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Review

Health Impacts of Biophilic Design from a Multisensory Interaction Perspective: Empirical Evidence, Research Designs, and Future Directions

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Abstract: Biophilic design introduces a variety of sensory elements into the built environment, incorporating a natural experience into daily life. From the environmental psychology aspect, the effects of multisensory stimulus are not a result of simply adding the effects of uni-sensory stimuli, and the interactive effects among sensory approaches need to be considered. With the demand for promoting health and well-being, increasing numbers of studies began to investigate sensory systems other than just the visual cue of the biophilic design. This review focuses on the multisensory effect of biophilic design on human psychological and physiological responses as well as cognitive function. We summarized empirical evidence of the interactions between two and three sensory modalities from existing research. In addition, we systematically summarized the key methods and technologies used in experimental studies that explore the health benefits of biophilic design in terms of study types and population, environmental exposure simulation, health benefit measurement, and experimental process design. We finally identified some knowledge gaps in and future directions for biophilic design studies from the multisensory interaction perspective. The experimental design of quantifying the effects of multisensory interaction and its lasting effects are the focus of future research.

Keywords: multisensory interaction; biophilic design; experimental research; psych-physiological responses; cognitive function

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1. Introduction

Biophilia is the term popularized by Harvard biologist Edward O. Wilson to describe human's innate connections with nature [1]. Therefore, biophilic design particularly emphasizes the connection between humans and nature and enhances the comfort and well-being of the built environment by incorporating natural elements and processes. For example, the visual connection with nature could lower blood pressure and heart rate [2] and positively impact attitude and overall happiness [3]. In addition, the non-visual connection with nature could reduce systolic blood pressure and stress hormones [4,5] and result in perceived improvements in mental health and tranquility [6,7]. Yale social ecologist Stephen Kellert proposed the three-dimensional framework for biophilic design, suggesting that "human satisfaction and wellbeing continue to be reliant on perceiving and responding to sensory variability, especially when this occurs in structured and organized ways within the built environment" [8]. Biophilic design becomes a reasonable approach to encourage the multi-sensorial experience of contact with nature in the built environment, which could provide positive effects on human health and well-being.

The perception of the built environment by individuals is inherently multisensory, with the five common senses of the human body being auditory, olfactory, taste, visual, and

haptic. However, in studies related to the current built environment, taste is an abstract aspect that is not easily integrated into the environment. Meanwhile, thermal sensation as a passive tactile contact is a key element of haptics, which could seriously affect people's comfort and perception levels in the built environment, therefore many experiments have used thermal sensation as an important indicator. Our review focuses particularly on the four visual, auditory, thermal, and olfactory sensory factors, which are the most influential in built environments[1].

Previous studies have thoroughly examined the independent effects of single-sensory stimulation on human comfort, physiological and psychological responses, and cognitive function. For example, the visual connection with nature could help with mental stress recovery [9] and improve cognitive performance [10]. A view of greenery from windows has been shown in several studies to have restorative effects on people's well-being. Specifically, a landmark study from Ulrich found that patients who had a green view in their wards recovered faster and required less pain medication than those who had a brick wall view [11]. Li and Sullivan also proved that a classroom view of green landscapes leads to better performance in attention and increased recovery [12]. In addition, types of view are crucial for restoration. Felsten pointed out that a view containing water and a more dramatic nature scene is more restorative [13]. Besides the view, daylight is another visual clue of nature that has multiple health advantages [14,15]. For instance, Kullar and Lindsten found that working in a classroom without daylight may disturb the hormone pattern and negatively influence students' academic performance [16]. Zadeh et al. also found that daylight can positively affect circadian rhythms and reduce morning sleepiness [17]. Research on the soundscape in the built environment is always related to the negative effects of noise. For example, studies have shown that the presence of urban man-made noise can affect human memory [18], attenuate attention [19], and increase depressive mood [20]. Meanwhile, natural sound as a positive-effect soundscape can be beneficial to human stress recovery and memory performance. Benfield et al. found that listening to pure natural sound can improve people's memory ability and a 3 min exposure to natural sound following an unsettling video can lead to greater mood recovery [21]. As a noise-masking tool, natural sound can improve speech privacy while increasing cognitive performance, concentration, and worker satisfaction [22]. Thermal comfort in different climate zones has been well studied (Thermal Comfort Database II) [23], including different thermal sensations on different body parts [24–26], physiological models for describing thermal comfort level [27–29], and personal comfort devices for satisfying personal thermal needs [30]. A noticeable change in research topics is that studying the undesirable thermal environment has shifted towards studying the desirable quality of air movement and personal comfort control systems [30,31]. Researchers proposed that comfort standards should rely on dynamic and spatially variable indoor climates for comfort evaluation. The concept of alliesthesia—the physiological basis for thermal delight proposed by De Dear—supports the transformation from neutrality to delight [32], which also has analogies to other senses as well. Olfactory atmospheres in the built environment were shown to have a significant influence on our health and well-being [33]. Sick-building syndrome (SBS) is an office condition defined by the World Health Organization in 1979 and describes the illness caused by air pollution in the built environment. The symptoms include headache, dizziness, nausea, eye, nose/throat irritation, dry cough, and even personality changes. Many of the outbreaks of SBS that have been reported over the last half-century were linked to an unfamiliar and unpleasant smell in the poorly ventilated environment [34,35]. To alleviate SBS symptoms, researchers have demonstrated that both increased ventilation rates and reduced air pollution can exert a significant influence on subjective health and well-being [36]. Meanwhile, undesirable and negatively valenced malodors tend to be associated with negative outcomes on the health, well-being, and mood of those who are exposed to them. Meanwhile, it is important to note that pleasant ambient scents can also be used to help improve our mood and well-being [37]. More recent studies find that short-term exposure to pleasant ambient fragrances, such as grapefruit odor [38], can

impact people's attention, anxiety, and mood, with different effect sizes on genders. In terms of the office setting, many researchers have argued that lavender can sometimes be used to enhance productivity by reducing stress [39,40]. These findings indicated that we need to reduce air pollution and increase positive scent stimulus at the same time to promote health and well-being.

Despite this extensive body of work, much of the research remains siloed, with studies often focusing on single-sensory approaches. At the same time, since vision plays a dominant role in our perception [41], other sensory modalities, such as acoustic, olfactory, and thermal senses, are mostly neglected in the design process. For example, when we introduce water features into the indoor environment, not only does the floating water make people relax visually and cool thermally, but also the water sound can mask high-frequency sound and create a relatively quiet space [8]. Therefore, integrating multisensory design can promote the occupants' well-being. For instance, a recent study conducted in a living lab found that biophilic interventions have the most potential to positively mitigate the experience of stressors. Participants felt less stressed in each of the biophilic conditions, especially in the multisensory intervention [42]. However, the effects of multisensory stimuli are not a result of simply adding the effects of uni-sensory stimuli together. Research on multisensory interactions has increased over the last few decades in the field of cognitive neuroscience and neurophysiology. However, the effect of the built environment on human health and comfort through a multisensory approach has not been fully investigated. Only a few studies analyzed different combinations of environmental senses, with less than 9% percent of studies considering visual, acoustical, and thermal senses together [43]. Among existing multisensory studies, most have focused on reducing the negative impacts of different sensory stimuli [44]. However, a higher level of experiential delight is needed to achieve the goal of well-being, we should get beyond mere 'comfort' and design for these higher-level experiences [45]. Specifically, sound privacy, thermal discomfort, low lighting level, and poor indoor air quality (IAQ) have been identified as important factors contributing to an unhealthy environment. Research on beneficial environmental parameters, including natural view, natural sound, scent, aesthetics, security, and ergonomic design factors is still limited.

In summary, research on single senses is now relatively complete, but research on more than two sensory approaches is still limited, this review aims to address this gap by summarizing existing scientific evidence on the perception and response to biophilic environments through various sensory approaches. Additionally, it seeks to identify gaps in the current research and propose directions for future studies, ultimately advocating for a more integrated multisensory approach to design that prioritizes human health and well-being.

2. Methods

We conducted a scoping review following Arksey and O'Malley's framework [46], which is a particularly useful approach when the information on a topic has not been comprehensively reviewed or is complex and diverse [47]. We aim to summarize evidence from existing biophilic design literature, rapidly map the key concepts of biophilia underpinning the multisensory design, and identify gaps in the sensorial evidence. Since this topic involves multiple environmental factors together which have not been reviewed comprehensively before, a scoping review will help us assemble multisensory studies and propose a potential research direction in the biophilic design field (Figure 1).

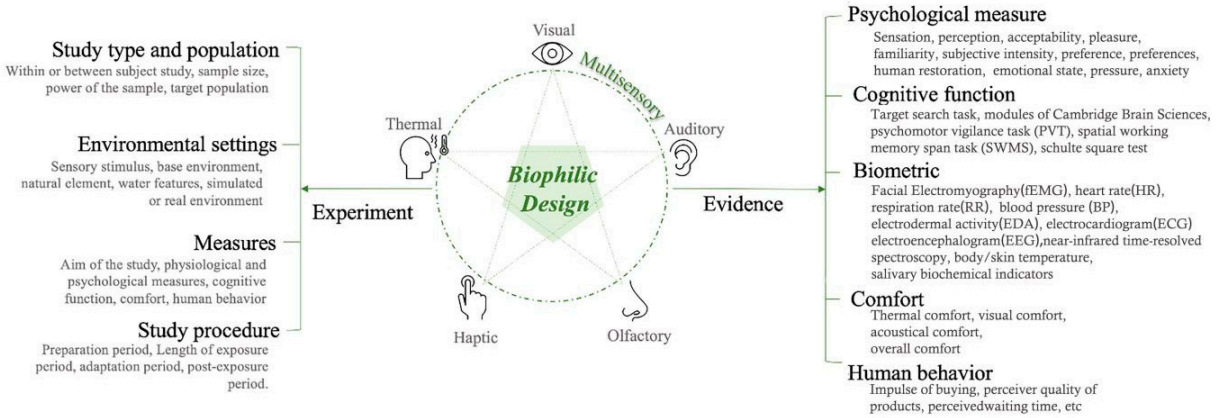


Figure 1. Knowledge framework for multisensory implementation of biophilic design.

