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The relationship between the perceptual experience of a waterfront-built environment and audio-visual indicators

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ABSTRACT

This study evaluated the effects of water span and the number of building levels (3, 6, 17 storeys) on the quality of human recovery, security, and overall experience (comfort, satisfaction, and preference). In addition, we investigated the effects of including different sound sources in the waterfront high-rise built environment on the above subjective evaluations. After measuring the architectural parameters of the waterfront settlement and identifying the sound sources, simulations were carried out using virtual reality 3D technology with a human walking perspective. The analysis showed that in terms of security, the wider the water span, the lower the human perception of security ($p < 0.01$). The water span did not affect the quality of recovery or overall experience. The degree of recovery, perception of security, and overall experience displayed a strong negative connection with the number of storeys in the building. Among them, low and multi-storey buildings (3 to 6 storeys) had the best effects on human recovery quality, security, and overall experience. In a waterfront high-rise setting, it is desirable to include the sound of birdsong and to a lesser extent stream sounds. Furthermore, men rated lower than women in terms of quality of recovery, security, and overall experience under conditions of water span, number of building levels, and variation in sound sources. Compared to women, men needed more restorative sound sources.

1. Introduction

Bodies of water are the most important component of waterfront architectural spaces. Depending on the span of the water body, bodies of water can be classified as oceans, lakes, rivers, etc. A blue space is an outdoor area, either natural or manmade, where people can interact with water, physically or virtually, by being in, on, or next to it (i.e., a space where a person can see, hear, or otherwise perceive water) [1]. Green space is an important ecological element of an urbanised area and occupies an important place in urban space [2]. Similar to green space, blue space has the potential to be a public health resource [3]. Grey space is another type of man-made urban space, consisting mainly of sealed, hard concrete or tarmac surfaces. Unfortunately, the intensification of cities has increased areas of grey space and reduced the amount of green and blue space available to city dwellers [4]. There is also growing concern about landscape damage and visual pollution caused by waterfront high-rise buildings [5]. Evidence suggests that proximity to aquatic environments, referred to in this study as 'blue spaces' (e.g., shorelines, lakes, rivers), may have several beneficial effects; for example, cities near water are associated with a reduction in heat-related mortality [6]. The promotion of physical activity and the improvement of mental health and well-being are the main health benefits of outdoor blue spaces [7]. Furthermore, staying close to the coast can reduce some of the harmful impacts of socioeconomic deprivation on one's health [8]. Visitors of blue spaces can benefit from social connections and psychological advantages [9]. Blue space availability is positively correlated with self-reported psychological and overall health and negatively correlated with anxiety and mood disorders [10]. Lower levels of psychological distress are associated with better blue space vision [11]. Moreover, exposure to the natural environment helps to restore depleted emotional and cognitive resources, and coastal locations are associated with the highest levels of recovery [12]. Blue space landscapes in urban park environments can help to relieve stress and restore attention levels, and different landscape features have varying levels of recovery [13].

Water is the most important and visually appealing element of the

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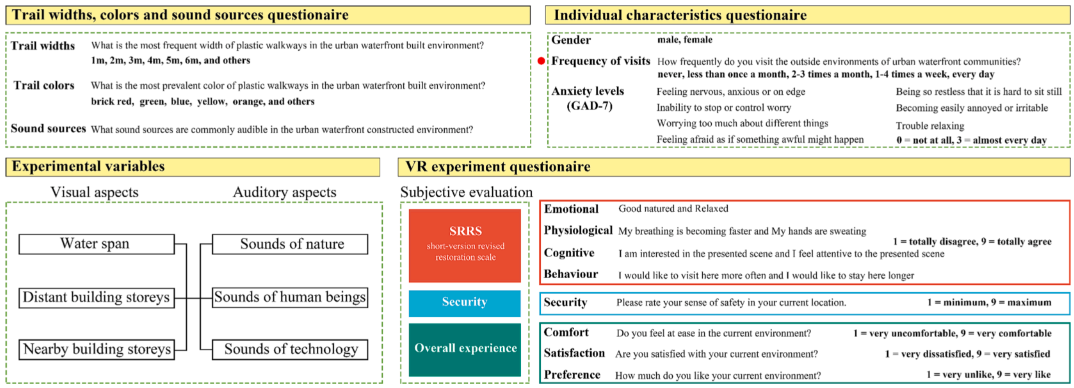


Fig. 1. Visual features, aural features, and subjective evaluation charts.

landscape [3]. The type of water feature plays a role in determining preference, for example, people prefer large bodies of water to rivers, lakes, and ponds, with the highest preference for 'large water surfaces' [14]. When choosing an environment, the spatiality of water elements is crucial, with lakes generally preferable to rivers and rivers to wetlands [15]. A previous study found that patients and students have the highest preference for images containing water [16]. There is a greater chance for negative emotions linked to urban areas to be diminished in natural environments, specifically those that have water [12]. Referring to Maslow, security is among the most fundamental human needs [17]. Security can be defined as "protection from harmful or undesirable stimuli in one's surroundings," encompassing protection from physical elements and risks to psychological safety [18]. Sound or audio information can significantly affect a person's sense of safety, and ambient sounds can affect how people experience social presence and safety in public areas [19]. People may feel unsafe as the communities surveyed are on the water's edge. While water is clearly an important landscape element, the more detailed effects of different water spans in the built environment have not been fully explored. In addition, most research on blue spaces and health has been conducted in Europe, the USA, and Australia, with little research conducted in other regions such as Asia [7]. There is also a lack of research involving architecture in the waterfront environment.

The number of tall buildings has increased exponentially in recent decades, yet many have been constructed with little attention to the principles of urban development and architectural design. In many cases, there is an overwhelming dissatisfaction with the scale environment and sense of place in tall buildings [20]. It has been shown that building height has a significantly greater impact on the sense of human oppressiveness than building width [21]. In addition, building height can affect the health of the neighbourhood's occupants [22]. Geometric and material buildings with envelope design elements can reduce outdoor noise levels [23]. Additionally, building height and lake width have an impact on public lake landscape preference [5]. Scenes with water, whether natural or man-made, are more favoured, have larger beneficial effects, and higher perceived restorativeness. Interestingly, images of artificial environments with water are frequently scored as positively as natural "green" areas [24]. The largest increases in house prices (up to 28%) due to environmental factors were for water-facing houses, especially if they overlooked water (8–10%) or open space (6–12%) [25]. People are willing to pay between 8% and 12% more to live in a home with a view of the water [26]. The way people engage with the urban waterfront is influenced by the visual and auditory senses, which allow people to recognize the cultural and natural richness of the urban waterfront environment [27].

The International Organization for Standardization (ISO) defines a soundscape as a particular contextual, situational, and acoustic environment that is perceived, experienced, and/or comprehended by an individual or group of individuals within the environment [28]. In contrast to noise control, the soundscape concept views sound as a resource and focuses on how to create a comfortable acoustic environment by protecting, encouraging, and increasing the positive and beneficial sounds in the environment while attenuating and controlling the harmful sounds in the environment. Ma et al., looked at the effects of urban and park noises on children's quality of restoration, and they discovered three main elements of restorative sound [29]. Wang et al., found that even though the sound levels are quite high, different sound types have a significant impact on the assessment of acoustic comfort [30]. These studies demonstrate that soundscapes are an important component of restorative environments [29]. In addition, there is a relationship between the soundscape and the senses of sight, hearing, and smell, with the audio-visual effect being the most significant.

The study of audio-visual interactions in outdoor environment has received more attention in recent years [31]. Jo et al., found that audio-visual satisfaction increased when the proportion of water and green-related elements was higher than the proportion of traffic-related elements [32]. Ha et al., discovered that a biodiverse campus environment had a restorative effect on university students through a study on the psychological recovery from multisensory (visual and auditory) stimulation of campus greenery [33]. According to research by Jin et al., visual and auditory information had an impact on overall satisfaction by 24% and 76% in diverse urban areas. Additionally, they identified a correlation between the soundscape and landscape of the urban environment and overall contentment [34]. The damage and visual pollution caused by waterfront high-rises also turned out to be of increasing concern [5]. Specifically, poor design was linked to both physical and psychological discomfort [35]. Therefore, it is crucial to comprehend how the visual characteristics of the waterfront constructed environment affect the quality of human recovery, security, and overall experience. There is also a need to understand the impact of including different sound sources in the waterfront high-rise built environment on the quality of human recovery, security, and overall experience.

The potential for restorative characteristics exists in all environments [36]. According to Maslow, one of the most fundamental human needs is safety [17]. We determined that comfort, satisfaction and preference were very congruent; to make the study briefer, we merged comfort, satisfaction, and preference into the overall experience. The overall experience impression has been placed last. Consequently, recovery, security, and overall experience are interconnected from the foundation to the total. From a health perspective of stress recovery, the emphasis is on people's environment-based sense of safety, followed by their overall psychological feeling. With the high intensity of building development due to the price premium effect, it is increasingly important for buildings in urban waterfront spaces to be designed in such a way as to ensure the quality of restoration, security, and overall experience (comfort, satisfaction, and preference). Therefore, this research focused on the following questions:

(1) What is the impact of the visual character of the waterfront

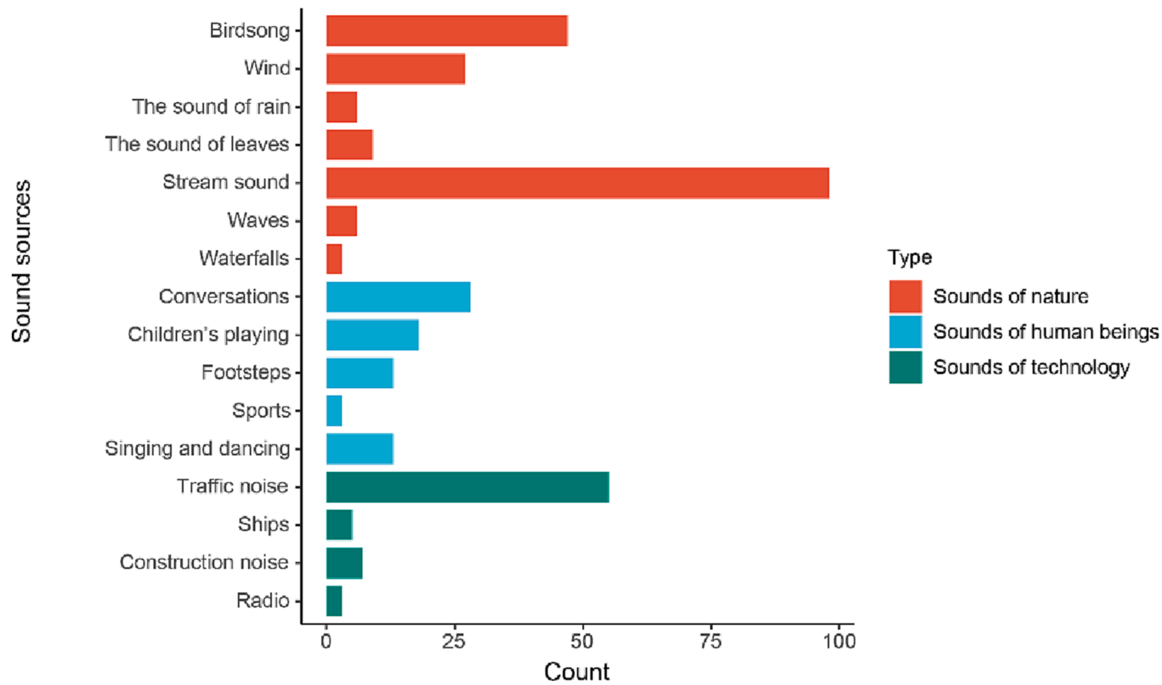


Fig. 2. Frequency statistics of perceptible sound sources in urban waterfront spaces.

environment on the quality of human recovery, security, and the overall experience?

(2) What impact does the inclusion of different sound sources in a waterfront high-rise environment have on the quality of human recovery, security, and overall experience?

(3) What impact do different personal characteristics have on the quality of human recovery, security, and overall experience?

