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The impact of the community's sound environment on social interactions among residents

Xiaochao Chen [a], Jian Kang [a,*], Mincong Wang [b]

[a] Institute for Environmental Design and Engineering, The Bartlett, University College London, London, WC1H 0NN, United Kingdom
[b] School of Architecture and Landscape, University of Sheffield, Sheffield, S10 2TN, United Kingdom

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ABSTRACT

The built environment significantly influences social interactions, which are crucial for residents, but little is known about how these interactions are affected by the community's sound environment. This study conducted sound intervention experiments in the community to investigate the impact of alterations in the sound environment on residents' social behaviours. The social interaction situations under five sound intervention conditions were recorded and evaluated from three dimensions: participation, occurrence, and depth. The results indicated that a more natural sound environment in the community leads to a higher proportion of socially interactive residents and an increased occurrence of social interactions among residents. Birdsong interventions increased paired social interactions by 16.3 % compared to traffic noise, while water sound interventions increased grouped social interactions by 16.6 % compared to the control. Compared to the frequency in the lowest group, individual prolonged pair social interactions increased by 0.26 occurrences with birdsong intervention, and prolonged group social interactions increased by 0.19 occurrences with water sounds intervention. The findings can inform community designers about the strategic use of sound to enhance the environment and promote social interactions among residents.

1. Introduction

1.1. Environmental characteristics of communities

Over half of the global population resides in urban areas, and this proportion is estimated to reach 68 % by mid-century [1]. Rapid population growth and urbanization are considered global health challenges faced in the 21st century [2]. As more urban residents live in high-density residential communities, interest in the connection between environmental quality and residents' health has grown in recent decades [3]. Numerous studies have identified the residential environment as a critical factor influencing the health of residents [4], including subjective perception and mental health, such as perceived density, depression and self-rated general health [5–7], as well as physical health, such as cardiovascular risk, outdoor activities, and social behaviours [8–11]. With regard to the built environment of the residential communities, existing studies have been focused on the green area, walkability, and physical attributes such as thermal comfort and acoustic environment ([5]; Y. [12–14]). Investigating the environmental characteristics of residential communities may reveal potential health risks for residents and provide a theoretical basis for planners and designers to create better living environments.

1.2. Sound environments in residential areas: beyond quietness

The sound environment is essential for residential communities, as noise exposure has been proven to affect mental and physical health adversely [15,16]. Existing studies have investigated the link between the residential environment and noise annoyance [17], as well as the adverse effects of community noise, including sleep disturbance, physiological disorders, hearing impairment, and overall well-being [13,18]. Thus, controlling noise levels and human exposure is crucial for creating a high-quality community sound environment [19,20]. Quietness is crucial for residential environments, as evidenced by global regulations on noise and the establishment of quiet areas in cities. Additionally, the positive effects of certain beneficial sounds on quality of life should be

Abbreviations: **SP**, Social Participation; **OSI-B**, Occurrence of Brief Social Interactions; **OSI-P**, Occurrence of Prolonged Social Interactions; **DSI**, Depth of Social Interactions.

* Corresponding author.
E-mail addresses: xiaochao.chen.20@ucl.ac.uk (X. Chen), j.kang@ucl.ac.uk (J. Kang), mwang58@sheffield.ac.uk (M. Wang).

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considered [21]. In recent decades, the development of the soundscape discipline has promoted a comprehensive understanding of the sound environment, soundscape evaluation and planning [22]. Unlike traditional noise control methods that focus on merely reducing the volume of unwanted sounds, the soundscape approach views environmental sounds as resources and explores their positive effects [21], making it a valuable tool for urban space design [23]. The positive effects of sound resources on people's perception and health have been investigated, such as providing better experience of the site, mood recovery, mental restoration and behaviour encouragement ([24]; J. [25–27]). Therefore, in a community setting, considering only the quietness of the sound environment is insufficient to fully reflect its quality.

1.3. Behavioural impacts of sound environments

Human behaviour is influenced by the acoustic environment, a phenomenon rooted in the mammalian auditory system's innate ability to gather and process environmental information, thereby affecting behaviour [28]. This characteristic is extensively utilized in the commercial sector, where the indoor sound environments of spaces such as casinos, shopping malls, restaurants, and bars are meticulously designed to influence consumer behaviour. Research indicates that classical music in wine shops leads customers to purchase pricier wines. One explanation is that classical music fosters a refined, upper-class atmosphere, leading customers to consider high-priced items. Alternatively, classical background music might signal the merchandise's price and quality to customers [29]. The tempo of music can affect individuals' perception of time passage [30]; slower-paced music tends to be associated with extended shopping durations, thus potentially increasing the likelihood of higher expenditure [31]. Conversely, in restaurant settings, fast-paced background music accelerates behaviours such as eating and drinking [32].

