The p-values for arousal, pleasure, and restoration were all below 0.05, indicating statistically significant differences based on the selected material scenes.

Table 6. Results of RM ANOVA for subjective emotion.

Source	Measure	SS	df	MS	F	Sig.	η^2
Material	Arousal	98.16	2.93	33.53	30.76	<0.001	0.16
	Pleasure	57.15	2.93	19.49	23.34	<0.001	0.13
	Restoration	45.13	2.93	15.38	15.38	<0.001	0.14
Error	Arousal	504.24	462.59	1.09			
	Pleasure	386.85	463.26	0.84			
	Restoration	275.99	463.65	0.60			

Figure 5 shows differences in arousal, pleasure, and restoration among the four material scenes commonly used in industrial buildings: concrete, wood, white paint, and red brick.

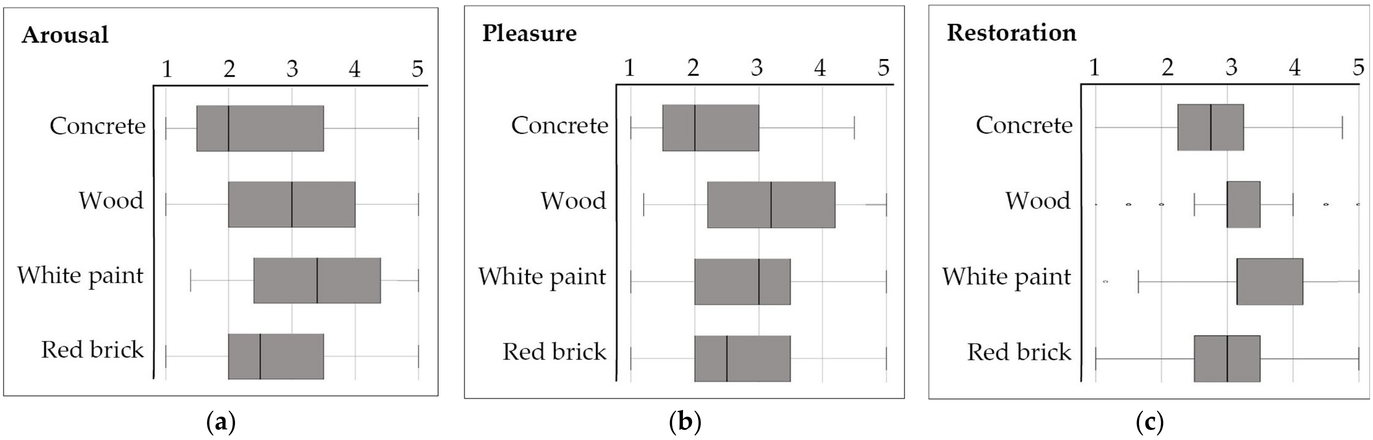

Figure 5. Changes in subjective emotions across different materials: (**a**) Arousal; (**b**) Pleasure; (**c**) Restoration.

For arousal, participants rated the four material scenes: concrete (M = 2.47, SD = 1.19), wood (M = 3.04, SD = 1.12), white paint (M = 3.48, SD = 1.20), and red brick (M = 2.64, SD = 1.16). The Greenhouse–Geisser corrected estimate of sphericity deviation was $\omega = 0.99$. Results showed significant differences in arousal among the scenes, F (2.93, 462.59) = 30.76, $p < 0.001$, partial $\eta^2 = 0.16$. Bonferroni-corrected post hoc comparisons revealed that arousal ratings for concrete were significantly lower than for wood (t(474) = −5.27, $p < 0.001$, 95% CI [−0.83, −0.28]) and white paint (t(474) = −8.42, $p < 0.001$, 95% CI [−1.33, −0.71]). Red brick was rated significantly lower than wood (t(474) = −3.64, $p < 0.001$, 95% CI [−0.68, −0.12]) and white paint (t(474) = −7.00, $p < 0.001$, 95% CI [−1.17, −0.51]). Wood was rated significantly lower than white paint (t(474) = −3.67, $p < 0.05$, 95% CI [−0.77, −0.12]). Overall, white paint elicited the highest arousal, followed by wood and red brick, with concrete eliciting the lowest.