First of all, we frame our research question as "What is the current evidence on people's physiological, psychological, and cognitive responses to biophilic design through multisensory approaches?" Specifically, we focused on four well-studied senses in environmental perception studies: visual, acoustical, olfactory, and thermal. Then, we used Google Scholar to search for peer-reviewed papers and book chapters in the fields of building science, public health, and environmental psychology. In terms of the searching process, we started with reviews on single-sensory studies and then explored the experimental studies investigating more than one sensory approach to environmental settings with biophilic features. Initially, a preliminary selection was conducted based on the titles and abstracts of the relevant literature, and 316 research papers were selected. We also use the snowball method to search through the reference list of multisensory studies to increase our database. Since we mainly focused on the positive effects of exposure to biophilic features, we excluded articles evaluating interaction effects caused by negative indoor air quality (IAQ), noise, glare, and dim light in combination with other environmental senses, as well as non-neurophysiological and non-urban scale studies. The detailed inclusion and exclusion criteria are shown in Figure 2. As a result, a total of 26 research papers were identified and included. The details of each paper can be found in the table. We charted the selected studies by key findings, experimental design and procedure, measures, and statistical method. Based on this, we summarized results from different sensory studies and provided a study design methodology for future work.

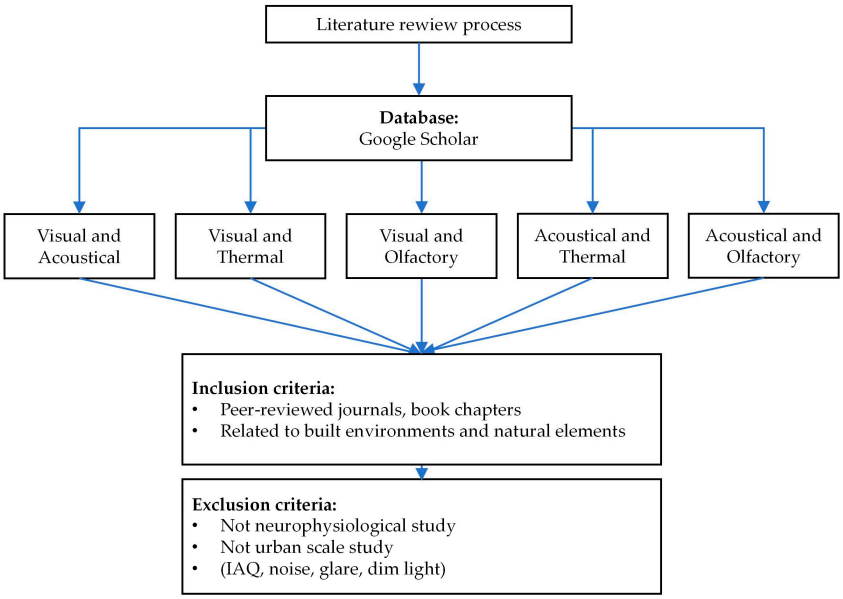


Figure 2. Literature searching criteria.

3. Research Findings

3.1. Bi-Sensory

3.1.1. Visual–Acoustical

Visual–audio interactions can significantly influence the overall perception of a space. This is because when visual and acoustical feelings are coupled, attention paid to the visual cues would change the conscious perception of sound and vice versa. Under the umbrella of biophilic design, the goal of studies involving visual–auditory interactions was to focus on introducing natural scenery and sound into the built environment. Specifically, this topic has been widely explored on the urban scale, where studies found that the pleasantness of the visual environment was related to the judgments of the soundscape [48,49]. Studies also demonstrated that a combined visual–auditory natural environment led to a greater recovery in stress levels than the view-only scenario [50]. In addition, the contribution of natural sound to the overall impression of the urban environment was more significant than natural visual factors when there is a high level of road traffic noise [51].

For the indoor environment, Jahncke et al. found that people prefer offices with natural elements, whereas natural sound was associated with restorative qualities [52]. In addition, a study focusing on open-space offices found that natural sound always had greater effects on people's recovery from fatigue and annoyance compared to environmental noise no matter whether the visual scene was natural or not, and the combination of water and natural environment was the best restorative condition [53]. Based on the visual–auditory interaction, Sun et al. also proposed a personal factor to modify the impact of natural window views on sound perception in a living room, called "audiovisual aptitude" [54]. A recent study conducted in a living lab found that an immersive biophilic indoor environment with visual and auditory biophilic features could improve occupant satisfaction and cognitive performance while reducing stress [42]. Another study found that the visual–auditory environment produced a better acute recovery effect. While with a longer recovery time, the auditory restorative environment might produce the most pronounced stress-recovery effects, followed by the visual restorative environment [55].

Water as a key feature in the biophilic design framework could offer a multisensory experience by providing visual, acoustical, thermal, and tactile delight [8]. Specifically, water sound is a natural and cost-effective tool to mask noise [56–59], reduce physiological stress levels [60], boost cognitive function, and improve mood [3]. However, using water features indoors is rare. Abdalrahman and Galbrun found that the introduction of the water feature which generates a water sound and produces visual stimuli improved perception dramatically [61,62]. They also suggested that water features need to be incorporated into the open-space office with plenty of workstations. More recently, Hasegawa and Lau summarized 27 visual–auditory review studies and highlighted the benefits of using water in an indoor environment, including that water features are influential visual factors for improving psychological responses and audio features have a similar potential [63].

3.1.2. Visual–Thermal

Vision may have a relevant influence on how we perceive other senses. For example, studies found that daylighting may have psychological and physiological interactions with thermal sensation. Kulve et al. found that the changes in visual and thermal comfort were positively related [64]. Specifically, thermal discomfort can be compensated for by lighting color and intensity, resulting in a higher perceived visual quality [64]. Through a controlled experimental investigation by using natural daylighting, Chinazzo et al. summarized that the quantity of daylight could influence thermal perception, resulting in a cross-modal effect, with a low daylight illuminance leading to a less comfortable and less acceptable thermal environment in cold conditions and a more comfortable one in warm conditions [65]. By giving participants more control over daylighting and electrical lighting, Haldi and Robinson concluded that there is no significant interaction between thermal and visual sensation, but people tended to be more thermally and visually comfortable when both conditions met their satisfaction [66]. Whether the relationship is strong or

not, we could confidently say that from the psychological aspect, the interaction between daylighting and thermal sensation cannot be ignored. However, previous studies did not find significant interaction effects on physiological parameters, such as skin temperature, cognitive behavior therapy (CBT), and energy expenditure. Although the interaction between daylighting and thermal sensation has been studied for years, another vision-based biophilic component, a window view, was lacking enough literature support. Only one study explored the relationship between window view and thermal comfort and found that people felt significantly cooler when there was an accessible window view [67].

3.1.3. Visual–Olfactory

The combined visual and olfactory stimulation of the environment is relaxing. Song et al. showed that the combination of visual and olfactory stimulation increased sensations associated with "natural" and "realistic" [68]. Li et al. demonstrated that visual–olfactory co-stimulation could reduce fatigue, enhance self-esteem, relieve stress, improve spatial working memory, and reduce psychomotor vigilance errors [69].

3.1.4. Acoustical–Thermal

Previous studies investigated the interaction between acoustical and thermal senses in the built environment, but the results were controversial. Tiller et al. found that acoustic conditions can affect people's thermal comfort with no reverse effect [70]. Pellerin et al. reported that sound level may alter thermal pleasantness only in warm conditions [71]. However, a study in Japan suggested that the thermal environment must be taken into consideration in acoustical studies by claiming that the operating temperature can affect people's acoustical sensations [72]. A more recent study found that acoustic comfort was found to be greater at 25 °C compared to those at 20 °C or 30 °C [73].

As a representative of natural sound, water sound affected not only acoustic perception but also thermal and overall indoor environmental comfort. Yang and Moon [74] used recorded water sound from indoor fountains to study the interaction between sound and thermal comfort and its effect on acoustical perception. They found that water sounds could enhance pleasantness, calmness, and naturalness without increment of noise, loudness, or annoyance in a hot thermal environment.

3.1.5. Acoustical–Olfactory

Olfactory and acoustical elements individually or combined have received the most research attention in the retail context. A study found that when plants' scents and pleasant sounds are combined, consumers rate the environment positively and experience enhanced satisfaction [75,76]. The multisensory effect between scent and sound was also investigated in healthcare research. With cautious usage, ambient scent and music can reduce patients' anxiety in the waiting room of a plastic surgeon [77]. Recently, a study examined the nature of any cross-modal interactions between ambient sound and smell in a laboratory setting designed to capture the sensory cues that might be encountered in a typical urban environment [78]. The influence of odor on sound evaluation showed that the presence of odor had little effect on the evaluations of birdsong and low-volume sound. However, the concentration of odor was associated with a positive evaluation of noise. For example, a study found that the aroma of lilac can reduce the annoyance caused by traffic noise in urban streets [79]. Therefore, a positive sensory stimulus might improve the evaluation of perception through other senses, while a negative sensory stimulus has the opposite effect. In the built environment, acoustical and olfactory elements are highly correlated with each other. For overall comfort, the effect of sound was stronger than odor; while for congruency, the effects of sound and odor were almost equal.

3.1.6. Other Bi-Sensory Elements

Studies on thermal–olfactory and olfactory–touch interactions have been conducted, albeit in a limited number. One study found that thermal discomfort may produce a "revenge

effect" for fragrance comfort, and fragrant stimuli resulted in an increase in the beta-band in "slightly warm" environments [80]. Research on the design of medical facilities suggests that when it is challenging to establish direct connections with the natural environment, an indirect natural experience model could be utilized. This may involve incorporating natural materials such as wood to stimulate the sense of touch, evoking olfactory memories with natural scents, and creating a "realistic" natural experience through various means.

3.2. Multisensory Experience

Most of the studies with the multisensory concept only focused on two senses [44]. It may be due to two main reasons: (1) it is hard to control more than two sensory variables in the experimental design; (2) the interactive effects among different sensory experiences might be too small to detect. However, some studies used multiple environmental factors that represent different senses to create a prediction model for indoor environmental comfort. For example, Krüger and Zannin discussed thermal, luminous, and acoustic comfort in the same study and proposed that designers should systematically consider all senses indoors to promote a healthy environment [81]. Huang et al. found that both thermal and acoustical senses dominate the satisfaction level of the indoor environment [82].

There are even fewer publications when we constrain all the existing studies to the realm of biophilic design. Yang and Moon incorporated three different room temperatures and three illuminance levels along with different types and levels of sound (including water sound) [73] and found that the effect of acoustic factors was the greatest on indoor environmental comfort, followed by room temperature and illuminance. Thermal perceptual comfort is susceptible to auditory and visual environments; however, the impact of the visual environment and thermal environment on auditory comfort is not significant [83]. A study investigated the recovery in a sensory-enriched break environment by integrating three sensory stimuli, including natural outdoor view and indoor greenery, bird sound, and herb scent [84]. They concluded that sensory-enriched environments were perceived as more pleasant and restorative compared to the standard break room. High levels of environmental pleasure are associated with low physiological stress responses in the sense of smell, to some extent with auditory stimuli, but not with visual stimuli [85]. Birdsong combined with visual–olfactory stimulation can increase physiological recovery and overall perception of quality assessment but has no significant impact on mental well-being [86]. Zhong et al. demonstrated in a sense walking experiment that high visual and smell environment quality can enhance soundscape evaluations, although the smell environment had a greater impact on the soundscape comfort degree (SCD) than the visual environment in waterfront space in mountainous cities (WSMCs) [87].