2. Methods

This study investigates the relationships between four independent variables and three dependent variables (quality of recovery, security, and overall experience) by controlling for water span, number of distant building storeys, number of near-building storeys, and type of sound sources, as shown in Fig. 1. The subjective perception evaluation explores the impact of audio-visual interactions on people [37]. Therefore, the visual and audio-visual interaction aspects were simulated, resulting in 21 sets of visual-only scenes and 126 sets of audio-visual interaction scenes, adding up to 147 sets in total. The 147 sets were obtained by multiplying 21 sets of visual-only scenes by six sounds, the six sounds being obtained through a questionnaire on the perceived frequency of sound sources in urban waterfront spaces. These sets were used for the evaluation of the quality of recovery, security, and overall experience (comfort, satisfaction, and preference).

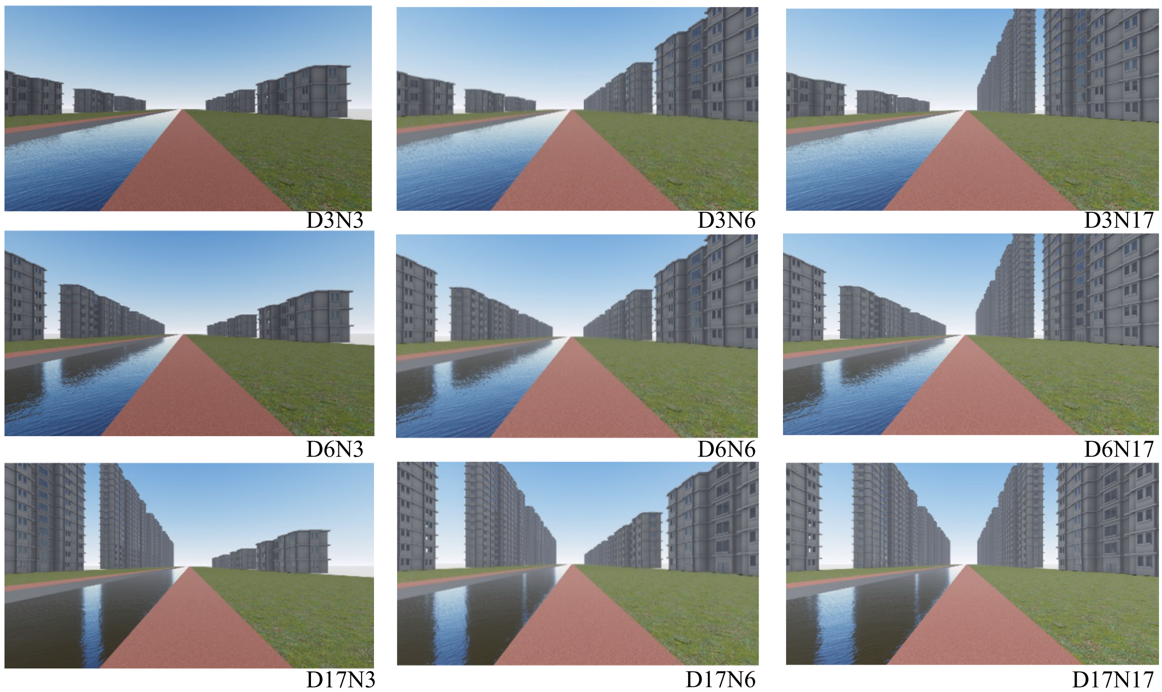
2.1. Visual data collection

The study simulates scenarios based on mean value data from three waterfront residental areas in Harbin, Wuhan, and Guangzhou, three typical cities located in northern, central, and southern China, respectively. The 3D models were downloaded from the 3D Warehouse website in Sketch Up 2018 and the form of the buildings was altered to make them fit the needs of the study [21,38–40]. There were no trees in front of the buildings. Tree density between 24% and 34% resulted in no change in stress recovery [41], and trees can shade the water span and thus affect the effectiveness of the water span for human resilience; therefore, no trees were added to this study.

In determining the water span. The water span refers to the distance from left to right of the water surface and is considered a geometric element that significantly impacts the river's relationship with the city. Urban water span dimensions heavily influence public perception, including concepts such as size, distance, visual contact, depth, reflection, attractiveness, and enclosure [42]. Water spans can be classified as small, medium, or large [43]. In 2004, Silva used four water spans (10, 50, 100, and 500 m) to investigate the relationship between water spans and the number of bridges [44]. Three water spans (10, 100, and 500 m) were chosen to represent different waterfront types of riverfront, lakefront, and coastal, respectively. The 500-m water span had only one side of close-view buildings in the simulated scenario, providing a simulation of the coastal environment.

Next, the number of building storeys was determined. The number of building storeys is based on the waterfront settlement buildings in different latitudes in the cities of Harbin, Wuhan, and Guangzhou in China (see appendix). The 27 urban waterfront residental areas in Harbin, Wuhan, and Guangzhou were measured in the field using a Trueyard SP1500H laser rangefinder. The buildings in the three areas were classified according to the indicators (GB-50352–2005 General Principles of Civil Building Design) for low-rise (1–3 storeys), multi-storey (4–6 storeys) and high-rise (14–18 storeys). The average number of storeys in the building after classification is 3 levels: 3 storeys (9 m), 6 storeys (18 m), and 17 storeys (51 m) respectively. In our experiments, there are three levels for the number of building stories: low, medium, and high (3, 6 and 17 stories).

To determine the constant parameters, the building widths are divided into 21 m (low storey), 50 m (multi storey), and 55 m (high storey) according to the average widths between low storey, multi storey, and high storey in each of the three cities. The distances between buildings are divided into 14 m (low storey), 13 m (multi storey), and 20 m (high storey) according to the average spacing between low storey, multi storey, and high storey in each of the three cities. The vertical distance between the buildings and the waterfront edge is based on the average distance of 25 m in the three cities as a constant value. Trail widths and colours questionnaire were completed by 220 participators (48.20% male, 51.80% female; 67.7% aged 18–25) from 15th to 18th October 2021. The trail widths results were 1 m (12.7%), 2 m (23.8%), 3 m (28.3%), 4 m (17.8%), 5 m (9.9%), 6 m (6.0%), and other (1.5%). The



（a）Riverfront built environment

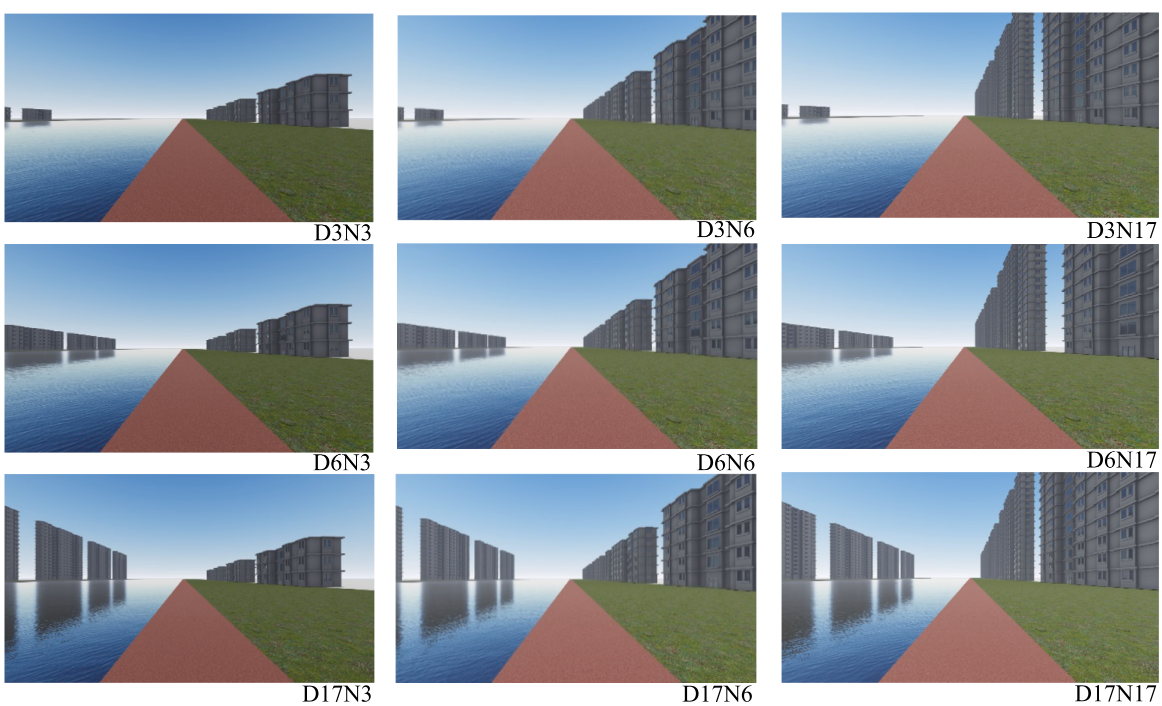


Fig. 3. Variation in the number of floors (3, 6, 17) of buildings in the distant and close view at 10 m, 100 m, and 500 m water spans. (D: Number of stories in the distance to the left; N: Number of stories close to the right).

trail colour results included brick red (28.4%), green (21.6%), blue (17.5%), yellow (13.8%), orange (2.8%), and other colours (3.7%). Therefore, 3 m and brick red were used as the width and colour of the trail simulation, respectively.

2.2. Auditory data collection

According to ISO/TS12913-2, the definition of sound sources is provided. The investigated acoustic environment should be characterized by the identification of audible sound sources and their relative dominance. In general, sound sources can be split into three categories: natural sounds, human sounds, and technological sounds [45]. From the 15th to the 18th of October 2021, 227 surveys (online questionnaires) on the perceived frequency of sound sources in urban waterfront settings were given in order to ascertain the type of sound in the experiment. “What sound sources are commonly audible in the urban waterfront constructed environment?”. We have chosen the two most common instances of each sound source for six sounds. The （b）Lakefront built environment

（c）Coastal built environment

Fig. 3. (*continued*).

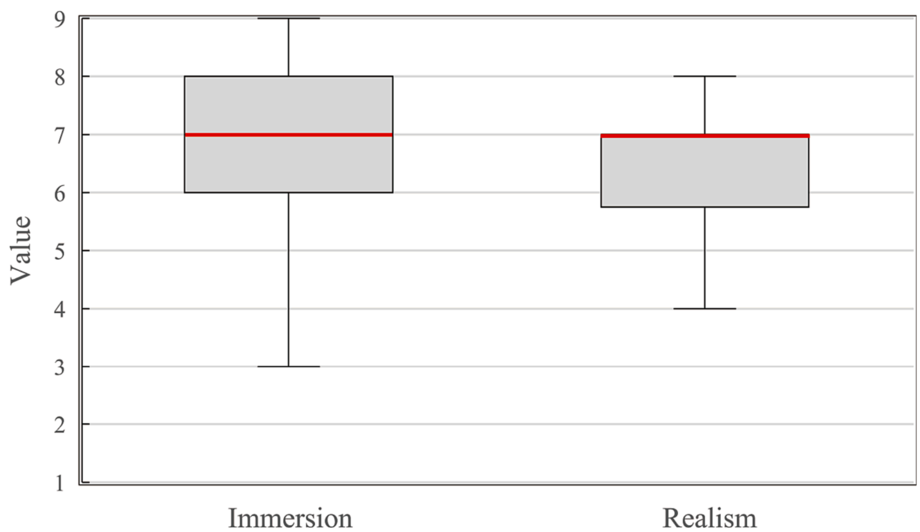


Fig. 4. Scores for immersion and realism.

following is a pre-experiment for sound source data frequency acquisition.

(1) The selection of sound stimuli was based on the outcomes of a web-based questionnaire, which was distributed online to citizens with experience of living in urban waterfront spaces, resulting in the collection of a wide range of sound sources that people often hear. The two most frequently perceived sound sources (sounds of nature, human beings, and technology) were selected for the laboratory test (Fig. 2). In order to determine the type of sound in the experiment, 227 surveys (online questionnaires) on the perceived frequency of sound sources in urban waterfront spaces were distributed from 15th to 18th October 2021. In total, 214 valid questionnaires were distributed, with an effectiveness rate of 94.27%, after 13 invalid questionnaires were eliminated (52.80% of males and 47.20% of females, mean age 32.87 years, standard deviation 13.20). Among the 214 questionnaires, the age distribution was mainly between 20 and 30 years old, accounting for about 50%. Overall, 21 sounds were reflected in the questionnaires. As shown in Fig. 2, stream sounds, birdsong, conversations, children's playing, traffic noise, and construction noise are the most commonly perceived sounds among the natural, human, and technology sound sources in the urban waterfront space.