For pleasure, ratings were as follows: concrete (M = 2.28, SD = 1.01), wood (M = 3.13, SD = 1.06), white paint (M = 2.76, SD = 1.07), and red brick (M = 2.70, SD = 1.01). The Greenhouse–Geisser corrected estimate was $\omega = 0.98$. Results showed significant differences in pleasure among the scenes, F (2.93, 463.26) = 22.34, $p < 0.001$, partial $\eta^2 = 0.13$. Bonferroni-corrected post hoc comparisons revealed that concrete was rated significantly lower than wood (t(474) = −7.73, $p < 0.001$, 95% CI [−1.13, −0.56]), white paint (t(474) = −4.36, $p < 0.001$, 95% CI [−0.76, −0.20]), and red brick (t(474) = −4.12, $p < 0.001$, 95% CI [−0.67, −0.15]). Wood was rated significantly higher than white paint (t(474) = 3.71, $p < 0.001$, 95% CI [0.10, 0.63]) and red brick (t(474) = 4.31, $p < 0.001$, 95% CI

[0.18, 0.68]). Overall, wood and white paint elicited the highest pleasure, while concrete elicited the lowest.

For restoration, ratings were as follows: concrete (M = 2.69, SD = 0.83), wood (M = 3.16, SD = 0.75), white paint (M = 3.42, SD = 0.77), and red brick (M = 2.97, SD = 0.80). The Greenhouse–Geisser corrected estimate was ω = 0.98. Significant differences were found among the scenes, F (2.93, 463.65) = 15.38, $p < 0.001$, partial $\eta^2 = 0.14$. Bonferroni-corrected post hoc comparisons showed that restoration ratings for concrete were significantly lower than for wood (t(474) = −5.52, $p < 0.001$, 95% CI [−0.72, −0.25]), white paint (t(474) = −8.78, $p < 0.001$, 95% CI [−0.94, −0.51]), and red brick (t(474) = −3.06, $p < 0.05$, 95% CI [−0.52, −0.04]). White paint was rated significantly higher than wood (t(474) = 3.02, $p < 0.05$, 95% CI [0.03, 0.46]) and red brick (t(474) = 5.01, $p < 0.001$, 95% CI [0.21, 0.69]). Overall, similarly to arousal, white paint elicited the highest restoration, while concrete elicited the lowest.

The Mann–Whitney U test was used to examine gender differences in subjective emotion ratings across materials. Scores for the female group (F group) were higher than those for the male group (M group) (see Table 7), with females reporting higher ratings in arousal, pleasure, and restoration. Differences in arousal and restoration between the groups were statistically significant ($p < 0.05$), while the difference in pleasure was not significant (see Table 8). However, these findings should be interpreted within the limitations of subjective self-reports.

Table 7. Subjective emotion ratings of female and male participants.

	Gender	Mean	Median	Standard Deviation
Arousal	F	2.71	2.50	1.20
	M	2.90	3.00	1.18
Pleasure	F	2.62	2.50	1.08
	M	2.71	3.00	1.04
Restoration	F	3.02	3.00	0.80
	M	3.15	3.00	0.79

Table 8. Statistical analysis results of gender groups.