4. Study Design Implication

We summarized the research method used by experimental studies focusing on using biophilic elements to generate sensory stimuli for human subjects. Table 1 summarizes the study design of selected studies in detail. They could be divided into four subsections: study type and population, environmental settings, measures, and study procedure. We summarized each subsection with thoughts on the current state of the art, knowledge gaps, and future study design approaches.

Table 1. Summary table of all the experimental studies.

No.	Reference	Sensory				Subject	Tool	Experimental Design	Environmental Procedure	Measures	Main Conclusions
		Visual	Acoustical	Thermal	Smell						
1	Park et al., 2020 [50]	✓[2]	✓			32 ordinary people (16 males, 16 females; age range: 20–39; half of them were in their 20 s and the other half were in their 30 s). Recruited from online study advertisement; hearing Screening; and psychometric Screening; UK	Biometric measures Questionnaire Visual: VR screen (360-degree video) Acoustical: headphones	Visual–auditory interaction vs. visual only Visual: rural landscape (with or without water features) vs. urban scenes Auditory: sound recorded along with the video	1 min baseline clip 1 min stressor clip 1 min recovery clip (experimental exposure) Responding to questionnaire	Psychological response (verbally respond to the questionnaire): Tranquility, preference, and pleasantness for the recovery clips Perceived restorativeness soundscape scale (PRSS) Physiological response: two facial electromyography data points (fEMG), heart rate (HR), respiration rate (RR), and electrodermal activity (EDA)	The rural settings had a better recovery when they were presented as visual–audio combined. Water features led to a greater recovery.
2	Hong and Jeon, 2013 [51]	✓	✓			20 ordinary people (15 males, 5 females; age range: 23–34; M_{age}: 27.2; standard deviation: 2.24). Hearing screening; consistency test; South Korea	Questionnaire Visual: beam projector Acoustical: headphones	Visual-only, audio-only, and visual–auditory interaction Visual: images of streetscapes with a combination of vegetation and water features (photomontage method) Auditory: 9 acoustic stimuli were constructed using 4 individual sounds	Continuous experimental exposure while responding to the questionnaire	Subjective evaluation: Preference for each stimulus Semantic differential test: 12 pairs of adjective attributes (quiet–noisy, calm–loud, pleasant–unpleasant, comfortable–uncomfortable, open–closed, wide–narrow, stable–unstable, harmonious–disharmonious, ordered–disordered, various–monotonous, distinct–ordinary, and natural–artificial.)	Increases in greenery from trees or bushes can improve streetscapes. Bird sounds were more useful for enhancing soundscape quality compared to water. The contribution of acoustic comfort to the overall impression was more significant than visual factors with a high level of road traffic noise.
3	Jahncke et al., 2015 [52]	✓	✓			40 (49 students[3]; 22 males, 27 females; M_{age}: 24.1). Recruited from the University of Gävle. Hearing Screening; UK	Questionnaire Visual: screen Acoustical: headphones	Visual: open plan office and urban nature Auditory: natural sound, quiet, broadband noise, office noise	Fatigue scenario Control and background questions 1 min exposure to each setting (8 settings) Statement questions Control and background questions	Perceived restorativeness scale (PRS) Restoration likelihood attitude toward the presented setting	Natural sound positively influenced evaluations of the natural setting compared to the office settings. There are significant interactions between acoustic and visual stimuli were found for all measures.
4	Ma and Shu, 2018 [53]	✓	✓			75 (Study1: 30, Study2: 15, Study3: 30; male/femal = 1:1; M_{age}: 25). Recruited from Tianjin University; hearing screening; working status and stress level assessment; Tianjin, China	Biometric measures Questionnaire Cognitive test Visual: screen Acoustical: headphones	Auditory-only (types and sequences) vs. visual–auditory interaction Visual: open plan office with and without natural elements Auditory: flowing water sound and urban noise	Within-subject study 5 min introduction of stress and attentional fatigue 2 min measure original status 3 min restoration period 2 min measurements of restorative effects 2 min rest (then next experiment unit)	Physiological responses: blood pressure (BP) and heart rate (HR) Psychological experience: 3 emotional states (tension, fatigue, and annoyance) Cognitive performance: task performance	Soundscape elements had an apparent positive effect on tiredness, restoration, and annoyance reduction. Sound elements had a greater effect on psychological restoration compared with visual scenes.
5	Sun et al., 2018 [54]	✓	✓			68 (40 males, 28 Females; M_{age} = 27.9, SD = 5.05, range: 20–46; 48 obtained a master's degree or higher). Hearing screening; Belgium	Questionnaire Visual: screen Acoustical: speaker	Auditory only vs. visual–auditory interaction Visual: 4 scenarios, airport car, restaurant, aircraft, and city park Auditory: 6 sound groups, the sound was recorded along with the scenario	Part 1: Audio: 3 sound contents Part 2: Video: 3 sound contents (10 min, experiments were repeated for four days for different scenes)	Preference: which of the 3 items sounds most different from the other two?	Audiovisual aptitude may affect the appraisal of the living environment.

Table 1. *Cont.*

No.	Reference	Sensory				Subject	Tool	Experimental Design	Environmental Procedure	Measures	Main Conclusions
		Visual	Acoustical	Thermal	Smell						
6	Abdalrahman and Galbrun, 2020 [62]	✓	✓			31 (16 males, 15 females; range: 24–60, M ¼ 36.3, SD ¼ 9.3). Participants were postgraduate students and staff members of Heriot-Watt University who worked in open-plan offices; hearing screening; UK	Questionnaire Visual: screen Acoustical: headphones	Audio-only vs. audio–visual interaction (Detailed information about Exp 1 is not discussed here). Visual: still images from the animation of the water feature (6 settings) Auditory: water mask: recording of 6 water features (the 20 s each); speech recording: open-plan office	Part 1 (30–35 min) [15 pairs of comparison]: Audio only/visual audio (7 s underwater sound—a 4-step cascade (CA), 1 s silence, and 7 s another underwater sound—a 37-jet fountain (FTW) Part 2 (5–10 min): [6 settings] Audio only/visual audio (7 s unmasked voice, 1 s gap, and 7 s voice masked by water sound) Rate perception changes	Preference of waterscape Sound perception changes	The introduction of a water feature improved the perception of the sound environment and adding visual stimuli improved perception by up to 2.5 times.
7	Galbrun and Calarco, 2014 [61]	✓	✓			38 (19 males, 19 females; range: 24–47; M_{age}: 30.1; standard deviation: 4.47). Hearing screening; consistency test; cultural groups UK	Questionnaire Visual: screen Acoustical: headphones	An audio-only vs. visual-only vs. visual–auditory interaction Visual: photo montages with different water features and the same natural background Auditory: 10 water sounds and road traffic noise	Pair comparison: Audio-only test: a select sound that is more peaceful and relaxing [20 min] + quality analysis of water sound [20—30 min] Visual-only test: the image that prefers to look at [20 min] + rate water feature display [5–10 min] Audiovisual test: feature they prefer in terms of peacefulness and relaxation [20 min]+ rate water feature display [5–10 min]	Pair comparison Sound qualities: semantic assessment, categorization, and evocation Water features' displays as man-made, natural, or neither	Equal attention should be given to the design of both visual and acoustical stimuli. Natural-looking features tended to increase preference scores compared to audio-only paired comparison scores.
8	Liu et al., 2023 [55]	✓	✓			28 (14 males, 14 females). Recruited from Qingdao University; psychiatric screening; climate adaptation screening; unhealthy behaviors such as alcohol and tobacco addiction screening; BMI screening; Qingdao, China	Biometric measures Visual: slides Acoustical: stereophonic loudspeaker	An audio-only vs. visual-only vs. visual–auditory interaction Visual: natural scenes (green trees and forests) Auditory: the sound of naturally running water, with a frequency of 400–500 Hz and a sound level of 40–50 dB	10 min baseline measuring stage 10 min stress induction stage (continuous high-frequency noise) 20 min stress recovery stage (the auditory and the visual-auditory stimuli, respectively)	Continuous electrocardiogram (ECG) data Heart rate variability analysis: mean heart rate, the root mean square of successive differences (RMSSD) between normal heartbeats, the low-frequency and high-frequency power ratio (LF/HF)	The visual and visual–auditory environment produced a better acute recovery effect. In longer recovery time, the auditory restorative environment might produce the most pronounced stress-recovery effects, followed by the visual restorative environment.
9	Aristizabal et al., 2021 [42]	✓	✓			37 (Cohort 1 (6 females, 7 males, M_{age} = 41.85); Cohort 2 (5 females, 8 males, M_{age} = 33.62); Cohort 3 (8 females, 4 males, M_{age} = 33.73) range(18–60));). Hearing and vision screening; cardiovascular disease, psychiatric, stress, depression, drug, and alcohol dependence screening; health assessment; duration of residence screening[4]; Minnesota, USA	Biometric measures Questionnaire Cognitive test Visual: digital screens Acoustical: speakers	An audio-only vs. visual-only vs. visual–auditory interaction Visual: indoor plants and rotating, digital projections of nature including fractal imagery and canopy-type plants Auditory: reminiscent of the natural, regional environment including blowing wind, trickling water, and sounds produced by regional fauna	Pair comparison: Baseline office environment with no environmental aspects (2 weeks) Introducing only visual biological conditions (8 weeks) Introducing only auditory biological conditions (8 weeks) Introducing visual and auditory biological conditions (8 weeks)	Physiological indicators of stress, including changes in heart rate and electrodermal activity Feelings of stress, environmental satisfaction, perceived productivity, mood, and connectedness to nature Objective indicators of cognitive performance Working memory test, inhibition control, and task-switching	Immersive biophilic environments can improve occupants' satisfaction and cognitive performance while reducing stress. Highlight the need to consider non-visual factors in biophilic design.