(2) In order to verify that the captured sound is accurate, the equipment and procedures are based on the findings of earlier research. Using a calibrated BSWA 801 sound level meter situated 1.5 m above the ground, field recordings were made [46,47]. The measurement indicator was constant equivalent sound level (LAeq). During the measuring time, there was no precipitation or lightning, and the wind speed was<5 m/s.

(3) Participants uniformly wore VR headsets (A7110 Pico Neo) and open-type headphones (HD660S, Sennheiser) in a semi-anechoic laboratory for the audiovisual tests (Fig. 5). Consequently, our experiment avoids the limitations of online listening tests.

2.3. VR environment simulation

The study used 3D computer modelling software (version 2018 Sketchup and Lumion 10.3.2). The study was conducted from the Sketchup 3D Warehouse under the category 'buildings' using the search term 'residents building' in 'MODELS'. The date of the simulation scenarios was on 21st June 2021 and the sun was directly overhead at 12:00 pm [40]. The realistic brick red trail # b07c77 (R:176; G:124; B119) was absorbed using colour absorbers in Adobe Photoshop CC 2017, the trail material was shaded to 0.0 in Lumion 10.3.2, and the reflectance of both the trail and the green area was set at 0.0 to reduce the difference between groups. Based on field research, the site between the building and the trail was set as a green area, and Landscape 08B 2D grass was selected as the green area between the building and the trail from the options in the Lumion 10.3.2 material library. The water surface material is the software's own material (water surface name: Reflecting Lake).

In this experiment, as depicted in Fig. 3 of the text, there were 21 visual-only scenes, and the addition of six sounds produced 126 scenarios (21 * 6). This experiment consisted of a total of 147 scenes (21 + 21*6), including 21 visual-only sequences and 126 audio-visual scenes. The actual observations revealed that the buildings on either side of the

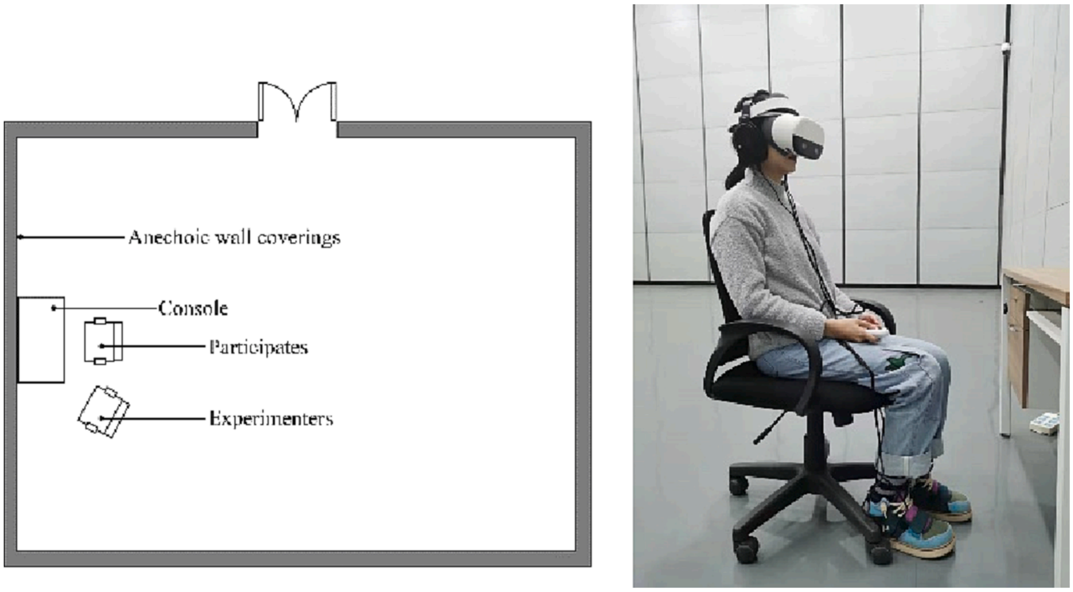


Fig. 5. Laboratory layout and site photos.

Table 1
Subjective evaluation scale of the experiment.

Measurement	Variable	Description	Scales
SRRS (Short-version revised restoration scale)	Emotional	Good natured	1 2 3 4 5 6 7 8 9 Totally disagree Totally agree
		Relaxed	1 2 3 4 5 6 7 8 9 Totally disagree Totally agree
	Physiological	My breathing is becoming faster	1 2 3 4 5 6 7 8 9 Totally disagree Totally agree
		My hands are sweating	1 2 3 4 5 6 7 8 9 Totally disagree Totally agree
	Cognitive	I am interested in the presented scene	1 2 3 4 5 6 7 8 9 Totally disagree Totally agree
		I feel attentive to the presented scene	1 2 3 4 5 6 7 8 9 Totally disagree Totally agree
	Behaviour	I would like to visit here more often	1 2 3 4 5 6 7 8 9 Totally disagree Totally agree
		I would like to stay here longer	1 2 3 4 5 6 7 8 9 Totally disagree Totally agree
Security	Security	Please rate your sense of safety in your current location	1 2 3 4 5 6 7 8 9 Minimum Maximum
Overall experience	Comfort	Do you feel at ease in the current environment?	1 2 3 4 5 6 7 8 9 Very uncomfortable Very comfortable
	Satisfaction	Are you satisfied with your current environment?	1 2 3 4 5 6 7 8 9 Very dissatisfied Very satisfied
	Preference	How much do you like your current environment?	1 2 3 4 5 6 7 8 9 Very unlike Very much like

water surface were visible in the riverfront and lakefront scenarios, and the building heights of the first row of building simulation scenarios (riverfront and lakefront) on either side differed. Therefore, the number of building levels on either side of the water surface span varied between the two scenarios of 10 m and 100 m, and the study referred to the buildings on the left side as the distant view and the buildings on the right side as the nearby view. Fig. 3 shows the virtual model view that was presented to the participants. The experimental simulation scenario is intended to prevent other ambient variables from influencing the study outcomes. In this exploratory phase of our experiment, we decided to employ only "schematic" computer-generated images (made with AutoCAD) as stimuli because, according to the literature, tall structures differ in more dimensions than height (e.g., shape, spatial structure, ornamentation). This design was used in order to control for potential historical or ideological variables and to isolate the emotional and behavioral effects of height alone [39]. Moreover, visual information such as color, architectural style, and degree of congestion in photos will impact the subjective attitude responses toward street scales [48]. Consequently, only the required water spans, building stories, paths, and green space variables are included in the scenarios.

Before beginning the experiment, it was necessary to examine the immersion and realism of the audio-visual scenes to ensure the validity of the experimental environment [49]. This was evaluated by means of two questions: (1) 'Immersion in these audio-visual scenes' was evaluated on a 9-point linear scale ranging from '1 = Completely disagree' to '9 = Completely agree'. (2) 'These audio-visual scenes give you a realistic experience' was evaluated using a 9-point linear scale ranging from '1 = Completely disagree' to '9 = Completely agree'. As depicted in Fig. 4, the median immersion and authenticity score is approximately 7.

2.4. Questionnaire

We used the questionnaire method in the lab, presented in terms of quality of recovery (short-version revised restoration scale) [50], security [51], and overall experience (comfort [29], satisfaction [29], and preference [32]) ratings. All scales are nine-level scales as shown in Table 1.

The short version of the modified recovery scale (SRRS) created by Han [52] was used to assess the restorative potential of the environment, consisting of eight items equally distributed across four dimensions: emotional, cognitive, physical, and behavioural (Table 1). Respondents responded on a 9-point Likert scale to indicate their level of agreement with the items, ranging from 1 for 'totally disagree' to 9 for 'totally agree'. Because this category measures physiological arousal, which is the opposite of a rehabilitative state, it was decided to reverse the composite score for physiological reactions. The video and audio-visual combination's restorative quality alone was used to calculate the mean

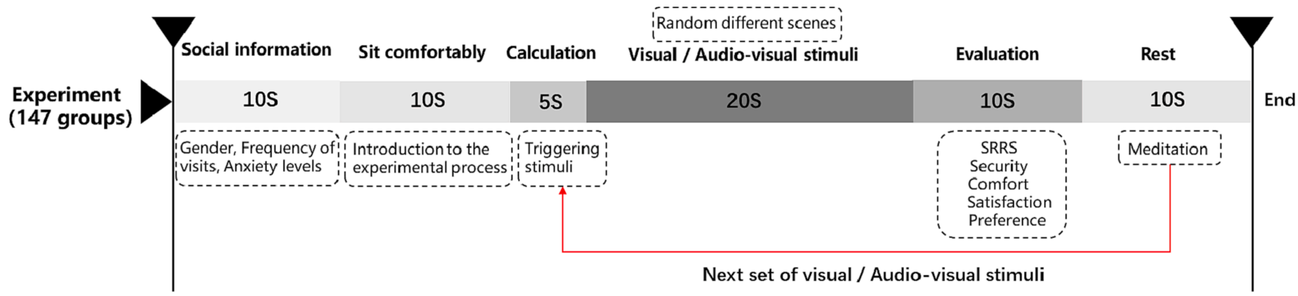


Fig. 6. Experimental flow.

Table 2
Kruskal-Wallis examined differences in water span quality, safety, comfort, contentment, and preference. Significant differences are marked with * ($p < 0.05$) and ** ($p < 0.01$). 1: 10 m, 2: 100 m, 3: 500 m.

Waterfront types	Indicators (Sig.)				
	Short Version Revised Recovery Scale (SRRS)	Security	Comfort	Satisfaction	Preference
Water span (1 vs. 2 vs. 3)	0.978	0.030*	0.346	0.765	0.928
Post-hoc tests		1 > 3			

Table 3
Spearman's rho correlation of each indicator with water span, excluding sound conditions. Significant correlations are marked with* ($p < 0.05$) and ** ($p < 0.01$).

	Short Version Revised Recovery Scale (SRRS)	Security	Comfort	Satisfaction	Preference
Water span	0.006	**−0.080****	0.032	0.008	0.009

Table 4
Kruskal-Wallis test for differences in quality of restoration, perception of security and overall perception of experience between waterfront types in the number of storeys of nearby buildings. Significant differences are marked with * ($p < 0.05$) and ** ($p < 0.01$). 1: 3 storeys, 2: 6 storeys, 3: 17 storeys.

Waterfront types	Indicators (Sig.)				
	Short Version Revised Recovery Scale (SRRS)	Security	Comfort	Satisfaction	Preference
10 m (1 vs. 2 vs. 3)	0.006**	0.242	0.002**	0.003**	0.010**
Post-hoc tests	1 > 3		1 > 3 2 > 3	1 > 3	1 > 3
100 m (1 vs. 2 vs. 3)	0.040*	0.046*	0.003**	0.005**	0.004**
Post-hoc tests	1 > 3		1 > 3	1 > 3	1 > 3
500 m (1 vs. 2 vs. 3)	0.005**	0.005**	0.002**	0.001**	0.001**
Post-hoc tests	1 > 3 2 > 3	1 > 3 2 > 3	1 > 3 2 > 3	1 > 3 2 > 3	1 > 3 2 > 3

of the eight indicators [52].

The other questions included Feeling Security [53], 'Please rate your sense of safety in your current location.' (1 = Minimum, 9 = Maximum); Comfort [54], 'Do you feel at ease in the current environment?' (1 = Very uncomfortable, 9 = Very comfortable); Satisfaction [54], 'Are you satisfied with your current environment?' (1 = Very dissatisfied, 9 = Very satisfied). In this experiment, for comparison purposes, the study also included the commonly used criterion variable 'Preference'. Preference was defined as follows: 'How much do you like your current environment?' (1 = Very much dislike, 9 = Very much like), and 'You do not need to worry about being right or wrong or if you share others' opinions because this is your level of preference for the environment' [55]. Preference the common criterion variable was included.