	Arousal	Pleasure	Restoration
Mann–Whitney U test	45,887.00	48,157.00	45,677.50
Wilcoxon W	94,715.00	96,985.00	94,505.50
Z	−2.03	−1.041	−2.17
Asymp. Sig. (2-tailed)	0.04	0.298	0.03

3.3. Correlation Between Thermal Perception and Emotions

Figure 4 presents the correlation analysis results between subjective thermal perception and emotional dimensions, based on repeated measures ANOVA, highlighting significant associations among variables under different material conditions. The normality and linearity assumptions of the Likert-scale data were assessed through descriptive statistics (with skewness and kurtosis within ±1) and visual inspection of scatterplots. To account for the ordinal nature of Likert responses, a Spearman rank correlation analysis was also performed, yielding results consistent with the Pearson analysis. The analysis showed that arousal and pleasure were significantly positively correlated with visual sensation, thermal sensation, and thermal comfort. Additionally, thermal comfort was significantly positively correlated with restoration.

These results suggest that the thermal effects of material color (i.e., the hue–heat hypothesis) and the psychological impression of the space are significantly associated with thermal comfort evaluations in thermally neutral or cool environments. Biophilic materials, such as wood, were positively correlated with higher thermal comfort ratings by enhancing visual comfort, promoting relaxation, and creating positive impressions. This finding aligns with the principles of the biophilia hypothesis.

3.4. Functional Preference

To further investigate the relationship between material scenes and functional preferences, a two-dimensional analysis was conducted. On the one hand, we examined how the same material scene was perceived across different functional space types; on the other hand, we compared users' preferences for different material scenes within the same functional context. Chi-square tests and Bonferroni-adjusted pairwise comparisons were used to determine the relative suitability of each material scene for specific space functions and to clarify user preference patterns. The detailed results are presented below.

The distribution of preferences for the same material scene across different functional spaces showed statistically significant differences (χ^2 = 123.768, p < 0.001), as illustrated in Figure 6 and Table 9. Bonferroni-adjusted pairwise comparisons revealed the following: Concrete material scenes were more frequently preferred for exhibition (37.7%) and study/work (31.3%) functions; Wood material scenes were more preferred for social (41.5%) and rest (40.5%) functions, and were least preferred for exhibition spaces (7.9%); White-painted material scenes received the highest preference for study/work spaces (36.4%), significantly more than for social (19.5%) and rest (16.7%) spaces, while their preference for exhibition (25.1%) did not differ significantly from the other three functional spaces; Red brick material scenes received the lowest preference for study/work spaces, with only 11.1%.

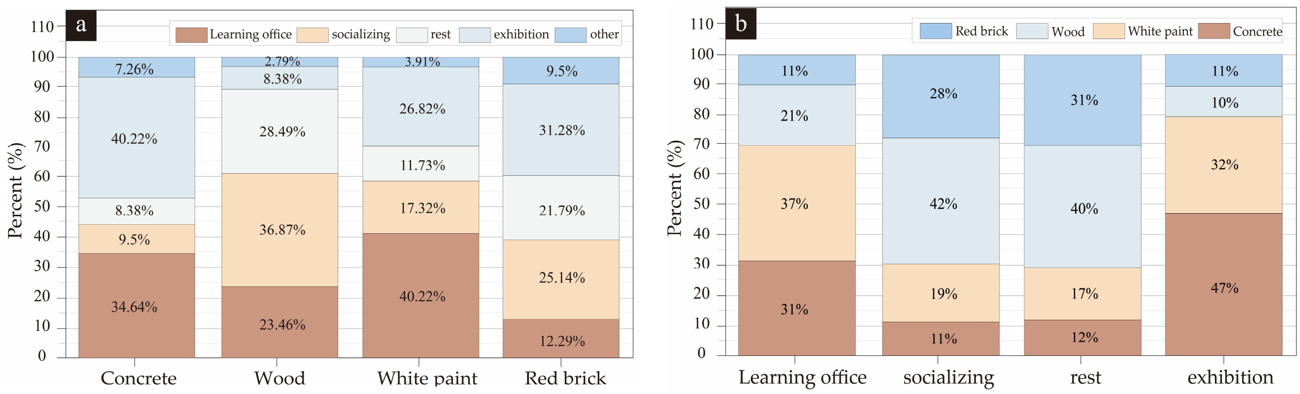

Figure 6. Functional preference ratings of respondents: (**a**) Comparison between materials; (**b**) Comparison between functions.