Table 1. *Cont.*

No.	Reference	Sensory				Subject	Tool	Experimental Design	Environmental Procedure	Measures	Main Conclusions
		Visual	Acoustical	Thermal	Smell						
10	Kulve et al., 2018 [64]	✓		✓		35 (All females; age range: 18–30; M_{age}: 22.2). Recruited via advertisements at the university and the website digi-prik.nl. BMI screening; inclusion criteria: Caucasian females, generally healthy. Exclusion criteria: color blindness, ocular pathologies, medication use, pregnancy, hypertension, general feeling of illness on the day of the experiment, (history of) cardiovascular diseases, and contraindication of the telemetric pill. The Netherlands	Biometric measures Questionnaire Visual: luminance level and color temperature (electrical lighting) Thermal: room temperature	Visual: Study 1: Dim (5 lux) and Bright (1200 lux) with constant color temperature (4000 K) Study 2: Color temperature (2700 K and 5800 K) with constant luminance level (50 lux) Thermal: baseline temperature 29 °C, low temperature 26 °C, and high temperature 32 °C	For both studies: 30 min baseline measure (29 °C) 15 min break 75 min 1st block (26 or 32 °C) 15 min break 75 min 1st block (29 °C) 15 min break 75 min 1st block (26 or 32 °C)	Questionnaire for thermal and visual perception: Thermal: "thermal comfort", "thermal sensation", "preferred temperature change", "self-assessed shivering", and "self-assessed sweating" Visual: "perceived light intensity", "perceived light color", "visual comfort", "preferred light intensity change", and "preferred light color change" Body temperature, skin temperature: 26 body sites; core temperature Energy expenditure: oxygen consumption and carbon dioxide production	Visual perception and thermal perception affect each other. Higher visual comfort levels were correlated with higher thermal comfort votes. Thermal discomfort can be partly compensated by lighting that results in a higher perceived visual comfort.
11	Chinazzo et al., 2019 [65]	✓		✓		84 (42 males, 42 females age range: 18–30). Recruited from the subject pool of the Universities. Vision screening; inclusion criteria (age 18–30 years old, no abuse of alcohol or use of drugs, full-color vision, generally healthy, French-speaking–mother tongue or C2 level, BMI between 18 and 25 kg/m^2, no visual or motor abnormalities). Lausanne, Switzerland	Biometric measures Questionnaire Visual: luminance level (daylighting) Thermal: room temperature	Visual: daylight illuminance (low ~130 lx, medium ~600 lx, and high ~1400 lx)—change filter Thermal: 3 temperature levels (19, 23, and 27 °C) (each participant experiences one T)	For each room temperature 45 min pre-test phase 10 min break, change filter 30 min daylight exposure 1 10 min break, change filter 30 min daylight exposure 2 10 min break, change filter 30 min daylight exposure 3	Subjective perception ratings: 4 types of thermal perception: thermal state (thermal sensation, comfort, and preference) and thermal ambiance (thermal acceptability). and overall perception Evaluate overall comfort The reason for the discomfort Physiological measurements: skin temperature	Cross-modal effects of daylight on thermal responses occurred, but only at a psychological level rather than at a physiological one. Daylight affected only thermal evaluations, not thermal sensation.
12	Ko et al., 2020 [67]	✓		✓		86 (43 males, 43 females; age range: >18). Recruited from the University of California. Vision screening; sleep disorders screening; California, USA	Biometric measures Questionnaire Cognitive test Visual: view content (natural view) Thermal: room temperature	Visual: with or without a window view Thermal: 28 °C (slightly warm condition)	For each window setting: 15 min setup 5 min survey 10 min creativity tests 5 min break in chamber 25 min cognitive tests 5 min survey 10 min break in the reception area	Thermal perception: thermal sensation, comfort, acceptability, and pleasure Mean skin temperature Emotion: circumplex model Cognitive performance: working memory, concentration, short-term memory, spatial planning, and creativity performance test Eye symptoms and perceived stress level	People close to a window can tolerate small thermal comfort deviations. Window view can enhance positive emotions, reduce negative emotions, and improve workers' productivity.

Table 1. *Cont.*

No.	Reference	Sensory				Subject	Tool	Experimental Design	Environmental Procedure	Measures	Main Conclusions
		Visual	Acoustical	Thermal	Smell						
13	Song et al., 2019 [68]	✓			✓	21 (All females; Mage: 21.1 ± 1.0 years). Recruited from a Japanese university. Exclusion criteria: smoking, treatment of diseases, menstrual period; Japan	Biometric measures Questionnaire Visual: screen Scent: essential oil odor bag diffuser	Visual-only vs. olfactory-only vs. visual–olfactory interaction Visual: a photograph view of a forest landscape of Hinoki cypress trees (Chamaecyparis obtusa, a type of conifer) Olfactory: hinoki cypress leaf oil	The participant remained sitting, and her physiological responses were continually measured. 60 s (the rest period) viewed a gray Background 90 s (stimuli) the visual, olfactory, combined visual and olfactory Subjective indices evaluation	Near-infrared time-resolved spectroscopy (oxy-Hb concentration in the participant's left and right prefrontal cortex) Heart rate variability and heart rate The HF component of HRV reflects parasympathetic nervous activity and the ratio of LF to HF reflects sympathetic nervous activity Modified semantic differential method	The forest-related stimuli induced a significant decrease in the oxy-Hb concentration in the prefrontal cortex and a significant decrease in sympathetic nervous activity. Significant increases in subjective feelings related to the terms "comfortable", "relaxed", "natural", and "realistic". The combined visual and olfactory stimuli demonstrated an additive effect.
14	Li et al., 2024 [69]	✓			✓	48 (24 males, 24 females; Mage: 22.66 ± 1.82). Recruited from college. Vision and olfaction screening; no prior history of mental, cardiovascular, or allergic diseases; anxiety and depression screening; BMI. No significant differences among the four groups in terms of gender ratio, age, height, weight, or body mass index (BMI); Beijing, China	Biometric measures Questionnaire Cognitive test Visual: plant Scent: plant breathing mask	Visual-only vs. olfactory-only vs. visual–olfactory interaction Visual: 2 (plant present vs. absent)—Coriander Olfactory: 2 (scent present vs. absent)—Coriander scent	All tests were in the same period of time (14:00–16:00) 5 min rest (baseline values): completed saliva collection, self-reported questionnaire, and cognitive tests 30 min (stimulation) 5 min rest: completed saliva collection, and self-reported questionnaire 30 min (stimulation) 5 min rest: completed saliva collection, self-reported questionnaire, and cognitive tests	Psychological indicators: the Profile of Mood States (POMS) questionnaire; Electrophysiological indicators: electrocardiogram (ECG), electrodermal activity (EDA), and electroencephalogram (EEG); Salivary biochemical indicators: salivary stress marker (cortisol), proinflammatory cytokines, and untargeted metabolomics; Cognitive performance: psychomotor vigilance task (PVT) and spatial working memory span task (SWMS).	The various types of sensory stimuli associated with coriander plants exhibited different intervention effects on mood and cognition. The combined stimulus demonstrated better effects compared to the single-sensory stimulus. All three stimuli—visual, olfactory, and combined—induced spontaneous neural oscillations associated with relaxation or cognitive function, and significant changes occurred in metabolic pathways related to antidepressant, anti-inflammatory, or neuroprotective effects. It appeared that visual stimuli elicited a greater response from the nervous system, while olfactory stimuli elicited a greater response from the endocrine and immune systems.
15	Yang and Moon, 2019 [74]		✓	✓		54 (25 males, 29 females; Mage: 22 ± 1.9). Recruited from university. Hearing screening; South Korea	Questionnaire Acoustical: water sound (speaker) Thermal: room temperature	Acoustical: 2 types and 4 levels of water sound (45, 50, 55 dBA, and 60 dBA) Thermal: 18 °C (cool), 24 °C (neutral), and 30 °C (warm)	For each room temperature: 30 min thermal adaptation 30 min experimental period [25 s sound stimulus + 15 s response (36 sound stimulus)]	Negative acoustic attributes and positive acoustic attributes Acoustic comfort, thermal comfort, and overall comfort	Room temperature affected both thermal perception and acoustic perception. Water sounds affected not only acoustic perception but also thermal and overall indoor environmental comfort.
16	Mattila and Wirtz, 2001 [75]		✓		✓	247 (Female: 75%, less than 20 years old: 65%). Subjects were anyone entering the store who agreed and completed the questionnaire; USA	Questionnaire Acoustical: sound system Scent: diffuser	Acoustical: 3 categories (no music/low arousal music/high arousal music) Olfactory: 3 categories (no scent/low arousal scent/high arousal scent)—Lavender (low arousal) and Grapefruit (high arousal)	In retail Pretest of scent and sound 15 min pre-scent of the store 3 shifts (10:30 a.m.–12:30 pm, 2:00 p.m.–4.00 p.m., and 5:00 p.m.–7:00 p.m.) Randomly select customers leaving the store	Emotional response: arousal dimension and pleasure dimension Approach–avoidance behavioral responses The extent of impulse buying Environment evaluation	When ambient scent and music are congruent with each other in terms of their arousing qualities, consumers rate the environment significantly more positive.
17	Fenko and Loock, 2014 [77]		✓		✓	117 (28 males, 89 females; Mage: 47.92; ranged: 14-88). Recruited from the patients of plastic surgeon Dr. Abdul Yousef at the Elizabeth Hospital in Recklinghausen (Germany). Germany	Questionnaire Acoustical: CD player Scent: diffuser	Acoustical: 2 (music present vs. absent)—instrumental music with nature sounds Olfactory: 2 (scent present vs. absent)—Lavender scent	In the waiting room of a German plastic surgeon: Pretest of scent and sound Before the appointment: the demographic questions, evaluation of anxiety, and waiting environment After the appointment: objective and perceived waiting time and manipulation check questions about perceived scent and music	The level of anxiety (Clinical Anxiety Scale and STAI) Evaluation of the waiting environment (Physical Environment Quality Scale) Perceived waiting time duration Objective waiting time	When used separately, each of the environmental factors, music and scent, significantly reduced the level of the patient's anxiety compared to the control condition. The combination of scent and music was not effective in reducing anxiety.