2.5. Procedure

G*Power 3.1 was used to estimate the sample size and was calculated based on the expected medium effect size of f = 0.3, α = 0.05 and 1-β = 0.80, which showed that a total of 35 participants were needed, with an actual power of at least 0.8. Fifty undergraduate and graduate students between the ages of 18 and 26 from the School of Architecture at Harbin Institute of Technology took part in this experiment (25 females, 25 males; M = 23.56 years, SD = 2.13). All individuals reported normal hearing and were not taking psychiatric medications. They wore loose, comfortable attire and did not engage in hard exercise or experience substantial exhaustion in the preceding two hours. Before the trial, participants were requested not to consume alcohol or caffeine for 12 h [37].

In the semi-anechoic chamber at the Second Campus of Harbin Institute of Technology (Fig. 5), 50 individuals participated in an audio-visual test involving 21 waterfront built environments and 6 sound sources commonly found in urban waterfront spaces. The test was conducted in a semi-anechoic chamber with a background noise of 25 dBA, which effectively prevented excessive background noise from adversely affecting the experimental results [50,56]. The experiments included only model scenarios for the subjective evaluation of video and audio-visual interactions [57], and the experimental procedure is displayed in Fig. 6. In virtual reality audio-visual interaction investigations, VR headgear and open-type headphones are typically used [56,58]. Therefore, we utilized VR headsets (A7110 Pico Neo) to generate visual scenarios. (Display 2 × 3.5″ LCD screens. Resolution: 2880*1600. Refresh rate: 90 Hz); In the laboratory, we employed open-type headphones (HD660S, Sennheiser) to provide auditory data. (Impedance: 150 Ω. Sensitivity: 104 dB/mW. Frequency response range: 10–41500 Hz). The participants were seated comfortably [37] and were asked to scan a QR code using their mobile phones to access the questionnaire. They filled in their social information, including gender, frequency of visits, and anxiety level, while the researcher explained the experimental procedure to the participants. Participants were asked, "How frequently do you visit the outside environment of urban waterfront communities?". The options were "never, less than once a month, 2–3 times a month, 1–4 times a week, every day". Since the personal

Table 5
Spearman's rho correlation of each indicator with the number of near-view building storeys at different water spans, excluding sound conditions. Significant correlations are marked with* ($p < 0.05$) and ** ($p < 0.01$).

	Short Version Revised Recovery Scale (SRRS)	Security	Comfort	Satisfaction	Preference
Water span 10 m nearby building storeys	**−0.149****	−0.061	**−0.151****	**−0.159****	**−0.142****
Water span 100 m nearby building storeys	**−0.114****	**−0.093***	**−0.159****	**−0.154****	**−0.155****
Water span 500 m nearby building storeys	**−0.250****	**−0.253****	**−0.281****	**−0.289****	**−0.287****

Table 6
Kruskal-Wallis test for differences in quality of restoration, perception of security and overall perception of experience between waterfront types in the number of storeys of distant buildings. Significant differences are marked with * ($p < 0.05$) and ** ($p < 0.01$). 1: 3 storeys, 2: 6 storeys, 3: 17 storeys.

Waterfront types	Indicators (Sig.)				
	Short Version Revised Recovery Scale (SRRS)	Security	Comfort	Satisfaction	Preference
10 m (1 vs. 2 vs. 3)	0.004**	0.000**	0.002**	0.001**	0.001**
Post-hoc tests	1 > 3 2 > 3	1 > 3 2 > 3	1 > 3 2 > 3	1 > 3 2 > 3	1 > 3 2 > 3
100 m (1 vs. 2 vs. 3)	0.492	0.004**	0.802	0.506	0.316
Post-hoc tests		3 > 2			

experience of frequency of visits may influence the ranking of the indication, we have included the personal experience of how frequently you visit the waterfront [9,59]. A two-digit multiplication of mental arithmetic was used for active stressors before the questionnaire was filled out [60–62]. Then, the test was administered, with the subjects taking a 10-second break after testing one set of stimuli and moving on to the next stimulus [32]. We assign each scene a serial number in Excel and then generate a new order using randomization. The sequence of the 21 visual scenes was disrupted and composited using the video editing software PR (Adobe Premiere Pro 2020) [57,63], and then the scenes under each sound were randomly merged to produce the entire experimental movie, thereby eliminating the order factor [37,64]. The sound sources were played and looped at 65 dBA in an A-weighted equivalent continuous sound level (LAeq) [65,66]. To investigate the acoustic features, we computed percentile SPL values, including LA10, LA50, and LA90 [34]. We utilized a BSWA 801 sound level meter to record various sound sources on a workday (9 am to 5 pm) with a measurement interval of 5 min, which was sufficient compared to the recommended measurement interval of 3 min [67]. Sound level values at 10%, 50% and 90% (LA10, LA50 and LA90) are recorded directly by the BSWA801 sound level meter [68]. And adding the time-domain variation (LA10, LA50, LA90) computations to the sample selection, and when these values reached a more consistent uniformity, we randomly picked these segments as the subjects of the sample to prevent too many blanks from interfering with the test's correctness. The recorded ambient auditory environment is played through headphones with open-type earcups (SENNHEISER HD660S). A head and torso simulator (Brüel & Kjr 4128-C-002) was utilized to record the stereophonic sound played on headphones for sound-pressure calibration [56,58]. Adobe Audition (version 2020, Adobe) was then used to modify SPL so that the sounds were similar to 65dBA [56,64]. As depicted in Fig. 5, participants required roughly 45 s to evaluate a scene (red arrowed segment) and completed around 40 sets in 30 min [32,37]. Therefore, we decided to have participants visit four times over the course of 10 days and execute the experiment once every 2–3 days. Studies have shown that an exposure time of 20 s for video and audio is sufficient [37].

2.6. Data statistics and analysis

The data were processed using SPSS 25.0. The main statistical methods were Kruskal-Wallis independent sample non-parametric analysis and Spearman rho correlation analysis, Wilcoxon signed rank test and Mann Whitney *U* test. In section 3.1, the effects of changes in water span and the number of building storeys (nearby and distant) on human recovery quality, security, comfort, satisfaction, and preference are discussed. Section 3.2 covers how the inclusion of different sound sources in a nearby of high-rise building environment would change human recovery quality, security, and overall experience (comfort, satisfaction, and preference). Section 3.3 discusses the effects of different personal characteristics (gender, frequency of visitation, anxiety level) on the quality of recovery, perception of security, and overall experience.

3. Results

3.1. Effects of visual environment changes (water span and building storeys) on the quality of human recovery, security, and overall experience (comfort, satisfaction, and preference)

3.1.1. Changes in water span

Table 2 displays the results of a Kruskal-Wallis independent sample nonparametric test to determine the relevance of water span on variations in recovery quality, security, comfort, contentment, and preference. Human evaluations of security were significantly influenced by water span. This may be because, under silent conditions, the human

Table 8
Pearson correlation coefficient between comfort, satisfaction, and preference (2-tailed). Significant associations are highlighted by *(p < 0.05) and **(p < 0.01).

	Comfort	Satisfaction	Preference
Comfort	1		
Satisfaction	0.951**	1	
Preference	0.946**	0.960**	1

Table 7
Correlation of each indicator with the number of distant building storeys at different water spans under the exclusion of sound condition. Significant correlations are marked with* ($p < 0.05$) and ** ($p < 0.01$).

	Short Version Revised Recovery Scale (SRRS)	Security	Comfort	Satisfaction	Preference
Water span 10 m distant building storeys	**−0.122****	**−0.124****	**−0.130****	**−0.139****	**−0.132****
Water span 100 m distant building storeys	0.002	**0.108***	0.021	0.005	0.010

Note: At a water span of 500 m (approximate coastal environment), there are only nearby buildings in the simulated scenario and no distant buildings are visible, so visual scenarios with a water span of 500 m distant building levels have not been discussed.

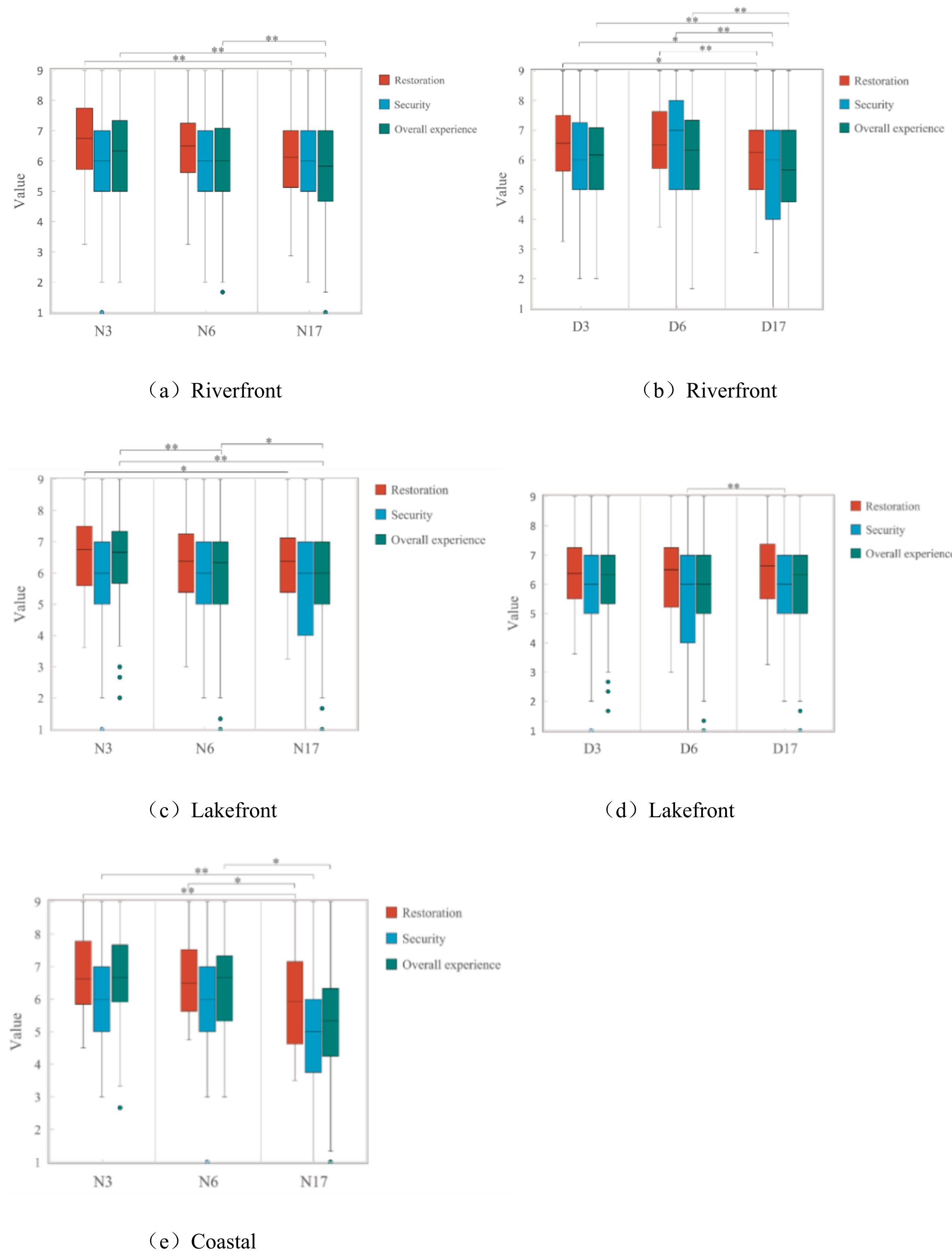


Fig. 7. Variations in indicators for different waterfront buildings under visual circumstances (N3: Nearby building 3 storeys; D3: Distant building 3storeys).

Table 9
Results of Wilcoxon signed-rank test between visual-only conditions and audio-visual conditions in riverfront. *$p < 05$. **$p < 01$. ***$p < 001$.