Table 9. Chi-square test results for functional preference by material 1.

	Study/Work	Socialize	Rest	Exhibition	χ^2	p
Concrete	62 (31.3%) [b]	17 (10.7%) [a]	15 (11.9%) [a]	72 (37.7%) [b]	123.768	<0.001
Wood	42 (21.2%) [b]	66 (41.5%) [a]	51 (40.5%) [a]	15 (7.9%) [c]		
White Paint	72 (36.4%) [b]	31 (19.5%) [a]	21 (16.7%) [a]	48 (25.1%) [a,b]		
Red Brick	22 (11.1%) [b]	45 (28.3%) [a]	39 (31.0%) [a]	56 (29.3%) [a]		

Note: Superscript letters (a–c) denote statistically different subgroups. All pairwise comparisons were adjusted using the Bonferroni correction.

Significant differences were also found in preferences for different material scenes within the same functional space (χ^2 = 123.768, $p < 0.001$), as shown in Figure 6 and Table 10. Bonferroni-adjusted pairwise comparisons revealed the following patterns: In study/work spaces, white-painted material scenes (41.9%) and concrete material scenes (37.3%) were significantly more preferred than other material scenes; In social spaces, wood material scenes (37.9%) were significantly more preferred than white-painted material scenes (18.0%) and concrete material scenes (10.2%); In rest spaces, wood material scenes (39.2%) and red brick material scenes (24.1%) were significantly more preferred than white-painted material scenes (12.2%) and concrete material scenes (9.0%); In exhibition spaces, concrete material scenes (43.4%) were the most preferred, significantly more than wood material scenes (8.6%) and white-painted material scenes (27.9%), while red brick material scenes (34.6%) did not differ significantly from concrete or white-painted material scenes.

Table 10. Chi-square test results for functional preference by material 2.

	Concrete	Wood	White Paint	Red Brick	χ^2	p
Study/Work	62 (37.3%) ^{a}	42 (24.1%) ^{b}	72 (41.9%) ^{a}	22 (13.6%) ^{b}	123.768	<0.001
Socialize	17 (10.2%) ^{a}	66 (37.9%) ^{c}	31 (18.0%) ^{a,b}	45 (27.8%) ^{b,c}		
Rest	15 (9.0%) ^{a}	51 (29.3%) ^{b}	21 (12.2%) ^{a}	39 (24.1%) ^{b}		
Exhibition	72 (43.4%) ^{b}	15 (8.6%) ^{c}	48 (27.9%) ^{a}	56 (34.6%) ^{a,b}		

Note: Superscript letters (a–c) denote statistically different subgroups. All pairwise comparisons were adjusted using the Bonferroni correction.

These findings indicate significant differentiation in material scene preferences across functional space types, underscoring the importance of selecting appropriate materials based on spatial function to enhance both functional suitability and perceptual congruence in environmental design.

4. Discussion

This study aimed to investigate the effects of four commonly used material scenes in industrial building renovations—wood, concrete, red brick, and white paint—on participants' emotions, thermal perception, and functional preferences. By creating virtual reality scenarios featuring these material scenes combined with questionnaire surveys, we analyzed the performance of these scenes in eliciting emotional responses, shaping thermal perception, and influencing functional preferences.