Table 1. *Cont.*

No.	Reference	Sensory				Subject	Tool	Experimental Design	Environmental Procedure	Measures	Main Conclusions
		Visual	Acoustical	Thermal	Smell						
18	Morrin and Chebat, 2005 [76]		✓		✓	774 (Range: >18). Recruited from the mall intercept procedure. Montreal, Canada	Questionnaire Acoustical: mall speaker Scent: diffuser	Acoustical: (music present vs. absent) slow tempo music Olfactory: (scent present vs. absent) citrus scents	In suburban shopping malls: Pretest of scent and sound Poster for participants' recruitment Questionnaire after shopping	Perceived quality of products The mood was measured with the first 2 dimensions of Mehrabian and Russell's (1974) PAD scale The environmental quality of the mall was assessed based on Fisher's (1974) scale	Atmospheric cues such as music and scent were more effective at enhancing consumer response when they were congruent with individuals' affectively or cognitively oriented shopping styles.
19	Ba and Kang, 2019 [78]		✓		✓	168 (54.8% females, Mage = 22 (SD = 2.6; min = 18; max = 27)). Recruited from universities via the Internet and by personal contacts. Audition and olfaction screening; no mental illness; and not pregnant. China	Questionnaire Acoustical: loudspeaker Scent: essential oils and perfume	Acoustical: 3 types (birds, conversation, and traffic) Olfactory: 4 types (lilac, osmanthus, coffee, and bread)	In a sound insulation chamber: Pretest of scent and sound Sound evaluation segment; 9 audios, 40 s each Odor evaluation segment; 12 odors, 40 s each Overall evaluation segment 40 s each 5 min ventilation in between for odor and overall evaluation segments	Acoustical comfort, sound preference, sound familiarity, and subjective loudness Olfactory comfort, odor familiarity, and subjective intensity Overall comfort	In the presence of birdsong and low-volume sound, overall comfort and congruency are unaffected by odor. For other combinations of sound and odor, with the increase in concentration, the overall evaluation gradually improves. A positive sensory stimulus can improve the evaluation of perception through other senses, while a negative sensory stimulus has the opposite effect. There is a masking effect between audition and olfaction.
20	Chang et al., 2023 [80]			✓	✓	81 (23 males, 58 females; age range: 18–26). Recruited online in advance; olfaction screening; neither non-smokers nor drug users; have lived locally for more than one year; all volunteers' clothing insulation ranged from 0.16 to 0.72 clo; Xi'an, China	Biometric measures Questionnaire Thermal: outdoor environment Scent: essential oils nebulizer	Thermal: 3 typical spaces The open square (OS) is paved with granite, devoid of vegetation, and unshaded by buildings. The tree-shaded space (TS) is shaded by beeches and its surface is composed of cement pavement and a grass lawn The landscape pavilion (LP) is surrounded by vegetation Olfactory: Lavandula officinalis, Rosa rugosa, and Mentha canadensis	All 3 fragrance stimuli were applied in each measured site for 3 experimental combinations 15 min of adapting to the ambient temperature and completing the first questionnaire Experience fragrance stimuli and were asked to complete the second questionnaire from 3 to 10 min of scent exposure 15 min later, volunteers completed the third questionnaire Repeated the described process until they had visited all sites and experienced all fragrance stimuli	Electroencephalogram (EEG) measures Positive and Negative Affect Schedule (PANAS) Thermal perception vote (thermal sensation vote (TSV) and thermal comfort vote (TCV)) Fragrance perception vote (fragrance sensation vote (FSV), fragrance pleasantness vote (FPV), and fragrance comfort vote (FCV)) Physiological equivalent temperature (PET) and mean TSV (MTSV)	Improving olfactory comfort can partially relieve thermal discomfort caused by high Ta in summer. Fragrance comfort and fragrance pleasure were improved with an increase in thermal comfort. Exposed to R. rugosa and L. officinalis, thermal discomfort may produce a "revenge effect" on fragrance comfort, resulting in fragrance discomfort. Fragrance stimuli increased the beta-band when 30.80 °C ≤ PET < 44.53 °C. When 44.53 °C ≤ PET < 58.27 °C, the alpha-band decreased significantly due to fragrance stimuli. Under different PETs, the relative theta-band in all cerebral cortex zones changed significantly, and the wave band was most significantly influenced by olfactory stimuli.
21	Yang and Moon, 2019 [73]	✓	✓	✓		60 (30 males, 30 females). Recruited from university; vision and hearing screening; they were asked to wear a clothing ensemble of nearly 0.75 clo according to the ASHRAE Standard 55–2004. South Korea	Biometric measures Visual: fluorescent lighting Acoustical: loudspeaker Thermal: room temperature	Visual: 3 illuminance level Acoustical: 4 types of sound (babble, fan, music, and water) with 4 sound levels Thermal: 20, 25, and 30 °C	3 thermal sessions: 30 min of adaptation period 15 min of response [for each sound, 25 s stimulus, 50 s response] 20 min of wash-out period for each illuminance level (3 illuminance levels)	Acoustic comfort Thermal comfort Visual comfort Indoor environmental comfort [using an 11-point numeric scale recommended by ISO 15666] [88]	The effect of acoustic factors was the greatest on indoor environmental comfort, followed by room temperature and illuminance.

Table 1. *Cont.*

No.	Reference	Sensory				Subject	Tool	Experimental Design	Environmental Procedure	Measures	Main Conclusions
		Visual	Acoustical	Thermal	Smell						
22	Du et al., 2023 [83]	✓	✓	✓		458 (Age range: >60) Recruited from the field; vision and hearing screening; Xi'an, China	Questionnaire Visual: outdoor view Acoustical: loudspeaker Thermal: outdoor temperature	Visual: Visible green index (VGI) Acoustical: 5 common types of stimulating sound (conversation, birdsong, traffic sound, dance music, and traditional opera) 3 ranges LAeq, low (40–45 dBA), medium (50–55 dBA), and high LAeq (60–65 dBA) Thermal: 4 selected spaces: square adjacent to water (WS); tree-shaded square (TS); landscape pavilion (LP); open square (OS); 9:00–11:30, 12:30–15:00, 15:30–18:00	15 min of random type of sound stimulation and fill out the questionnaire after Transfer to the next field and repeat 5 times until listening to all types of sounds	Meteorological parameters, illumination intensity (LUX) Sound types (STP) A weighted equivalent continuous sound pressure level (LAeq) Sky view factor (SVF) Visible green index (VGI) Thermal sensation vote (TSV), thermal comfort vote (TCV), acoustic sensation vote (ASV), acoustic comfort vote (ACV), sunlight sensation vote (SSV), visual comfort vote (VCV), and overall comfort vote (OCV)	When PET was above 43.80 °C, the elderly felt thermally uncomfortable. Older adults perceived traffic sound as acoustically uncomfortable when LAeq was higher than 66.1 dBA. A higher VGI decreased the sensitivity of respondents to LUX. TSV and TCV were susceptible to the acoustic and visual environments. The influence of the visual environment and PET on ASV and ACV were not significant. There was a significant correlation between PET and SSV. Acoustic and thermal comfort had a one-vote veto tendency relative to overall comfort but no absolute veto power. Thermal comfort was the most important factor affecting overall comfort in summer while acoustic comfort was the most important in spring. A binary logistic regression to predict the overall comfort of elderly adults had 84.7% accuracy, indicating a good performance.
23	Sona et al., 2019 [84]	✓	✓		✓	122 (58 males, 64 females; M_{age} = 22.69, SD = 2.23). Recruited from German students. No allergies to the scents used. Germany	Biometric measures Visual: LED screen Acoustical: LED screens with speakers Scent: dispenser	Visual: an artificial window, Acoustical: consisting of 3 high-resolution LED screens with speakers Olfactory: a scent composed of rosewood, geranium, ylang-ylang, olibanum (frankincense), and hyssop in the natural outdoor condition and composition of rosewood and cardamom in the built indoor condition	The 5 conditions are as follows: (1) Control, (2) Nature, (3) Lounge, (4) Scented nature, and (5) Scented lounge 50 min depletion phase 15-min restoration phase and fill in the questionnaire Post-restoration phase	Perception of the space Pleasantness of window view, sound, and odor Perceived Restorativeness Scale Personal resources Fatigue, mood, and arousal	Analyses showed that the subarachnoid hemorrhage early brain edema score (SEBEs) simulating either a natural or a lounge environment was perceived as more pleasant and restorative (fascination/being away) than a standard break room, which in turn facilitated the recovery of personal resources (mood, fatigue, and arousal).

24	Marcus et al., 2019 [85]	✓	✓		✓	154
						(Age range: 18-50;
						city (n = 50, 28 females, 22 males, M_{age}: 27);
						park (n = 52, 26 females, 26 males, M_{age}: 28);
						forest (n = 52, 28 females, 24 males; M_{age}: 27)).
						Recruited from Stockholm (about 1.5 million inhabitants) where they are presumably exposed to a higher degree of the city.
						Vision, hearing, and olfaction screening;
						inclusion criteria comprised self-declared health, not pregnant, and not using prescription medication.
						Stockholm, Sweden
							Biometric measures
							Questionnaire
							Visual:
							2D 360° virtual reality photo
							VR mask (Oculus Rift)
							Acoustical:
							headphones
							Scent:
							a custom-built nine-channel air-dilution olfactometer
								Visual:
								a densely built-up urban area, a park, or a forest
								Acoustical:
								city noise: traffic; park noise: one bird; forest noise: nine bird species and the sound of a slight breeze)
								Olfactory:
								city odors: diesel, tar, and gunpowder; park odors: grass; forest odors: 2 evergreen species and mushroom
									30 seconds baseline measurement
									150 s stress induction period (shock at 40, 50, 70, 100, and 150 s).
									180 s recovery period
										The average perceived pleasantness
										Physiological stress test (SCL–measures)
										Stress Sensitivity Scale
										SCL (skin conductance level)
											The park and forest, but not the urban area, provided significant stress reduction.
											High pleasantness ratings of the environment were linked to low physiological stress responses for olfactory and auditory but not for visual stimuli.
											Olfactory stimuli may be better at facilitating stress reduction than visual stimuli.

Table 1. *Cont.*

No.	Reference	Sensory				Subject	Tool	Experimental Design	Environmental Procedure	Measures	Main Conclusions
		Visual	Acoustical	Thermal	Smell						
25	Qi et al., 2022 [86]	✓	✓		✓	308 (13% male; M_{age}: 22.92 (SD = 2.20; Range: 18–31). Recruited from a single college campus. Vision, hearing, and olfaction screening; Shaanxi, China	Biometric measures Questionnaire Visual: 360° virtual reality photo Acoustical: mini wireless speakers Scent: odor sensor	Birdsong only vs. birdsong + photo (4 types)/odor (4 types) vs. birdsong + photo + congruent odor (4 types) Visual: a white wall as the control; short-cut lawn; rose garden; osmanthus tree garden; pine forest Acoustical: Birdsong: downloaded from the open sources on the Internet Streptopelia decaocto (500–800 Hz); riolus chinensis (1 k-3 kHz); Passer montanus (3 k-4 k Hz); Chloris sinica (4 k-6 k Hz); Garrulax canorus (2 k-6 k Hz) Olfactory: leaves from the lawn; flowers of rose bushes; flowers of osmanthus trees; leaves (pine needles) of pine trees	5 min introduction and questionnaire (part 1) 5 min relaxation 1 min baseline 2 min stimulation Questionnaire (part 2-4) 5 min rewards distribution Ventilation	ST (skin temperature), SCL (skin conductance level), and EEG (electroencephalogram) STAI-S (the state version of the State-Trait Anxiety Inventory) Semantic differentials (SDs) survey concerning the overall quality evaluation of the environment (overall attraction, overall harmony, and overall preference)	Integrating visual stimuli of birdsong improved physiological restoration and the overall perceived quality evaluation but held no psychological effect. Introducing olfactory stimuli of birdsong had an adverse restoration physiologically and no significant effect on psychological restoration and the overall preference but enhanced the perceived overall feelings of attraction to the landscape and a sense of overall harmony. Introducing a combination of visual–olfactory stimuli led to increased physiological restoration (only for β-EEG) and overall perceived quality evaluation but also had no significant effect psychologically.
26	Zhong et al., 2022 [87]	✓	✓		✓	172 (78 males, 94 females; M_{age}: 21). Recruited from the Architecture Department of Chongqing University. Normal hearing and a basic knowledge of soundscapes and landscapes. Chongqing, China	Questionnaire Vi- sual/Acoustical/Scent: outdoor environment	Sense walking Visual/Acoustical/Olfactory: seven waterfront spaces in mountainous cities (WSMCs) in Chongqing were randomly selected as the study areas, namely, Jiangbeizui (JB), Shacixiang (SC), Chaotianmen Square (CT), CBD Riverside Park (CB), Liziba Park (LZ), Jiulongpo Park (JL), and Nanbin Park (NB)	A researcher walking alone or with one or more participants Each participant spent 5 min at each of the walking points to evaluate the soundscape quality and fill out the questionnaire	List all of the sound sources they noticed (referred to the suggestions in ISO/TS 12913-2: 2018 [89]); soundscape comfort degree (SCD) Visual environment comfort degree (VECD); visual environment natural degree (VEND); visual environment diversity degree (VEDD) Smell environment comfort degree (SECD); name the main odors II	In terms of visual elements, the proportions of paved ground, pedestrians, and buildings had negative effects on the soundscape, while those of the sky, water, and natural terrain had positive effects. High visual and smell environment quality can enhance soundscape evaluations, although the smell environment had a greater impact on the SCD than the visual environment in WSMCs.