Indicators	Scenario (audio condition)	Statistics (Z)	p
Short Version Revised Recovery Scale (SRRS)	Stream sound	1.549	0.121
	Birdsong	6.273	0.000***
	Conversations	8.666	0.000***
	Children's playing	1.378	0.168
	Traffic noise	9.655	0.000***
	Construction noise	10.249	0.000***
Security	Stream sound	1.076	0.282
	Birdsong	4.968	0.000***
	Conversations	6.018	0.000***
	Children's playing	1.700	0.089
	Traffic noise	8.344	0.000***
	Construction noise	8.385	0.000***
Overall experience	Stream sound	3.825	0.000***
	Birdsong	9.704	0.000***
	Conversations	13.969	0.000***
	Children's playing	1.889	0.059
	Traffic noise	15.432	0.000***
	Construction noise	16.800	0.000***

impression of safety is vulnerable to the effects of water span. We found that people feel significantly more secure when they are on the riverfront than on the coast.

As demonstrated in Table 3, Spearman's rho correlation analysis of the water span with each indicator can further illustrate their link. The findings revealed a substantial negative link between water span and safety ($p < 0.01$), regardless of the number of nearby and distant building stories, indicating that in urban waterfront environments, there is a very weak negative link between water span and human experience of security (correlation coefficient = 0.08), with the perception of security somewhat diminishing with increasing water span. On a 9-point Likert scale, perceptions of security are ranked from highest to lowest as riverfront environment (5.98), lakefront environment (5.79) and coastal environment (5.56). There was no correlation discovered between water span and quality of recovery or overall experience (comfort, satisfaction, and preference).

3.1.2. Changes in the building storeys

(1) Nearby building storeys: Kruskal-Wallis independent sample non-parametric analysis was used to test the significance of differences in the nearby buildings and recovery quality, perception of security, comfort, satisfaction and preference, as shown in Table 4. The number of nearby building storeys has a significant effect on the quality of human recovery, perception of safety, comfort, satisfaction and preference under different waterfront types (except for the riverfront where the number of near-view building levels has no significant effect on the perception of human safety). In most cases, the near-view low-rise building indicator is rated significantly higher than the near-view high-rise building.

Spearman's rho correlation analysis of the number of storeys in the nearby building with each indicator can further illustrate their relationship, as shown in Table 5. The results were as follows:

At a water span of 10 m (the riverfront environment), there was a significant negative correlation ($p < 0.01$) between the number of near-view building storeys and the quality of recovery and overall experience (comfort, satisfaction, and preference), regardless of the number of distant building storeys. This means that the higher the number of near-view building storeys, the lower the quality of recovery and overall experience (comfort, satisfaction, preference) ratings of people. However, the number of near-view building storeys did not affect people's perception of security. Therefore, the lower the number of storeys in the range of 3–6 storeys in the near-view building, the better the quality of human recovery and the sense of overall experience.

At a water span of 100 m (the lakefront environment), there was a significant negative correlation between the number of near-view building storeys and the quality of recovery ($p < 0.01$), security ($p < 0.05$), comfort ($p < 0.01$), satisfaction ($p < 0.01$), and preference ($p < 0.01$), regardless of the change in the number of distant building storeys. This indicates that the higher the number of near-view building storeys in the lakefront environment, the lower the human ratings of quality of recovery, security, and overall experience (comfort, satisfaction, and preference). Therefore, the lower the number of storeys in the range of 3–6 storeys in the near-view building, the better the quality of human recovery and the sense of overall experience.

At a water span of 500 m (the coast environment), there was a significant negative correlation ($p < 0.01$) between the near-view building storeys and the quality of recovery, security, and overall experience (comfort, satisfaction, and preference). In the coastal environment, the higher the number of near-view building storeys the lower the ratings of recovery quality, security, and overall experience (comfort, satisfaction, and preference) of people. Therefore, the lower the number of storeys in the range of 3–6 storeys in the near-view building, the better the quality of human recovery and the sense of overall experience.

(2) Distant building storeys: Kruskal-Wallis independent sample non-

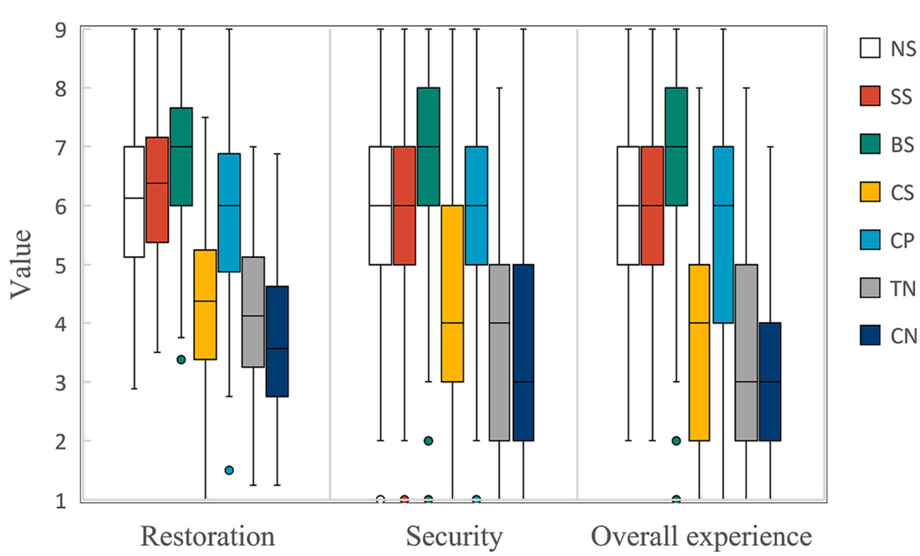


Fig. 8. Comparison of scores between no sound and single sound source in the nearby high-rise environment of riverfront (NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise).

Table 10
Kruskal-Wallis independent sample nonparametric analysis for variations in the quality of restoration, the impression of security, and overall perception of experience between the riverfront and surrounding high-rise environment sound sources. Significant distinctions are denoted by* ($p < 0.05$) and ** ($p < 0.01$), and *** ($p < 0.001$).

Sound sources	Indicators (Sig.)		
	Short Version Revised Recovery Scale (SRRS)	Security	Overall experience
SS-BS	0.164	0.081	0.002**
SS-CS	0.000***	0.000***	0.000***
SS-CP	0.005**	1.000	0.001**
SS-TN	0.000***	0.000***	0.000***
SS-CN	0.000***	0.000***	0.000***
BS-CS	0.000***	0.000***	0.000***
BS-CP	0.000***	0.251	0.000***
BS-TN	0.000***	0.000***	0.000***
BS-CN	0.000***	0.000***	0.000***
CS-CP	0.000***	0.000***	0.000***
CS-TN	1.000	0.469	1.000
CS-CN	0.020*	0.003**	0.000***
CP-TN	0.000***	0.000***	0.000***
CP-CN	0.000***	0.000***	0.000***
TN-CN	0.439	1.000	0.001**

(NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise).

parametric analysis was used to test the significance of differences in the distant buildings and recovery quality, perception of security, comfort, satisfaction and preference, as shown in Table 6. In the riverfront environment, the number of distant building storeys has a significant effect on the quality of human recovery, perception of security, comfort, satisfaction and preference. The Vision Low Rise indicator scores significantly higher than the Vision High Rise. In the lakefront environment, the number of distant building storeys has a significant effect on the perception of human security, and does not affect human recovery quality, comfort, satisfaction or preference. The perception of safety is rated significantly higher for visionary high-rise buildings than for visionary multi-storey buildings.

Spearman's rho correlation analysis of the number of storeys in the distant building with each indicator can further illustrate their relationship, as shown in Table 7. The results were as follows:

At a water span of 10 m (the riverfront environment), there was a significant negative correlation ($p < 0.01$) between the number of levels of the distant building and the quality of recovery, security, and overall experience (comfort, satisfaction, preference), regardless of the number of levels of the nearby building. This means that the higher the number of levels of the distant building in the riverfront environment, the lower the quality of recovery, security, and overall experience (comfort, satisfaction, and preference). However, in the range of 3–6 storeys in the distant building, the higher the number of storeys, the better the quality of recovery, security, and overall experience. Beyond 6 storeys, the quality of recovery, security, and the overall experience for people decreased sharply.

At a water span of 100 m (the lakefront environment), there was a significant positive correlation ($p < 0.05$) between the number of distant building storeys and the perception of security, regardless of the change in the number of near-view building storeys. This indicates that the security of being in the lakefront-built environment did not decrease with the increase in the number of building storeys and that the higher the number of distant building storeys was beneficial to one's perception of security. However, the effect on the quality of recovery and the sense of

Table 11
Results of Wilcoxon signed-rank test between visual-only conditions and audio-visual conditions in lakefront. *$p < 05$. **$p < 01$. ***$p < 001$.

Indicators	Scenario (audio condition)	Statistics (Z)	*p*
Short Version Revised Recovery Scale (SRRS)	Stream sound	2.000	0.045*
	Birdsong	5.745	0.000***
	Conversations	9.043	0.000***
	Children's playing	3.724	0.000***
	Traffic noise	9.785	0.000***
	Construction noise	10.309	0.000***
Security	Stream sound	0.963	0.336
	Birdsong	4.834	0.000***
	Conversations	6.152	0.000***
	Children's playing	0.802	0.423
	Traffic noise	8.081	0.000***
	Construction noise	9.060	0.000***
Overall experience	Stream sound	4.829	0.000***
	Birdsong	9.713	0.000***
	Conversations	14.632	0.000***
	Children's playing	4.293	0.000***
	Traffic noise	15.618	0.000***
	Construction noise	16.793	0.000***

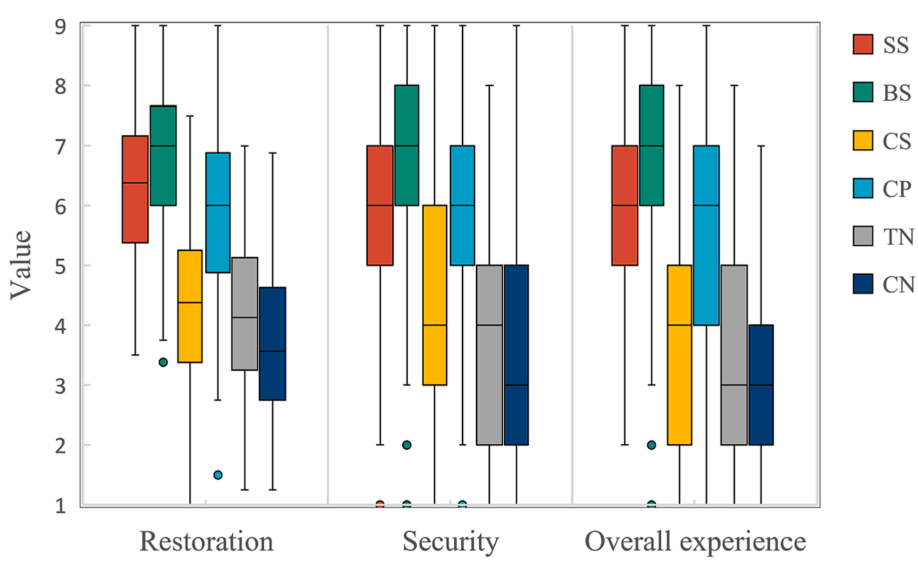


Fig. 9. Comparison of sound levels from a single source in the nearby riverfront high-rise area. (NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise).

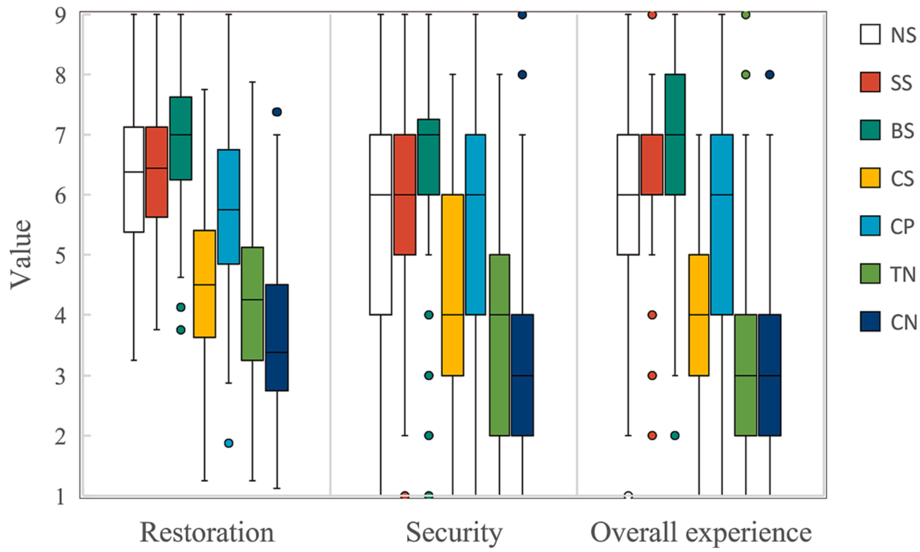


Fig. 10. Comparison of scores between no sound and single sound source in the nearby high-rise environment of lakefront. (NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise).