4.1. Materials and Thermal Perception

Significant differences were found in thermal sensation and thermal comfort ratings among the different material scenes ($p < 0.05$). Participants generally reported that spaces with wood and red brick material scenes appeared warmer both visually and in perceived thermal sensation compared to those with white paint and concrete material scenes. Thermal sensation ratings were significantly positively correlated with visual perception ratings ($r(636) = 0.722$, $p < 0.001$). According to the hue–heat hypothesis (HHH), colors with wavelengths closer to the red end of the visible spectrum are more likely to be perceived as warm, while those toward the blue end are perceived as cool. The results of this study support the expectation that warm-toned material scenes are more readily perceived as warm. Wang et al. [64], using thermal sensation votes (TSV) and heart rate (HR) measurements, explored the relationship between color and thermal sensation and comfort ratings, finding that participants reported higher thermal sensation scores in warm-colored spaces than in cool-colored spaces. Therefore, in industrial building renovations, using warm-colored material scenes such as wood may be associated with higher thermal perception ratings.

Meanwhile, respondents' thermal comfort ratings did not fully align with their thermal sensation ratings. Wood material scenes and concrete material scenes were perceived as the most and least comfortable materials, respectively, consistent with their visual and thermal sensations of warmth and comfort. However, white paint material scenes, despite scoring lower in thermal sensation, were rated as more thermally comfortable than the warmer red brick material scenes. This inconsistency may result from several complex factors [65], which limit the establishment of a strong linear relationship between thermal sensation and comfort [66]. On one hand, environmental complexity plays a role: factors like temperature, air velocity, and humidity directly affect thermal sensation, while elements such as sound [67], lighting, and air quality can also influence thermal perception [68]. On the other hand, subjective factors, including individuals' psychological states and expectations, significantly affect thermal comfort evaluations [69]. In the experimental environment, white paint material scenes created a brighter space than red brick material scenes, which may have contributed to participants' perceptions of greater thermal comfort. Therefore, in industrial building renovations, it is essential to consider multiple material scene characteristics, such as hue and brightness, to enhance thermal comfort in spaces.

Additionally, no significant gender differences were observed. The existing literature reports mixed findings on the influence of gender on thermal comfort perception, with some studies identifying statistically significant differences and others finding no significant effects [70]. Further research is needed to clarify these inconsistencies.

4.2. Materials and Emotions

Participants generally reported that spaces with white-painted material scenes were associated with the highest restoration ratings and relatively high arousal levels among the four material scenes. This finding is consistent with previous research. Zhang et al. [71] found that white is often perceived as a color that can simultaneously promote restoration and arousal. These results align with insights and case studies suggesting that such colors may be linked to perceptions of restoration in therapeutic landscapes [72]. In white-painted material scenes, spaces were perceived as overall brighter, which may contribute to higher visual stimulation and arousal ratings. Additionally, environmental memory can influence emotional experiences [73]; bright material scenes may evoke associations with sunlight, leading to higher relaxation ratings. Previous studies have shown that environments perceived as calm and restorative are related to lower physiological stress levels and may be associated with long-term health benefits [74–76]. However, the psychological effects observed here reveal a more nuanced interpretation. The high restoration and arousal ratings associated with white-painted scenes challenge the biophilia hypothesis, which assumes natural materials are inherently more beneficial to emotional well-being. As an artificial material, white paint lacks traditional biophilic attributes, yet in the industrial renovation context, its brightness, clarity, and associations with cleanliness and spaciousness appear to foster restoration. This suggests that in non-natural environments, abstract visual qualities—such as luminance, order, and simplicity—may serve as alternative forms of "soft fascination" as defined by attention restoration theory (ART). Rather than relying solely on naturalness, white-painted environments may promote attentional recovery through sensory clarity and minimal distraction.

Wood material scenes were generally reported as the environments most associated with positive emotion ratings, providing participants with the highest pleasure scores. This result aligns with studies showing that students typically prefer indoor spaces with exposed wood structures [77], perceiving them as more orderly, harmonious, and of higher spatial quality than spaces with only wooden decorations. Such environments have also been linked to lower ratings of psychological fatigue [26,27,78,79]. This preference may be related to the wood material scene's perceived tone. In a study on landscape flowers, Zhang et al. [71] found that yellow tones are often perceived as energizing, evoking positive affective responses such as excitement and surprise [80]. Previous research has shown that positive emotions—whether induced by nature or other factors—are positively correlated with ratings of pro-environmental and prosocial behaviors, since most environmentally friendly actions are inherently prosocial [81]. In other words, higher positive environmental perception ratings may be associated with greater willingness to engage socially. Therefore, wood material scenes may be an effective material choice in industrial building renovations to create environments that foster positive emotions and encourage social interaction.