4.1. Study Type and Subject

Due to differences in research questions, sample size, experimental procedures, and people's behavioral responses, different researchers have adopted different research designs. According to statistics, 20 studies were experimental studies, and 6 studies were field studies; the majority of papers conducted short-term laboratory studies in a controlled environment, where environmental factors other than the target sensory elements were under control. The specific study questions and study sample size are shown in Table 2.

Table 2. Study type and population analysis table.

Project	N(Subject) and M:F and Mean Age and Type				Reference	Remark
Visual Acoustical	20–40	32(16:16)	30	Ordinary people	Park et al., 2020 [50]	
		20(15:5)	27.2	Ordinary people	Hong and Jeon, 2013 [51]	
		40(22:27)	24.1	Students	Jahncke et al., 2015 [52]	
		30; 15; 30 (1:1)	25	Students	Ma and Shu, 2018 [53]	
		31(16:15)	27.9	Ordinary people	Abdalrahman and Galbrun, 2020 [62]	
		38(19:19)	36.3	Students and staffs	Galbrun and Calarco, 2014 [61]	
		28(14:14)	30.1	Ordinary people	Liu et al., 2023 [55]	
		37(18:19)	/	Students	Aristizabal et al., 2021 [42]	
	68(40:28)		30–40	Ordinary people	Sun et al., 2018 [54]	Increase the statistical power for subgroup analysis in terms of gender, age, and education
Visual Thermal	Study 1: 19 Study 2: 16 All females		22.2	Students and ordinary people	Kulve et al., 2018 [64]	All participants went through three room-temperature settings
	84(42:42)		18–30	Students	Chinazzo et al., 2019 [65]	Each participant only experienced one out of three temperature levels
	86(43:43)		/	Students	Ko et al., 2020 [67]	Compare the window and windowless environments at the same room temperature
Visual Olfactory	21 All females		21.1	Students	Song et al., 2019 [68]	
	48(24:24)		22.7	Students	Li et al., 2024 [69]	
Acoustical Thermal	54(25:29)		22	Students	Yang and Moon, 2019 [74]	Participants underwent three experiments
Acoustical Olfactory	247(1:3)		less 20> 65%	Ordinary people	Mattila and Wirtz, 2001 [75]	Field studies can easily recruit participants, as anyone stepping into the test area could be a candidate
	117(28:89)		47.9	Patients	Fenko and Loock, 2014 [77]	
	774(/)		/	Shoppers	Morrin and Chebat, 2005 [76]	
	168(76:92)		22	Students and ordinary people	Ba and Kang, 2019 [78]	Laboratory study
Thermal Olfactory	81(23:58)		18-26	Ordinary people	Chang et al., 2023 [80]	Field study
Visual Acoustical Thermal	60(30:30)		/	Students	Yang and Moon, 2019 [73]	Participants underwent three experiments
	458(/)		>60	The elderly	Du et al., 2023 [83]	Field study
Visual Acoustical Olfactory	122(58:64)		22.69	Students	Sona et al., 2019 [84]	Each participant was exposed to a multisensory environment
	154(82:72)		27/28	Ordinary people	Marcus et al., 2019 [85]	
	308(40:268)		22.92	Students	Qi et al., 2022 [86]	
	172(78:94)		21	Students	Zhong et al., 2022 [87]	Field study (sense walking)

Due to limited resources and the high costs associated with maintaining a controlled environment, laboratory studies typically involve fewer than 100 participants (except for acoustical–olfactory experiments). However, as the complexity of multisensory experiments and the number of experimental groups increases, so does the number of participants. When

the number of senses increased to three or more, between-subject experiments required at least a hundred people, and only the intended within-subject experiments used 60 people as a sample.

When we look at the form of recruitment, we find that more than half of the studies were recruited from universities (57%), and a few others were recruited from special approaches and organizations such as online, on-site, and in hospitals (Figure 3). Similarly, participants recruited from the university were overwhelmingly students and mostly under 25 years old, with only one study explicitly stating that it recruited staff from the university. Some studies recruited participants from specific groups, such as the elderly over 60 years of age, patients in hospitals, and shoppers who came to the mall (Figures 4 and 5).

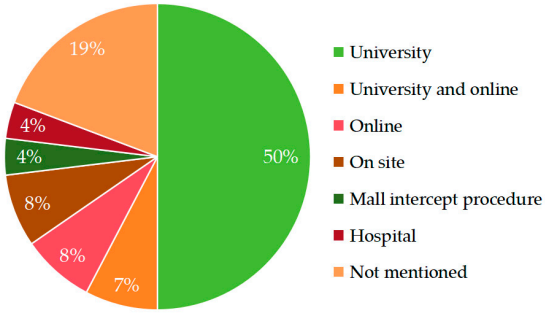


Figure 3. Recruitment method.

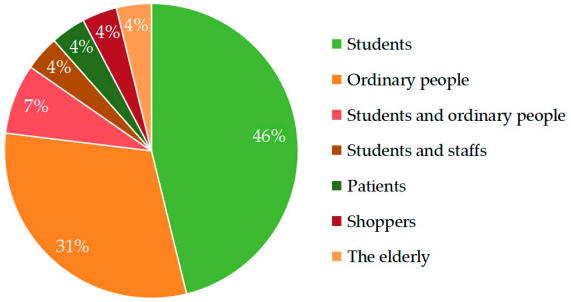


Figure 4. Types of participants.

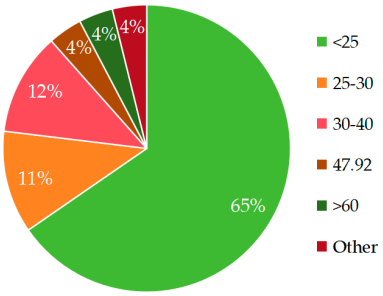


Figure 5. Average age distribution[5].

Due to the consideration of control variables, the vast majority of experiments restrict the characteristics of the population very strictly, such as age range, sex ratio, height and weight, etc. Of the 24 experiments that explicitly stated the sex ratio, 50% (12) studied the ratio of men to women as basically 1:1, and there were even two studies that only studied the female group (Table 2), thus only two studies analyzed the heterogeneity of the population of different ages. Galbrun and Calarco have statistically analyzed cultural groups, such as "Middle Eastern", "Asian", and "African"; however, cultural differences were not statistically analyzed due to small sample sizes for each cultural group.

In addition to screening for age and gender, studies similarly screened participants for sensory abilities, with 75% (15) of the 20 experiments involving screening subjects for hearing ability, either through self-reporting or testing with an audiometer. Only about half of the studies involving the senses of vision and smell screened for their visual and olfactory abilities. Notably, for the study on thermal sensation, Chang et al., 2023 [80] chose residents who had been in the area for more than a year to ensure that they had similar adaptations to the local climate; Chang et al., 2023 [80] and Yang and Moon, 2019 [73,74] achieved similarity in heat perception by controlling for the type of clothing worn by the participants. In addition, mental problems, smoking and drinking, health level, BMI index, pregnancy, medication use, etc., also played a very important role in the inclusion and exclusion criteria of the study. Furthermore, Galbrun and Calarco, 2014 [61] and Hong and Jeon, 2013 [51] conducted a consistency test on the participants to ensure the accuracy of the experimental results.

According to the countries where the experiments were conducted, a total of 11 countries from three continents were involved in the 26 papers, with Asia accounting for 46% (12 papers), Europe for 38% (10 papers), and North America for 15% (4 papers); there was a lack of research on countries in South America, Oceania, and Africa (Figure 6).

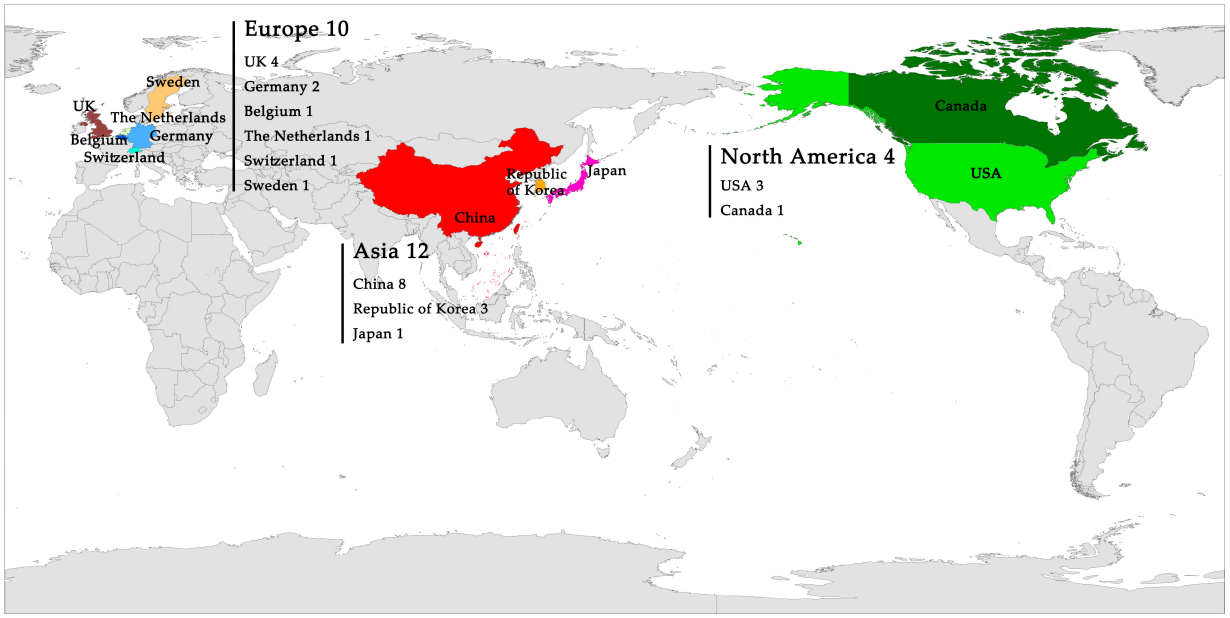


Figure 6. Map of study sites.