Table 12
Kruskal-Wallis independent sample nonparametric study evaluating variations in the quality of restoration, perception of security, and overall perception of experience between the lakefront and nearby high-rise sound sources. Significant differences are marked with * ($p < 0.05$) and ** ($p < 0.01$), and *** ($p < 0.001$).

Sound sources	Indicators (Sig.)		
	Short Version Revised Recovery Scale (SRRS)	Security	Overall experience
SS-BS	0.298	0.094	0.010*
SS-CS	0.000***	0.000***	0.000***
SS-CP	0.002**	1.000	0.000***
SS-TN	0.000***	0.000***	0.000***
SS-CN	0.000***	0.000***	0.000***
BS-CS	0.000***	0.000***	0.000***
BS-CP	0.000***	0.001**	0.000***
BS-TN	0.000***	0.000***	0.000***
BS-CN	0.000***	0.000***	0.000***
CS-CP	0.000***	0.000***	0.000***
CS-TN	1.000	0.062	0.026*
CS-CN	0.001**	0.000***	0.000***
CP-TN	0.000***	0.000***	0.000***
CP-CN	0.000***	0.000***	0.000***
TN-CN	0.182	0.869	0.001**

(NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise).

experience (comfort, satisfaction, and preference) is not significant (Fig. 6). Therefore, the higher the number of storeys in the range of 6–17 storeys in a distant building, the better the rating of people's perception of security.

Significant connections between the comfort, satisfaction, and preference measures (Table 8). In subsequent parts, therefore, comfort, satisfaction, and preference are merged into one overall experience assessment to assist analysis.

Fig. 7 depicts the median values of restoration quality, the impression of security, and the overall experience for different building floors along the coastline. In all waterfront environments, there is a minor difference between low-rise and multi-story buildings (3–6 stories), while high-rise buildings (17 stories) are the worst. On the opposite side of the lake, tall buildings enhance a person's feeling of safety. This is comparable to the findings of Zarghami et al., where building height had a greater impact on people's perception of pressure than building breadth, although water's effect was not included in his study [21]. Moreover, Li Lin et al., demonstrated that in a lakefront environment, taller buildings induce lower pleasantness and higher arousal levels, with lower pleasantness and higher arousal levels implying a sense of pressure. However, his study scenario was a vertical view of buildings on the opposite shore using lake sight distance as a criterion [5]. This study varies from those that came before it in that this finding was achieved from a dynamic pedestrian standpoint.

3.2. Effects of sound environment changes (sounds of nature, human beings, and technology) on the quality of human recovery, security, and overall experience (comfort, satisfaction, and preference)

From 3.1.2, with the rise in the number of buildings with nearer views in the waterfront area, the levels of human recovery quality, security, and overall experience (comfort, satisfaction, preference) decreased. In particular, the 17th floor of the nearby building had the greatest negative visual impact on people. Further research and analysis are needed to clarify the impact of the inclusion of sound in a waterfront nearby high-rise environment on the quality of human recovery, the sense of security, and the overall experience.

3.2.1. Adding sounds to the riverfront high-rise environment

As shown in Table 9 and Fig. 8, the addition of birdsong significantly ($p < 0.001$) improved the quality of recovery, security, and overall experience (comfort, satisfaction, and preference) when compared to no sound in a riverfront high-rise building environment by the Wilcoxon signed rank test. However, adding the sounds of conversations, traffic noise, and construction noise significantly reduced the quality of recovery, security, and overall experience (comfort, satisfaction, and preference) ($p < 0.001$). Additionally, the addition of stream sound had little to no impact on the degree of restoration or the feeling of security, except to significantly enhancing the overall experience of the person ($p < 0.001$).

We used Kruskal-Wallis independent sample nonparametric analysis to further compare the ratings across the various sources. As depicted in Table 10 and Fig. 9, there is no substantial difference between stream sound and bird-song in terms of recovery quality. The recovery quality of the sounds of the stream and birds was substantially higher than that of the sounds of humans and machines. The recuperation quality of children's play is much superior to that of traffic and construction noise;

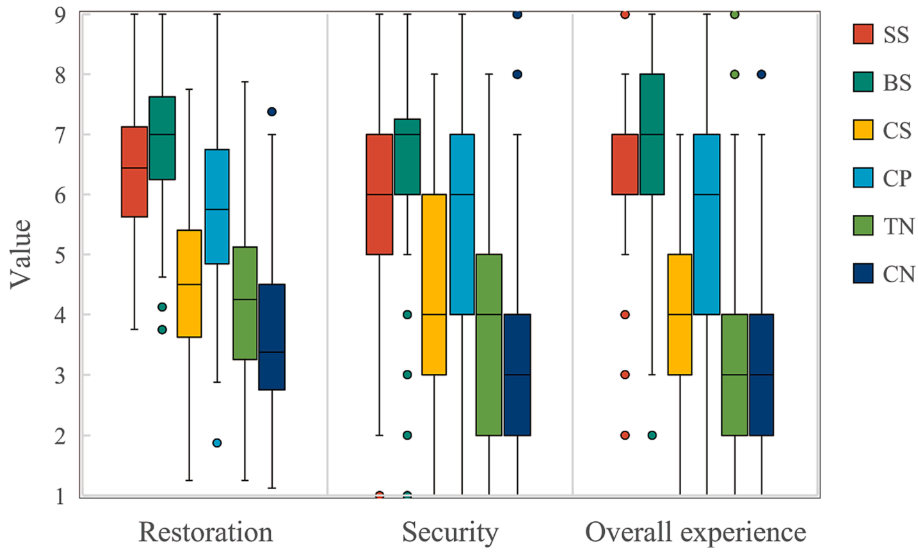


Fig. 11. Comparison of scores between the single sound sources in the nearby high-rise environment of the lakefront. (NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise).

Table 13
Results of Wilcoxon signed-rank test between visual-only conditions and audio-visual conditions in coastal. *$p < 05$. **$p < 01$. ***$p < 001$.

Indicators	Scenario (audio condition)	Statistics (Z)	p
Short Version Revised Recovery Scale (SRRS)	Stream sound	2.237	0.025*
	Birdsong	3.787	0.000***
	Conversations	4.981	0.000***
	Children's playing	1.216	0.224
	Traffic noise	5.263	0.000***
	Construction noise	5.764	0.000***
Security	Stream sound	1.531	0.126
	Birdsong	3.262	0.001**
	Conversations	1.476	0.140
	Children's playing	0.664	0.506
	Traffic noise	3.964	0.000***
	Construction noise	4.404	0.000***
Overall experience	Stream sound	3.939	0.000***
	Birdsong	5.977	0.000***
	Conversations	6.871	0.000***
	Children's playing	1.187	0.235
	Traffic noise	8.293	0.000***
	Construction noise	9.402	0.000***

There is no significant difference between the stream sound and bird song in terms of perception of security; There is no significant difference between the sound of children playing and the sound of nature, suggesting that the sound of children playing in an urban riverfront environment close to high-rise buildings can create a sense of security. There is a substantial difference between the stream sound and bird-song in terms of the overall experience, indicating that the overall experience of the stream sound is inferior to that of the bird-song in the urban waterfront area near high-rise buildings.

3.2.2. Adding sound to the lakefront high-rise environment

As shown in Table 11 and Fig. 10, the addition of birdsong significantly ($p < 0.001$) improved the quality of recovery, security, and overall experience (comfort, satisfaction, preference) when compared to no sound in a lakefront high-rise building environment by the Wilcoxon signed rank test. However, adding the sounds of conversations, traffic noise, and construction noise significantly reduced the quality of recovery, security, and overall experience (comfort, satisfaction, and preference) ($p < 0.001$). Adding the sound of children playing while at the lake significantly reduced the quality of recovery and overall perception of experience ($p < 0.001$). In addition, adding stream sounds significantly improved the quality of one's recovery ($p < 0.05$) and overall experience ($p < 0.001$), but it did not significantly improve one's security.

We utilized Kruskal-Wallis independent sample nonparametric analysis to further compare the ratings across the various sources. As illustrated in Table 12 and Fig. 11, There is no substantial difference between stream sound and bird-song in terms of recovery quality. The recovered quality of water and bird sounds is considerably superior to that of human and mechanical noises. The recovery quality of children's playing is much superior to that of speech, transportation, and construction sounds; There is no discernible difference between the sounds of a stream and bird-song in terms of the sense of safety. There is no substantial difference between the sound of a stream and the sound of children playing in terms of perceived security; In terms of overall experience perception, there is a considerable difference between the sound of bird-song and all other sound sources, indicating that the overall experience perception of bird song is greatest near urban lakefronts with tall buildings.

3.2.3. Adding sound to the coastal high-rise environment

As shown in Table 13 and Fig. 12, the inclusion of birdsong in the coastal high-rise building environment significantly increased the quality of recovery ($p < 0.001$), security ($p < 0.01$), and overall experience ($p < 0.001$) (comfort, satisfaction, and preference) compared to no sound by the Wilcoxon signed rank test. However, the addition of traffic noise and construction noise significantly reduced the quality of recovery, security, and overall experience (comfort, satisfaction, and preference) ($p < 0.001$). Conversations only significantly reduced the quality of recovery and overall experience ($p < 0.001$). In addition, adding stream sounds significantly improved the quality of recovery ($p < 0.05$) and overall experience ($p < 0.001$), but not the sense of security.

We applied Kruskal-Wallis independent sample nonparametric analysis to further compare the ratings across the various sources. As illustrated in Table 14 and Fig. 13, There is no discernible difference between the recovery quality of stream sound and bird song. There was a notable distinction between bird songs and children's play; There were no significant variations in the impression of security among the sounds of a stream, bird-song, conversation, and children playing; There were no statistically significant variations in the total experience perception between the stream sound and bird-song, which were superior to all

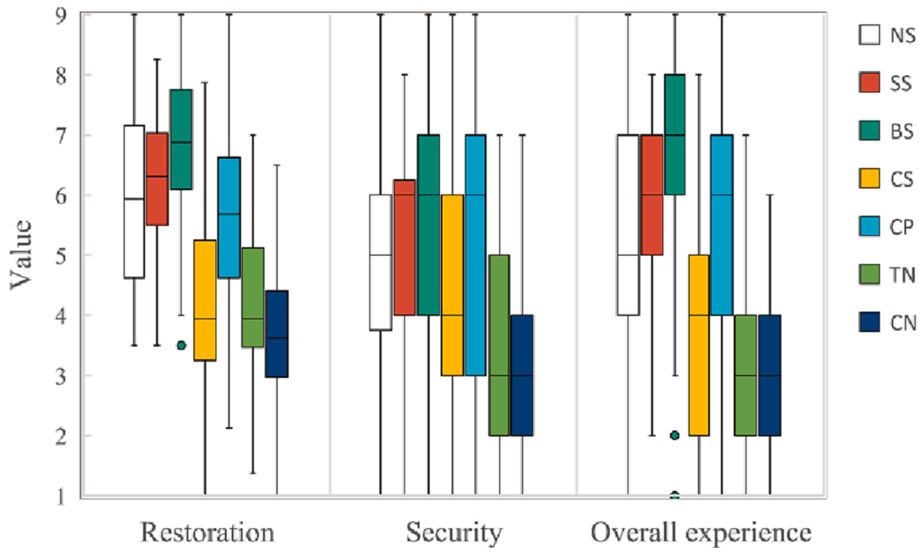


Fig. 12. Comparison of scores between no sound and single sound source in the nearby high-rise environment of coastal. (NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise).