Concrete material scenes consistently received the lowest ratings across restoration, arousal, and pleasure dimensions, indicating a significantly less favorable user experience. This outcome provides robust empirical support for the biophilia hypothesis within the specific context of industrial renovation. Compared to wood, concrete was perceived as visually cold, artificial, and emotionally detached—lacking the sensory richness and organic qualities characteristic of biophilic environments, which likely contributed to the diminished emotional responses. Crucially, even in industrial settings where concrete's rawness, minimalism, and authenticity are often valorized as evoking an architectural "sublime" state, these attributes did not translate into positive user experiences in our study. The persistently low emotional ratings strongly suggest that the absence of biophilic cues plays a decisive role in shaping user affect, outweighing potential aesthetic appreciation of industrial minimalism. This reinforces the enduring primacy of perceived naturalness for emotional well-being, even within stylized or non-natural spatial contexts. Supporting this, previous studies found non-natural surfaces like metal furniture elicit lower coherence, preference, and restoration ratings than wood [82]. Therefore, in industrial renovation projects prioritizing restoration, arousal, and pleasure, designers should be cautious about extensive concrete use and consider incorporating biophilic materials like wood to optimize emotional perception.

The finding that females reported significantly higher ratings in arousal and restoration aligns with prior research suggesting greater emotional sensitivity and responsiveness among women in environmental perception contexts [83,84]. The lack of a significant gender difference in pleasure ratings may reflect the more individually variable or aesthetic nature of this dimension, which might be less influenced by gender alone. These differences underscore the importance of considering gender as a potential moderator in material perception studies. However, given the reliance on subjective self-reports, these results should be interpreted with caution, and future studies should consider incorporating physiological or behavioral measures for validation.

4.3. Materials and Functions

As shown in Figure 6 and Table 9, users demonstrated statistically significant differences in functional preferences across different material scenes. Concrete material scenes were most preferred for exhibition and study/work functions. This may be attributed to the rational, minimalist, and highly ordered spatial atmosphere they create. Concrete surfaces typically present low emotional coloration, a cool and austere texture, and high visual density, which help highlight exhibition items by minimizing distractions and also support focused activities, such as work and study. Wood material scenes were significantly favored for social and resting spaces, illustrating the material's strong associations with naturalness, emotional warmth, and psychological comfort. The warm tones and rich textures of wood promote feelings of ease and belonging, making such scenes well suited for informal interaction and mental restoration. White-painted material scenes were more preferred in study/work spaces, possibly due to their high brightness, sense of cleanliness, and enhanced spatial clarity, which are conducive to concentration and task performance. However, their adaptability to exhibition, social, or resting scenarios was relatively lower than that of wood or concrete, suggesting a more neutral functional expression. Red brick material scenes received the lowest preference for study/work functions, likely because their coarse appearance and pronounced visual textures may distract attention and interfere with cognitive focus. Nonetheless, they showed relatively higher compatibility with resting spaces, which may stem from their historical connotations and warm chromatic tones—attributes conducive to evoking calmness and nostalgia in leisure environments.