4.2. Environmental Settings

Multiple biophilic design strategies could be applied to introduce nature indoors and create sensory experiences in experimental settings. Among the selected studies, researchers adopted different biophilic elements and their combinations, which will be introduced in the following section (Table 3).

Table 3. Environmental settings analysis table.

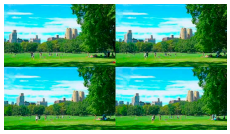
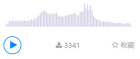
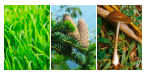
Types of Elements	Content	Reference	Environmental Settings	
Visual	Nature scenery or natural elements	Park et al., 2020 [50]; Hong and Jeon, 2013 [51]; Jahncke et al., 2015 [52]; Ma and Shu, 2018 [53]; Sun et al., 2018 [54]; Abdalrahman and Galbrun, 2020 [62]; Galbrun and Calarco, 2014 [61]; Ko et al., 2020 [67]; Sona et al., 2019 [84]; Du et al., 2023 [83]; Zhong et al., 2022 [87]		
	Pictures of landscapes or urban nature	Park et al., 2020 [50]; Hong and Jeon, 2013 [51]; Jahncke et al., 2015 [52]; Sun et al., 2018 [54]; Liu et al., 2023 [55]; Aristizabal et al., 2021 [42]; Song et al., 2019 [68]; Marcus et al., 2019 [85]; Qi et al., 2022 [86]		
	Photomontages with different natural features	Abdalrahman and Galbrun, 2020 [62]; Galbrun and Calarco, 2014 [61]		
	Video sequence of a park in the natural outdoor condition	Sona et al., 2019 [84]		
	Greenery existing in offices, such as plants and window view	Ma and Shu, 2018 [53]; Ko et al., 2020 [67]; Li et al., 2024 [69]		
Acoustical	Recording sound live	Park et al., 2020 [50]; Jahncke et al., 2015 [52]; Sun et al., 2018 [54]	Environmental sound: all sounds present in the target environment were included	
		Hong and Jeon, 2013 [51]; Ma and Shu, 2018 [53]; Abdalrahman and Galbrun, 2020 [62]; Galbrun and Calarco, 2014 [61]; Sona et al., 2019 [84]; Du et al., 2023 [83]	Single-resource sound: only one type of sound resource exists when recording the sound, such as water sound, bird sound, and the wind sighing in the trees	
	Network download sound	Marcus et al., 2019 [85]; Qi et al., 2022 [86]		
	Rhythmic music	Mattila and Wirtz, 2001 [75]; Fenko and Loock, 2014 [77]		
Olfactory	Flora scent	Song et al., 2019 [68]	Hinoki cypress leaf oil	
		Mattila and Wirtz, 2001 [75]; Fenko and Loock, 2014 [77]	Lavender	
		Ba and Kang, 2019 [78]	Lilac and Osmanthus	
		Li et al., 2024 [69]	Coriander	
		Chang et al., 2023 [80]	Lavandula officinalis, Rosa rugosa, and Mentha canadensis	
		Qi et al., 2022 [86]	Leaves from the lawn; flowers of rose bushes; flowers of osmanthus trees; leaves (pine needles) of pine trees	

Table 3. *Cont.*

Types of Elements	Content	Reference	Environmental Settings	
		Marcus et al., 2019 [85]	Grass, European silver fir, mushroom from Octanol	
	Wood and herb scent	Sona et al., 2019 [84]	A scent composed of rosewood, geranium, ylang-ylang, olibanum, and hyssop	
	Fruit scents	Mattila and Wirtz, 2001 [75]	Grapefruit	
		Morrin and Chebat, 2005 [76]	Citrus	
	Food scent	Ba and Kang, 2019 [78]	Coffee and bread	
	Urban scent	Zhong et al., 2022 [87]	Natural odors, emission odors, food odors, building material odors, and human odors	
		Marcus et al., 2019 [85]	Diesel, tar, and gunpowder	

For visual exposure, a large majority of studies used screens or VR to display the selected image. However, Park et al. used virtual reality to show the recorded urban video [50]. Yin et al. used virtual reality technology to watch immersive 360-degree field-of-view videos to create a more immersive experience [90]. Instead of using pictures or pre-recorded videos, Yin et al. stimulated three-dimensional virtual offices in VR by using Rhino5 software in advance and rendered in real-time during experiments by using Unity software (version 2017.1.0f3) [9,10]. For acoustical exposure, researchers played sound either through headphones or screen speakers in lab studies and used portable speakers to play the stimulus in field studies. For thermal-related exposure, studies were conducted in lab settings by changing room temperature directly. Experimental sessions were separated based on different temperatures given that it would take a long time to switch between temperatures, and also a long time is needed for participants to adapt. Only one study changed the temperature by directing subjects to three typical spaces [80,83]. For olfactory exposure, the most common way to disperse the scent is using a diffuser, but essential oil and perfume can also be used to create a scented environment.

4.3. Measures

We categorized all measures into five domains: psychological measures, cognitive function, biometrics, comfort, and human behavior (Table 4).

Psychometric methods have their earliest origins and are widely used, and with the development of technology, some studies also incorporated biometric measures along with psychological indicators, because physiological measures can help the researcher understand human responses objectively in real time. Studies in recent years have shown that more and more researchers are using physiological indicator measures, and their methods are more diverse. Cognitive tests were also incorporated into experiments to measure participants' performance. Research on comfort has grown rapidly, especially in the last few years and especially with respect to thermal comfort. Along with physiological and psychological measures, researchers also recorded human social behavior in field studies.

Table 4. Measurement method analysis table.

Measure	Content	Reference	Remark
Psychological measures	Sensation, acceptability, pleasure, familiarity, and subjective intensity	Park et al., 2020 [50]; Hong and Jeon, 2013 [51]; Sun et al., 2018 [54]; Abdalrahman and Galbrun, 2020 [62]; Galbrun and Calarco, 2014 [61]; Aristizabal et al., 2021 [42]; Kulve et al., 2018 [64]; Chinazzo et al., 2019 [65]; Ko et al., 2020 [67]; Yang and Moon, 2019 [73]; Yang and Moon, 2019 [74]; Mattila and Wirtz, 2001 [75]; Fenko and Loock, 2014 [77]; Morrin and Chebat, 2005 [76]; Ba and Kang, 2019 [78]; Sona et al., 2019 [84]; Chang et al., 2023 [80]; Marcus et al., 2019 [85]; Qi et al., 2022 [86]; Zhong et al., 2022 [87]	Helped to explain participants' attitudes toward providing sensory stimuli
	Preferences	Park et al., 2020 [50]; Hong and Jeon, 2013 [51]; Jahncke et al., 2015 [52]; Sun et al., 2018 [54]; Abdalrahman and Galbrun, 2020 [62]; Galbrun and Calarco, 2014 [61]; Mattila and Wirtz, 2001 [75]; Ba and Kang, 2019 [78]; Chang et al., 2023 [80]	A straightforward way to compare different sensory combinations
	Human restoration	Park et al., 2020 [50]; Jahncke et al., 2015 [52]; Sona et al., 2019 [84]	
	Emotional state	Ma and Shu, 2018 [53]; Ko et al., 2020 [67]; Mattila and Wirtz, 2001 [75]; Morrin and Chebat, 2005 [76]; Sona et al., 2019 [84]; Li et al., 2024 [69]	
	Pressure	Ko et al., 2020 [67]; Aristizabal et al., 2021 [42]; Marcus et al., 2019 [85]	
	Anxiety	Fenko and Loock, 2014 [77]; Qi et al., 2022 [86]	
Cognitive function	Design a target search task	Ma and Shu, 2018 [53]; Aristizabal et al., 2021 [42]	Evaluated participants' task performance
	Modules of Cambridge Brain Sciences	Ko et al., 2020 [67]	Evaluated participants' working memory, concentration, short-term memory, and spatial planning and used self-developed tasks to evaluate creativity performance
	Psychomotor vigilance task (PVT) and spatial working memory span task (SWMS)	Li et al., 2024 [69]	Evaluated cognitive performance
Biometrics	Facial electromyography (fEMG) Respiration rate (RR)	Park et al., 2020 [50]	Recorded several physiological indicators to measure the stress recovery process
	Blood pressure (BP)	Ma and Shu, 2018 [53]	
	Heart rate (HR)	Park et al., 2020 [50]; Ma and Shu, 2018 [53]; Aristizabal et al., 2021 [42]; Song et al., 2019 [68]	
	Electrodermal activity (EDA)	Aristizabal et al., 2021 [42]; Li et al., 2024 [69]; Marcus et al., 2019 [85]; Qi et al., 2022 [86]	Skin conductance level (SCL) reflects the activity of the sympathetic nervous system. Used to assess stress levels, with lower levels indicating greater relaxation
	Electrocardiogram (ECG)	Liu et al., 2023 [55]; Li et al., 2024 [69]	
	Electroencephalogram (EEG)	Chang et al., 2023 [80]; Li et al., 2024 [69]; Qi et al., 2022 [86]	Analyzed changes in human mood
	Employ near-infrared time-resolved spectroscopy to measure oxygen-hemoglobin concentrations in the left and right prefrontal cortex of the participants	Song et al., 2019 [68]	Investigated the physiological and psychological relaxation effects
	Body/skin temperature	Kulve et al., 2018 [64]; Chinazzo et al., 2019 [65]; Ko et al., 2020 [67]; Qi et al., 2022 [86]	Analysis of human thermal comfort indicators
	Salivary biochemical indicators: salivary stress marker (cortisol), proinflammatory cytokines, untargeted metabolomics	Li et al., 2024 [69]	