Table 14
Kruskal-Wallis nonparametric analysis of independent samples for variations in the quality of restoration, sense of security, and overall perception of experience comparing sound sources in the coastline and surrounding high-rise area. Significant differences are marked with * ($p < 0.05$) and ** ($p < 0.01$), and *** ($p < 0.001$).

Sound sources	Indicators (Sig.)		
	Short Version Revised Recovery Scale (SRRS)	Security	Overall experience
SS-BS	1.000	1.000	0.921
SS-CS	0.000***	0.167	0.000***
SS-CP	0.420	1.000	0.025*
SS-TN	0.000***	0.000***	0.000***
SS-CN	0.000***	0.000***	0.000***
BS-CS	0.000***	0.003**	0.000***
BS-CP	0.014*	1.000	0.000***
BS-TN	0.000***	0.000***	0.000***
BS-CN	0.000***	0.000***	0.000***
CS-CP	0.002**	0.756	0.000***
CS-TN	1.000	1.000	0.841
CS-CN	1.000	0.108	0.001**
CP-TN	0.001**	0.004**	0.000***
CP-CN	0.000***	0.000***	0.000***
TN-CN	1.000	1.000	0.520

(NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise).

other sources.

In conclusion, the inclusion of different sound sources in waterfront near-rise buildings can change the perceived human experience. In particular, the addition of birdsong to all waterfront types significantly increased the quality of recovery, security, and overall experience ($p < 0.001$), while the addition of conversations, traffic noise, and construction noise significantly decreased the quality of recovery, security and overall experience ($p < 0.001$). However, stream sounds, while significantly increasing the overall experience of the built environment for all waterfront types ($p < 0.001$), did not significantly increase the perception of human security. Therefore, in urban waterfront high-rise built environments, birdsong is more beneficial to people's quality of recovery, security, and overall experience than stream sounds. In addition, there is a need to reduce or control the frequency of the occurrence of conversations, traffic noise, and construction noise.

3.3. Effects of individual characteristics changes (gender, frequency of visits, and anxiety levels) on the quality of human recovery, security, and overall experience (comfort, satisfaction, and preference)

To examine the effects of personal characteristics on the evaluation, this section compares current gender differences among 50 university students, frequency of visitation, and anxiety level in terms of quality of recovery, security, and overall experience scores.

3.3.1. Gender-related differences

The differences in perceived experience ratings by gender were compared by the MU test (Mann Whitney *U* test), and the results are shown in Table 15. When there was no sound, there were significant differences ($p < 0.01$) between the genders in the ratings of quality of recovery, security, and overall experience (comfort, satisfaction, and preference). Compared to women, men had lower ratings for quality of recovery, security, and overall experience (comfort, satisfaction, and preference). There was a significant difference ($p < 0.05$) between the genders in the evaluation of the quality of recovery at the sound of birdsong, with men rating the quality of recovery lower than women. There was a significant difference ($p < 0.01$) between the genders in the evaluation of the quality of recovery and security at the sound of conversations and children's playing, with men rating lower than women. Additionally, there was a significant difference ($p < 0.01$) between the genders in the evaluation of security at the sound of traffic noise, with men rating the feeling of security lower than women. Similarly, there was a significant difference between the genders in the ratings of feeling security ($p < 0.01$) and overall experience ($p < 0.01$) when the construction noise was underway, with men rating it lower than women.

As shown in Fig. 14, sound sources causes variations in the quality of recovery, sense of security, and overall experience for men and women. Men rated the quality of recovery, sense of security, and overall experience lower than low women, but men's ratings (relative to no sound) increased more than women's after hearing stream sounds and birdsong, indicating that men were more positively influenced by soundscape recovery than women.

3.3.2. Difference in frequency of visits

With the varying frequency of visits, people may have different expectations of the environment, which may affect soundscape perception. Therefore, the impact of visit frequency on restoration of quality, perception of security and overall experience evaluation was analysed.

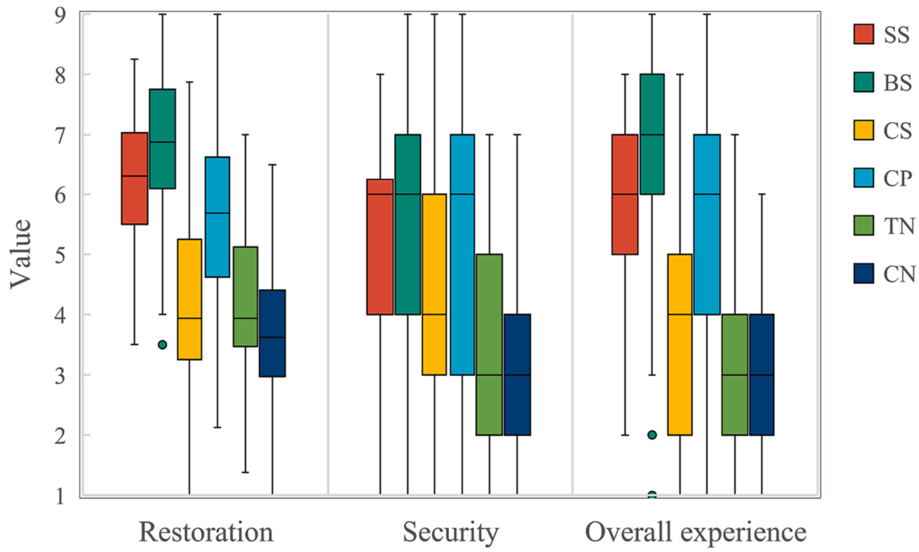


Fig. 13. Comparison of scores between the single sound sources in the nearby high-rise environment of the coastal. (NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise).

Table 15
The Mann-Whitney *U* test evaluates gender variations in recovery quality, feelings of safety, and overall experience. The importance of the difference is shown by two-tailed p-values. The p-values lower than or equal to the significance level of 0.05 are in bold.

	Perceptual experience indicators		
Sound sources	Short Version Revised Recovery Scale (SRRS)	Security	Overall experience
NS	**0.000**	**0.000**	**0.000**
SS	0.537	0.875	0.145
BS	**0.010**	0.299	0.093
CS	**0.000**	**0.008**	**0.000**
CP	**0.000**	**0.000**	**0.000**
TN	0.864	**0.002**	0.092
CN	0.074	**0.000**	**0.000**

NS: No sound; SS: Stream sound; BS: Birdsong; CS: Conversations; CP: Children's playing; TN: Traffic noise; CN: Construction noise.

Table 16 demonstrates the results of Spearman's correlation analysis, which showed a substantial link between visitation frequency and perceptions of security and overall experience under different sound conditions. The higher the frequency of visits in the sound of birdsong, the higher the overall experience rating. Next, the more visits the person has during the sound of children playing, the higher the rating of feeling safe. Moreover, the greater the frequency of visits the lower the overall experience when it comes to the sound of traffic noise and construction noise. This means that frequent visitors to urban waterfront spaces had a preference for the sound of birdsong and children's playing but were less tolerant of mechanical sounds.

3.3.3. Difference in anxiety levels

Before focusing on any psychological recovery that the subjects may have achieved, their psychological state at the beginning of the experiment was analysed using the Generalised Anxiety Scale (GAD-7) (Table 17). In telemedicine clinical studies, the Generalized Anxiety Scale is now utilized as a screening instrument for depression and anxiety disorders [69]. On the basis of score differences, mental states can be divided into five categories: no anxiety disorder (scores 0–4), mild anxiety disorder (scores 5–9), moderate anxiety disorder (scores 10–14), and severe anxiety disorder (scores 15–21) [70]. The results indicated that 33 individuals were anxiety-free, 10 individuals had mild anxiety, 6 individuals had moderate anxiety, and 1 individual had severe anxiety.

As shown in Table 18, there is a significant correlation between anxiety level and recovery quality, sense of security, and overall experience in the different sound conditions by Spearman's correlation analysis. In the visual condition only, the more anxious the person was, the lower the ratings of quality of recovery, sense of security, and overall experience. During stream sounds, the more anxious people were had lower ratings of quality of recovery, security, and overall experience. During the sound of birdsong, the more anxious people were had lower the ratings of quality of recovery and sense of safety. During the sound of conversations, the more anxious people were had lower ratings of quality of recovery and overall experience. During the construction noise, the more anxious people were had higher ratings of overall experience. We discovered that students with high anxiety were less concerned about construction noise, possibly because they live in a noisy environment (e.g., the school is on the side of a major road) and there is a high level of traffic noise around the school, so they have adapted to this noisy environment (After our survey, participants did live in a relatively noisy environment). This result parallels the findings of Kou et al., Long-term, those whose primary restrictions are work- and family-related modify their perceptions of sound and passively adapt to the high levels of sound [71].

4. Discussion

4.1. Impact on quality of recovery, security, and overall experience

This study used a self-assessment approach and virtual reality technology to explore the effects of exposure to urban waterfront building environments with different water spans, building storeys, and sound source types on the quality of human recovery, security, and overall experience. Previous studies have found that tall buildings can be oppressive to people and blue spaces such as waterfronts have a rehabilitative effect, so what effects do tall waterfront buildings have on people?

The results of the study show that different water spans, building storeys, and sound source types have different psychometric effects. In terms of recovery quality, the number of storeys can be limited to 3–6 from a visual aspect, which means that low and multi-storey buildings can improve recovery quality in all environments, whether riverfront, lakefront, or coastal. In terms of hearing, birdsong and stream sounds can be introduced in the high-rise environment to improve the quality of recovery. In terms of security, the number of storeys can be limited to

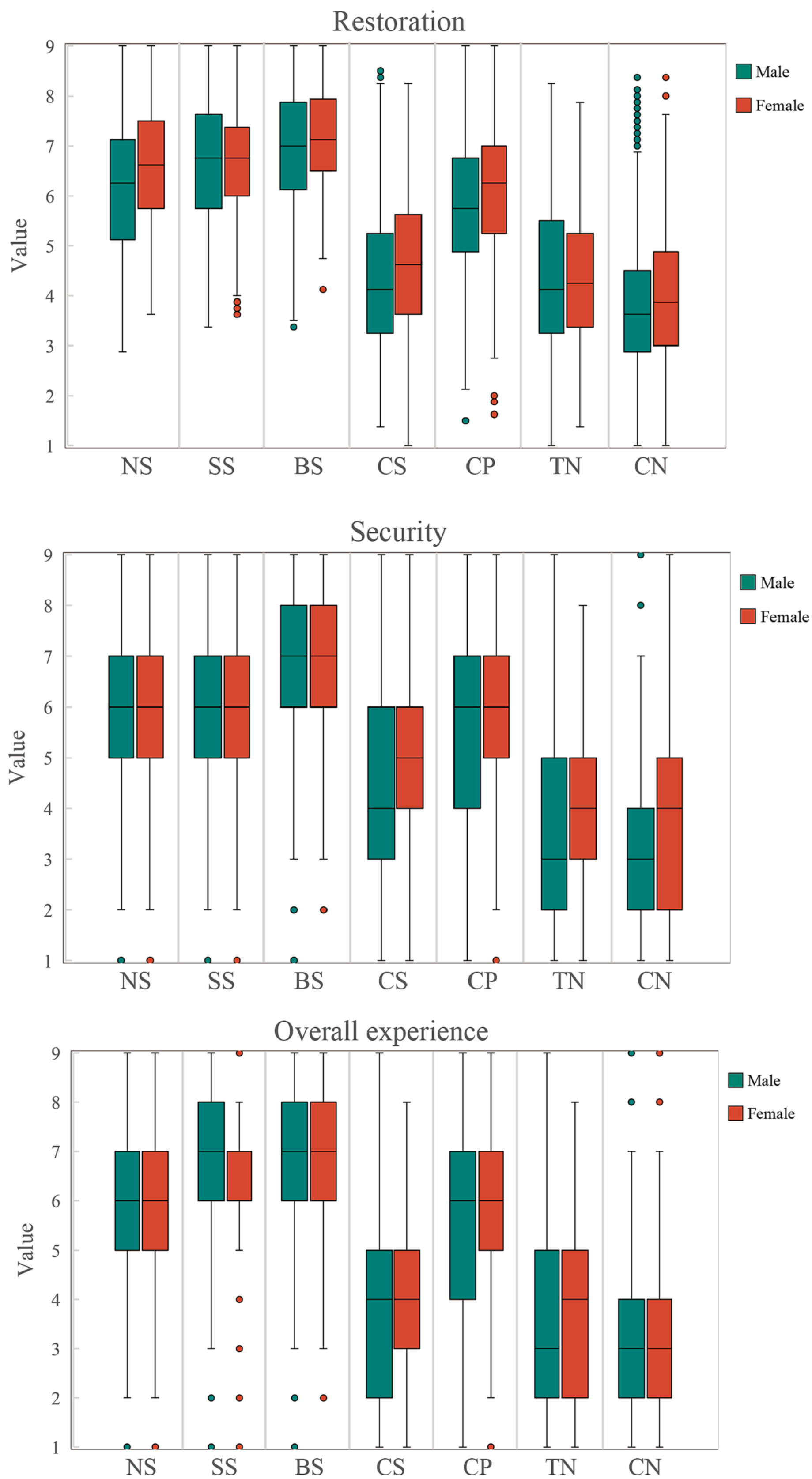


Fig. 14. Comparison of the influence of gender on the evaluations of each indicator for distinct sounds (NS: No sound, SS: Stream sound, BS: Birdsong, CS: Conversations CP: Children's playing, TN: Traffic noise, CN: Construction noise).