As shown in Figure 6 and Table 10, respondents demonstrated different material scene preferences for various functional spaces in industrial building renovations. The results indicate that in office and study environments, participants preferred lighter-colored material scenes, such as white paint and concrete material scenes. One possible explanation is that light-colored material scenes are associated with higher ratings of brightness, spaciousness, and openness [85], which may make people more inclined to work or study in these settings. Similar findings have been reported in previous research. For example, Busra Cosgun and Kemal Yildirim [86] found that cafés with light-colored walls received more positive perceptions and evaluations than those with dark-colored walls. In social environments, participants gave higher preference ratings to warm-toned wood material scenes. The warm tones of wood were perceived as conveying friendliness and emotional warmth and were more often associated with a relaxed and pleasant atmosphere. Preferences for natural wooden environments also align with the idea that such spaces can encourage social interaction, supporting the potential link between biophilic environments and prosocial behavior [81]. In resting environments, the wood material scene (39.2%) and the red brick material scene (24.1%) received higher preferences in rest spaces, which may be attributed to their shared qualities of soft perception, warm coloration, and a sense of historical atmosphere—characteristics that help create a soothing and tranquil environment for relaxation. In contrast, white-painted and concrete material scenes, due to their cooler and overly utilitarian appearance, are less likely to evoke a sense of comfort or relaxation. Consistent with previous studies, we found that wooden spaces were associated with lower ratings of psychological fatigue [26,27,78,79]. This result supports the idea that indoor natural elements may contribute to stress reduction and highlights the potential benefits of wood as a biophilic design material. Due to its soft and warm visual qualities, wood is often linked with higher ratings of comfort and restoration [77], which may explain its high preference scores in resting environments. In exhibition spaces, the concrete material scene (43.4%) was the most preferred, significantly surpassing the wood material scene (8.6%) and the white-painted material scene (27.9%). This preference may be attributed to the concrete's neutral gray tone, its visual unobtrusiveness, and its ability to emphasize spatial form without distracting from the exhibited content. Moreover, the raw texture and strong visual impact of concrete are often associated with an artistic or industrial aesthetic, enhancing the expressive quality of the exhibition environment. The red brick material scene (34.6%) also received a relatively high level of preference, likely due to its historical character and distinctive texture, which are especially well suited for cultural or heritage-themed exhibitions. These findings offer valuable insights into material selection for exhibition spaces, suggesting that material choices should not only meet functional requirements but also contribute to the aesthetic and symbolic qualities of the environment. They underscore the importance of selecting materials that align with the intended function and experiential goals of the space.

4.4. Limitations and Future Work

This study provides an initial exploration of how material scenes selection affects emotions, thermal perception, and functional preferences in industrial buildings; however, several limitations remain that future research should address.

First, regarding data collection methods: This study relied on self-reported data, which may introduce subjective biases, and did not fully control for potential demand characteristics in the VR environment, such as participants guessing the study's purpose, or for response biases. Future research should incorporate multimodal data—such as EEG and skin temperature monitoring—to validate the physiological mechanisms underlying emotional and thermal perception. Moreover, advanced statistical approaches, such as mixed-effects models and structural equation modeling, should be employed to reduce error and enhance objectivity. It is also worth noting that the participant sample consisted mainly of young university students aged 18–25 (84.3%), which may limit the generalizability of the findings to other age groups or professional populations. While this group was intentionally targeted to reflect typical users of educational or public industrial renovation spaces [87,88], broader sampling in future research is needed to validate the results across more diverse age cohorts and cultural backgrounds. Moreover, cross-cultural studies may help uncover culturally shaped differences in material perception and emotional or thermal responses.

Second, improvements in experimental scene design: In the current study, the same material was applied to both wall and floor surfaces to enhance the perceptual prominence of each condition and reflect typical practices in industrial renovation. However, this approach means that the observed effects pertain to the overall spatial atmosphere created by the material, rather than to its application on a specific surface. This limits the ability to attribute perceptual and functional responses to either wall or floor materials individually. To address this, future research should employ a factorial design that independently manipulates wall and floor materials, enabling surface-specific analysis of thermal perception, emotional response, and functional preference. Moreover, conducting experiments in more neutral or varied spatial contexts will help assess the generalizability of the findings. Finally, minor perceptual inconsistencies in reflectivity, brightness, and texture clarity inherent to VR rendering remain a limitation, which future studies may overcome by incorporating high-fidelity material samples or more advanced visualization technologies.