Table 4. *Cont.*

Measure	Content	Reference	Remark
Comfort	Visual comfort	Hong and Jeon, 2013 [51]; Kulve et al., 2018 [64]; Yang and Moon, 2019 [73]; Du et al., 2023 [83]; Zhong et al., 2022 [87]	
	Acoustical comfort	Hong and Jeon, 2013 [51]; Yang and Moon, 2019 [74]; Ba and Kang, 2019 [78]; Yang and Moon, 2019 [73]; Du et al., 2023 [83]; Zhong et al., 2022 [87]	
	Thermal comfort	Kulve et al., 2018 [64]; Ko et al., 2020 [67]; Yang and Moon, 2019 [74]; Chang et al., 2023 [80]; Yang and Moon, 2019 [73]; Du et al., 2023 [83]	
	Olfactory comfort	Ba and Kang, 2019 [78]; Chang et al., 2023 [80]; Zhong et al., 2022 [87]	
	Overall comfort	Chinazzo et al., 2019 [65]; Yang and Moon, 2019 [74]; Ba and Kang, 2019 [78]; Yang and Moon, 2019 [73]; Du et al., 2023 [83]	
Human behavior	Purchasing power	Mattila and Wirtz, 2001 [75]	Evaluated the extent of impulse buying in the experimental environment
	Perceiver quality of products	Morrin and Chebat, 2005 [76]	
	Compared patients' perceived waiting time with the objective waiting time	Fenko and Loock, 2014 [77]	

4.4. Study Procedure

The time for environmental exposure and perception could be different in experiments targeting different senses (Figure 7). For visual and sound perception, humans can process light and sound signals within a second. However, for thermal perception, a human's dermal system needs more time to sense the change in room temperature and make the relevant adaptation. For smell, the chemical composition of the scent needs time to mix with the air and diffuse to smell organs. Due to these differences, studies related to acoustical perception always used a shorter exposure time for each sound stimulus, which is usually less than 15 min and as short as 5 s. However, when considering the recovery and long-term effects, researchers tend to extend the duration of auditory intervention. In a long-term study conducted by Aristizabal et al., a sound file lasting 6 h and 30 min was utilized to replicate an authentic natural environment, which was cyclically repeated [42].

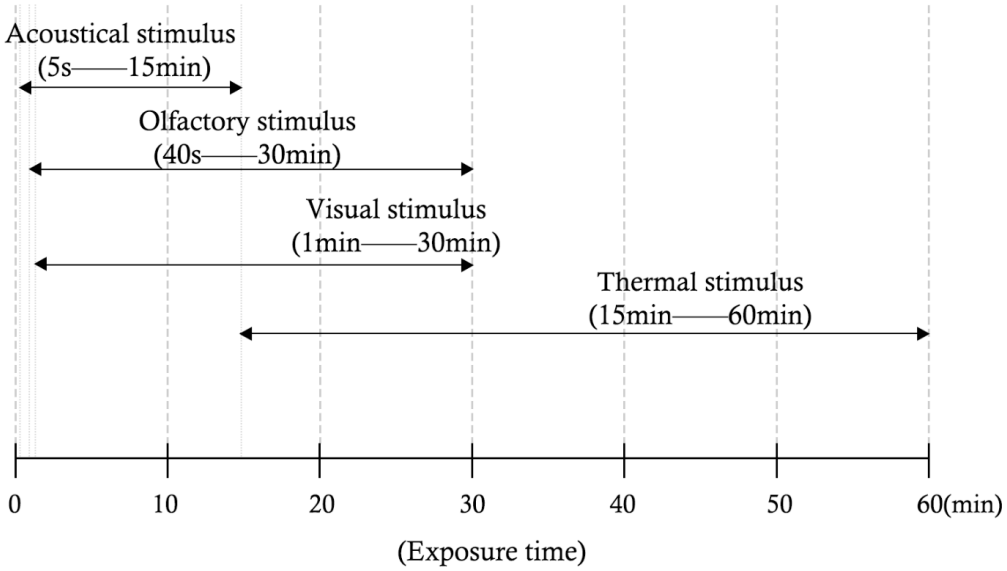


Figure 7. Exposure time for different stimuli (in most cases).

For research assessing visual perception, the exposure time ranged from 1 min to 30 min. The experimental time was always longer than 15 min when changing room temperature was needed. Therefore, if multiple sensory stimuli exist in a single experiment, a longer exposure time is needed for related human responses.

When designing a multisensory study, we not only need to consider the exposure time but also need to consider the carry-over effect of the previous experimental session. For visual and acoustical stimuli, people can quickly switch between different scenes. But when we included temperature as one of the environmental factors, researchers always set aside at least 15 min as adaptation time [64,65,73]. For the lab-based odor study, researchers ventilate the space for 5 min to clear out the residual of the previous scent [73].

5. Gaps and Future Directions

5.1. Beneficial Effects of Sensory Experiences

A noticeable shift has been seen from eliminating undesirable environments to creating beneficial environments. Studies began to look at positive design components advocated by theories of biophilic design, such as incorporating natural view, daylighting, natural sound, air movement, and flora scents indoors. However, we still need more scientific evidence to promote biophilic design. For example, how can we incorporate pleasant scents into the workspaces? How can we use natural sound as a sound masker in offices and public spaces? How can we create dynamic airflow in an office and urban public spaces?

5.2. Interaction between Multisensory Exposure to Nature

A deeper comprehension of interactions among senses would lead to a better understanding, modeling, and prediction of the impacts of sensory elements on people's comfort, perception, health, and well-being. In this review, we examined studies that investigated correlations between different sensory stimuli, including the interactions between visual and acoustical, visual and thermal, acoustical and thermal, and acoustical and olfactory stimuli. However, our findings highlight that studies on the interactions between visual and olfactory, thermal and olfactory, and among three or more senses remain limited. Additionally, tactile interactions with natural elements such as flowers, trees, water, and rocks are acknowledged as potential factors influencing human experience. However, research in this area remains limited. Current studies predominantly focus on the passive tactile perception related to thermal sensations, overlooking the subjective aspects of tactile engagement with these natural elements. This gap highlights the need for further exploration into the active, subjective dimensions of tactile interactions in natural settings.

Beyond these traditional senses, it is important to consider other environmental factors such as humidity and air pressure, which can interact with temperature to influence human sensory experiences. For instance, studies have shown that the combination of temperature and humidity can significantly affect thermal comfort physiological responses [91] and work performance [92]. Moreover, research found that optimal thermal comfort is not static and can depend on several interacting factors, including the direction and speed of airflow [93]. Furthermore, with the advancement of biology, new types of senses—such as emotions (e.g., stress and fear), time perception, and spatial perception—have been identified or defined. Future research should explore these emerging sensory dimensions and their possible connections with traditional sensory modalities. By doing so, we can achieve a more comprehensive understanding of multisensory interactions and their contributions to human well-being, thereby fostering innovation in biophilic design practices.

5.3. Subjects Heterogeneity and Limited Generalization

Existing research has predominantly focused on students or younger populations, with most experiments being conducted in regions like Western Europe, East Asia, and North America. This geographical and demographic concentration limits the generalizability of the findings, thereby restricting their applicability to a broader range of populations. Future studies should expand their focus to include diverse age groups, such as children, middle-

aged individuals, and the elderly. Additionally, consideration should also be given to the restorative effects on special populations, such as the chronically ill and pregnant women. By doing so, research can generate more universally applicable conclusions, ultimately fostering a more comprehensive understanding of how biophilic design can contribute to health promotion across various demographics.

5.4. Study Design Methodology for Multisensory Studies

It becomes challenging to design experiments for studying multiple senses. Researchers need to choose between different experimental strategies for different senses. For example, visual studies may need to extend their experimental time to accommodate for the adaption of temperature. For studying the interaction between olfactory and acoustical, researchers need to set aside ventilation time between each pair of sounds and scents.

5.5. The Lasting Impact of Multisensory Experiences

Although most current studies focus on short-term effects (usually within two hours) under various experimental conditions, some studies have begun to explore long-term effects (weeks or months). This is crucial because some benefits of natural exposure are immediate, while others accumulate over extended periods. Therefore, in future studies, it is very necessary to quantify both the immediate and long-term effects of multisensory interaction, particularly exploring the underlying neural mechanisms and psychological processes, as understanding these aspects will be the key to optimizing the biophilic design for human well-being.

5.6. Objective Physiological Measures

The psychological and cognitive effects of environmental stimuli have been studied for more than a century. The processes of data collection heavily rely on subjective self-report factors, which have been criticized for their reliability and precision. Measurement of objective and real-time physiological data via sensors has recently been proposed as a solution to the lack of accuracy of subjective assumptions and has gained some traction, with more than half of the selected biophilic studies already incorporating physiological identification data into their analyses.

To advance our understanding of the complex impacts of biophilic design on human well-being, it is crucial to foster interdisciplinary collaborations. By integrating knowledge and methods from urban design, environmental psychology, public health, and neuroscience, better data interpretation and integration could take place, thereby revealing the intricate relationships between multisensory environmental stimuli and human responses. Such collaborations will not only enhance the accuracy and depth of research findings but also drive innovation and advancements in design practices, ultimately leading to built environments that better support human health and well-being.

6. Conclusions

This review advocates for the accumulation of more scientific evidence to quantitatively evaluate multisensory experiences in biophilic environments and their subsequent influence on health and well-being, thereby underscoring the research's value and future orientation. We therefore comprehensively analyzed empirical studies investigating the interactions between two and three sensory modalities in biophilic design, systematically summarizing the pivotal methods and techniques employed in these experimental studies. These include study types and subject selection, environmental exposure simulations, health benefit assessment indicators, and experimental process design. This analysis not only deepens our understanding of the health benefits associated with biophilic design but also provides methodological insights for future research endeavors.

The existing research shows that multisensory approaches can offer more substantial benefits than those focusing on single sensory modalities. However, current research exhibits limitations in studies involving more than two senses, especially three or more senses, inade-

quate coverage of different population types and geographical areas, as well as insufficient research on the long-term effects. Therefore, future research should focus on the comprehensive analysis of multisensory interactions. It is essential to consider the restorative effects across various populations and special groups. This inclusive approach will ensure that the benefits of biophilic design are accessible to all, thereby enhancing its impact on public health. At the same time, both short- and long-term impacts on health should be taken into account. Additionally, expanding the use of objective data collection methods and enhancing interdisciplinary collaboration will enable researchers to gain a deeper understanding of this field, ultimately leading to more effective health promotion outcomes.

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

Notes

[1] (ASHRAE GUIDELINE 10—Interactions Affecting the Achievement of Acceptable Indoor Environments | Engineering360, n.d.)

[2] The checkmarks in the "Sensory" column indicate which sensory elements were examined in each study.

[3] Eight participants were excluded before analysis, as they had reported having tinnitus or that they had not heard any sound during the experiment. One participant was excluded for not following the instructions, which left 40 participants for the analysis.

[4] In addition, all participants had been living in Minnesota for at least two years by the time the study began and were thus accustomed to the sounds introduced in this study.

[5] In this analysis, it is assumed that students whose specific age is not indicated are under 25 years old.

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