Table 16
Correlation between frequency of visits and various indicators.

	Short Version Revised Recovery Scale (SRRS)	Security	Overall experience
No sound	0.005	0.000	0.003
Stream sound	0.017	−0.009	0.012
Bird sound	0.044	0.054	**0.047****
Conversations	0.012	0.041	0.000
Children's playing	0.002	**0.099****	0.005
Traffic noise	−0.031	−0.058	**−0.100****
Construction noise	−0.053	−0.047	**−0.092****

Significance of 0.05 is shown in bold *$p < 0.05$.
**$p < 0.01$.

Table 17
Generalized Anxiety Inventory (GAD-7).

Description	Not at all	Several days	More than a week	Almost every day
Feeling nervous, anxious or anxious	0	1	2	3
Inability to stop or control worry	0	1	2	3
Worrying too much about a variety of things	0	1	2	3
Difficulty relaxing	0	1	2	3
Unable to sit still due to restlessness	0	1	2	3
Becoming easily upset or impatient	0	1	2	3
Feels as if something terrible is going to happen and is afraid	0	1	2	3

Table 18
Correlation between anxiety levels and various indicators.

	Short Version Revised Recovery Scale (SRRS)	Security	Overall experience
No sound	**−0.149****	**−0.149****	**−0.129****
Stream sound	**−0.104****	**−0.094****	**−0.055****
Birdsong	**−0.100****	**−0.078***	−0.023
Conversations	**−0.105****	−0.059	**−0.085****
Children's playing	−0.056	−0.032	−0.020
Traffic noise	−0.057	−0.025	−0.033
Construction noise	0.048	0.016	**0.056****

Significance of 0.05 is shown in bold *$p < 0.05$.
**$p < 0.01$.

3–6 from a visual aspect, which means that low and multi-storey buildings can improve the sense of security in the riverfront, lakefront, and coastal environments. In addition, people felt more secure in riverfront (10 m) and lakefront (100 m) environments and less secure in coastal (500 m) environments. In terms of hearing, birdsong can be introduced in the high-rise environment to improve the sense of security. In terms of the overall experience, the number of storeys can be controlled to 3–6 in the visual aspect to improve the overall experience of people, which means that low and multi-storey buildings can improve the overall experience of people in the riverfront, lakefront, and coastal environments. With regards to the hearing aspect, the birdsong and stream sounds can be introduced in the high-rise environment to enhance the overall experience.

In previous studies, the height of a building had the greatest impact on human vision [72]. The height of the building creates a greater sense of oppression than the width. On streets with widths of 30 m or less, tall buildings of 60 m or more in height and 15 m or more in width create the greatest sense of oppression [21]. In addition, tall buildings can induce a sense of awe and can lead to slower behavioural responses [39]. Building height, building density, and cleanliness have a big impact on occupant health [22]. For a lake width of 200 m, there is slight pressure on the public when the visible part of the building height reaches three times the average height of the tree profile [5]. The results of this study confirm this with tall buildings significantly reducing the quality of recovery, security, and the overall experience of people.

This study found a significant negative correlation between water span and perception of security ($p < 0.01$), and no correlation was found between water span and quality of recovery or overall experience. The inclusion of birdsong in a high-rise building environment significantly improved the quality of recovery, security, and overall experience ($p < 0.01$), while stream sounds were rated lower than birdsong in terms of quality of recovery, security, and overall experience. This is consistent with previous research. Previous research has shown that natural sounds have a positive effect on enhancing soundscape quality in real-world settings [73]. In urban street environments, birdsong contributed more to the soundscape quality of road traffic noise than stream sounds [74].

In addition, in terms of gender, men rated the quality of recovery, security, and overall experience significantly lower than women. Previous research indicates that women are more responsive to sound [75], but we focused on levels of stress recovery. First, with regard to the restoration of quality levels (Short version updated restoration), we discovered that younger males evaluated the recovery indicator lower than younger women, indicating that younger men may have higher anxiety levels due to social obligation or other factors. Also possible are physical factors. For instance, the risk of MACE (major adverse cardiovascular events) was greater in males (37%) than in women (21%) when psychological factors were considered. The link between depression and MACE is larger in males than in women, and anxiety greatly increases the risk of MACE in men [76]. In addition, one of the potential causes is that males were less responsive to environmental stimuli, resulting in lower recovery ratings.

Table A1
Researching typical waterfront settlements in Harbin.

Location	Water span (m)	Number of storeys	Building face width (m)	Spacing (m)	Vertical distance between building and water edge (m)
Songbei District - Yulong Bay	35	3	30	30	30
Jiangbei District-Guangdongjiayuan (Villa)	100	2	30	20	37
Jiangbei-Sunshine Jiayuan	20	2	24	6	20
Jiangbei-Jinhaos Classic	20	6	67	12	22
Nangang District-Forestry Design Institute Family Building (Xigou Street)	30	6	47	9	17
Daoli District-Xintiandi Home	35	6	94	11	13
Nangang District-Beihong Riverside Apartment	16	17	33	25	26
Xiangfang District - Hefu Manxianglin West	17	17	65	17	30
Songbei District-Mediterranean Sunshine (Phase I)	35	17	52	18	23

Table A2
Researching typical waterfront settlements in Wuhan.

Location	Water span (m)	Number of storeys	Building face width (m)	Spacing (m)	Vertical distance between building and water edge (m)
Jiangxia District-Water Blue County	100	3	14	10	20
East-West Lake District-Yinhu Jade	220	2	24	13	27
Hongshan District-Poly Heartland (Phase II Villa)	275	3	18	20	29
East-West Lake District-Aerospace Silver Lake Bay	275	5	30	30	40
Huangpi District-Panlong Waterfront Qinyuan	1000	4	50	12	10
Jiangxia District-Jinxiu Liang Yuan	300	6	88	15	22
Hongshan District-Poly Heartland (Phase III)	500	18	66	23	100
Chaokou Development Zone - Donghe Guanghu County	275	18	35	13	15
Hongshan District-Junweiyuan District	38	18	44	17	20

Table A3
Study of typical waterfront settlements in Guangzhou.

Location	Water span (m)	Number of storeys	Building face width (m)	Spacing (m)	Vertical distance between building and water edge (m)
Baiyun District - Royal Sands (Villa)	24	3	15	6	10
Tianhe District-Ming Yue Qing Quan Villa	70	2	17	10	20
Haizhu District - Yaxian Garden	95	3	17	7	40
Tianhe District-Tianpingjia Bus Area	10	6	34	7	12
Liwan District-Xinliyuan	30	6	23	10	18
Liwan District-Jinheyuan	20	6	20	7	25
Baiyun District-Jinshazhou New Community Area 1	10	18	52	20	8
Baiyun District-Lingnan New World	20	14	89	30	7
Liwan District-Lujin with Dragon Bay	16	18	55	15	29

4.2. Applications in related fields

Visually, keeping the number of building storeys in the riverfront, lakefront, and coastal environments at 3–6 storeys can improve the quality of human recovery, security, and overall experience. Furthermore, the presence of high-rise buildings (17 storeys) needs to be avoided. In terms of hearing, the inclusion of birdsong in waterfront high-rise environments can improve the quality of recovery, security, and overall experience, making the integration of a sound system into the urban environment a viable and effective soundscape design solution.

4.3. Limitations and future studies

Firstly, the results of this study were derived from younger participants and did not include middle-aged and older age groups; therefore, a broader demographic range of respondents needs to be used to improve the generalisability of the findings. Secondly, this study separately explored the effects of six single sound sources on the quality of visual landscape restoration to avoid the interference of too many factors, but real scenes usually contain multiple sounds at the same time. In future studies, sound source settings need to be considered more comprehensively to reduce the discrepancy between the indoor experimental setting and the actual outdoor environment.

5. Conclusions

In this study, a questionnaire survey was conducted in an anechoic laboratory using virtual reality technology to explore the visual characteristics of the built environment in urban waterfront residential areas and evaluate the changes in the quality of human recovery, security, and overall experience after the addition of sound sources. The results of the study can provide some reference for the design of urban waterfront-built environments.

1) Visual characteristics: Overall, the change in water span had an impact on the perception of human security and did not affect the quality of recovery or the overall experience. Variations in the number of storeys of the building influenced the quality of recovery, the sense of security, and the overall experience for people. Specifically, the wider the water span, the less secure one feels ($p < 0.01$). The perception of security ranked from highest to lowest were riverfront (5.98), lakefront (5.79), and coastal (5.56). The effect of water span on the quality of restoration and overall perception of experience was not significant. There is little difference in the restoration quality, sense of security, and overall sense of experience for low-rise and multi-storey buildings (3–6 storeys) across all waterfront types, with up to 6 storeys being appropriate, but three storeys are better rated for restoration quality, sense of security and overall sense of experience, and high-rise buildings (17 storeys) are rated lower for restoration quality, sense of security, and overall sense of experience. Generally, high-rise buildings on the far side of the lake can improve the sense of human security.

2) Inclusion of sound sources in the high-rise built environment: Overall, natural sounds have a positive effect on the quality of recovery, security, and the overall experience. Conversations and mechanical sounds have a negative effect on the quality of recovery, security, and overall experience. Specifically, the restoration benefits of including birdsong in a waterfront high-rise environment are better than stream sounds. This is because birdsong significantly improves the quality of recovery, security, and overall experience ($p < 0.01$). In contrast, stream sounds did not significantly improve the perception of security and were rated lower than the sound of birdsong in terms of quality of recovery

and overall experience. Additionally, adding the sounds of conversations, traffic noise, and construction noise significantly reduced the quality of recovery, security, and overall experience ($p < 0.01$). In the riverfront and coastal high-rise environments, the sound of children playing did not significantly affect the quality of recovery, security, or overall experience. In the lakefront high-rise environment, the sound of children playing significantly reduced the quality of recovery and the overall experience ($p < 0.01$).

3) Personal characteristics: Men scored lower than women in terms of quality of restoration, security, and overall experience under conditions of water span, number of building storeys, and variation in the sound source. However, men needed more restorative sound sources. Moreover, frequent visitors to urban waterfront spaces had a preference for the sound of birdsong and children's playing but were less tolerant of mechanical sounds. People with higher levels of anxiety were less tolerant of their visual surroundings, less likely to hear nature sounds and conversations.

The results of this study have the potential to help urban planners and architects create urban environments with high levels of audio-visual comfort in future urban planning and construction by allowing them to select the most appropriate number of building stories and sound sources.

CRediT authorship contribution statement

Haotian Gao: Conceptualization, Methodology, Resources, Data curation, Writing – original draft, Writing – review & editing, Project administration, Investigation. **Fangfang Liu:** Conceptualization, Methodology, Validation, Resources, Data curation, Writing – review & editing, Project administration, Funding acquisition. **Jian Kang:** Conceptualization, Writing – review & editing. **Yue Wu:** Conceptualization, Writing – review & editing. **Yongzeng Xue:** Writing – review & editing, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendices.

Table A1.
Table A2.
Table A3.

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