Third, the observed functional preferences may have been influenced by cultural expectations and semantic associations rather than direct perceptual effects. While our statistical analysis (chi-square) confirmed significant associations between materials and functional preferences, future studies should include methods to dissociate semantic memory from perceptual evaluation—for example, by controlling for contextual cues, using priming tasks, or including culturally neutral materials.

Fourth, enhancing VR technology capabilities: Although the Tobii VR eye-tracking system was employed to support the consistent and realistic presentation of stimuli, no eye-tracking metrics were analyzed in this study. Additionally, the use of static panoramic VR scenes restricted participants' natural exploration of the environment, which may have attenuated their emotional and thermal responses. While previous research has shown that static VR scenes can still evoke perceptual effects comparable to interactive settings [57], future studies are encouraged to incorporate interactive or semi-navigable environments along with behavioral tracking to improve ecological validity.

Fifth, expanding statistical methods: This study only employed univariate and bivariate analyses, which are inadequate for uncovering complex interactions among variables, such as mediation effects. Future research should use multivariate statistical modeling, such as mediation analysis and mixed-effects regression, to systematically examine the causal pathways among thermal perception, emotions, and functional preferences.

5. Conclusions

This study systematically compared four commonly used material scenes in industrial renovations—wood, concrete, red brick, and white paint—within industrial building contexts. Rather than assessing the materials in isolation, the experiment evaluated participants' responses to entire spatial settings characterized by each material scene. The study successfully addressed its research objectives, revealing the following findings:

1. Thermal perception: Both wood material scenes and red brick material scenes exhibited warm visual characteristics; however, there were significant differences in thermal comfort ratings. Wood material scenes received the highest thermal comfort score (M = 3.69, SD = 1.15), while concrete material scenes received the lowest (M = 2.30, SD = 1.22). Although red brick material scenes had higher thermal sensation ratings than white paint material scenes, white paint material scenes were perceived as more thermally comfortable (M = 3.21, SD = 1.23) compared to red brick material scenes (M = 2.84, SD = 1.27), highlighting a discrepancy between perceived visual warmth and actual comfort.
2. Emotional responses: White paint material scenes achieved the highest scores for restoration (M = 3.42, SD = 0.77) and arousal (M = 3.48, SD = 1.20), demonstrating both activating and restorative effects. Wood material scenes significantly increased pleasure (M = 3.13, SD = 1.06), supporting their potential to promote social interaction. Concrete material scenes received the lowest scores across all three emotional dimensions.
3. Functional preferences: In study/work spaces, white-painted material scenes (41.9%) and concrete material scenes (37.3%) were most preferred; in social spaces, preferences were concentrated on wood material scenes (37.9%); in rest spaces, wood material scenes (39.2%) and red brick material scenes (24.1%) were more favored; and in exhibition spaces, concrete material scenes (43.4%) showed the highest preference.

The present study theoretically extends the applicability of attention restoration theory (ART) and the biophilia hypothesis to industrial architectural contexts, revealing how spatial features such as high ceilings and exposed structures amplify material perception effects. In addition to reaffirming established findings (e.g., wood inducing pleasurable responses), the study uncovers new phenomena—such as white-painted materials eliciting higher arousal and restoration despite lower visual warmth—suggesting that industrial spatial characteristics may modulate the pathways through which materials influence thermal and emotional responses. These insights contribute to refining the boundary conditions of environmental psychology models. On the practical side, this study is the first to systematically compare perceptual differences among concrete, red brick, and white-painted materials in realistic industrial environments. Through VR-based experiments, it demonstrates their differential impacts on emotional responses, thermal comfort, and functional preferences, providing scientific evidence for material selection and human-centered spatial design in the adaptive reuse of industrial heritage.

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