In addition to influencing indoor behaviour, sound environments also affect people's activities in outdoor spaces. It was found that playing different background music in public spaces increased the average time people spent there [33]. In urban parks, Meng and Kang [34] discovered that park visitors were more attracted to areas where music and events were present. Franě; k et al. [35] studied the relationship between pedestrians' walking speed and the sound environment in urban areas, finding that people walked faster when exposed to traffic noise than to natural sound environments. Findings on the impact of outdoor sound environments on human behaviour have seen limited practical application, likely due to large spatial scales and complex influencing factors. To address this, some researchers focus on small urban public spaces, exploring ways to enhance urban space quality through optimized sound environments. For example, Chen and Kang [36] compared social interactions under five different soundscape interventions in urban park activity spaces and found that natural sounds could encourage social interactions.

1.4. Social interactions in communities

In modern society, the significance of social interaction is particularly pronounced. Social interactions not only form the foundation of psychological health but also play a critical role in shaping personal identity and forming social support networks (S. [37,38]). Communities, as the primary venues for social interactions, provide residents with a platform for mutual communication and interaction. Historically, connections between neighbours have been regarded as a fundamental aspect of society [39]. There is evidence that social interactions among neighbours reduce illness risk, enhance belonging and happiness, prevent cognitive and physical decline, and reduce loneliness and social isolation [40–42]. Existing research on promoting social interactions within communities primarily focuses on designing and planning public spaces and organising community activities [43,44]. Despite soundscape studies showing significant psychological and behavioural effects of the sound environment, research on enhancing community social interactions through sound optimization is scarce. Therefore, optimizing sound environments to enhance community social interactions is a crucial research direction that can improve residents' quality of life.

1.5. Research questions

Considering that communities are crucial venues for social interactions, this study investigates the impact of acoustic environments on residents' social interactions within community activity spaces. By conducting in-situ soundscape intervention experiments, the research seeks to address the following questions:

In the activity areas of residential communities, do changes in the acoustic environment affect.

- the ratio of the number of socially interactive residents participated in social interactions to the total number of subjects.
- the occurrence of social interaction behaviours among residents,
- the ratio of the total duration of all social interactions to all subjects' total time spent in the area.

2. Methodology

Sound intervention experiments were implemented in two public activity spaces within a residential community in Daqing, China. Loudspeakers introduced various interventional sounds to provide different acoustic environment conditions, and the changes after interventions were assessed and visualized by grid measurements. Residents' social behaviours under different conditions were observed and recorded by cameras. Subsequently, the coded data from the video recordings were analyzed to examine how residents' social behaviours were affected by the community acoustic environment. Fig. 1 illustrates the complete procedure of the sound intervention experiments.

2.1. Experimental site and participants

In recent decades, rapid urbanization in China has significantly increased urban populations. Consequently, residential communities with high-rise buildings have become the most common living environments for urban residents. A preliminary survey was conducted to identify representative communities suitable for sound intervention experiments. Satellite maps were initially used to select a series of community activity spaces of approximately 30 m by 30 m (around 1000 square meters) as potential experimental sites for further field observations. After on-site investigations, spaces with few users or those used exclusively by the elderly were excluded. Additionally, sites with unstable sound environments, such as those with frequent noise disturbances from construction, broadcasts, or sirens, were also excluded. Ultimately, two outdoor activity areas (Site A and Site B) within the Yinyi Community in Daqing City were chosen as experimental sites (Fig. 2). Yinyi Community is centrally located in Daqing City, surrounded by diverse land uses, and divided by a major urban road into North Area A and South Area B. Despite being constructed at different times, both areas share a similar design style. Site A, the primary outdoor activity area of Area A, measures approximately 40 m in length and 30 m in width (coordinates: 46°36′09″N 124°53′07″E, irregular shape). Site B, the primary outdoor activity area of Area B, measures approximately 45 m in length and 25 m in width (coordinates: 46°35′46″N 124°53′09″E, oval shape). Both sites are suitably sized, feature green vegetation and artificial ponds, and have relatively stable acoustic environments, meeting the conditions necessary for sound intervention experiments.

The demographic characteristics of Yinyi Community residents are shown in Table 1. Both areas have similar population compositions, with 63.3 % aged 20–59 years and 20.4 % elderly, comparable to Daqing City's 2020 census data (18–59: 64.4 %, 60 and above: 22.6 %). Due to

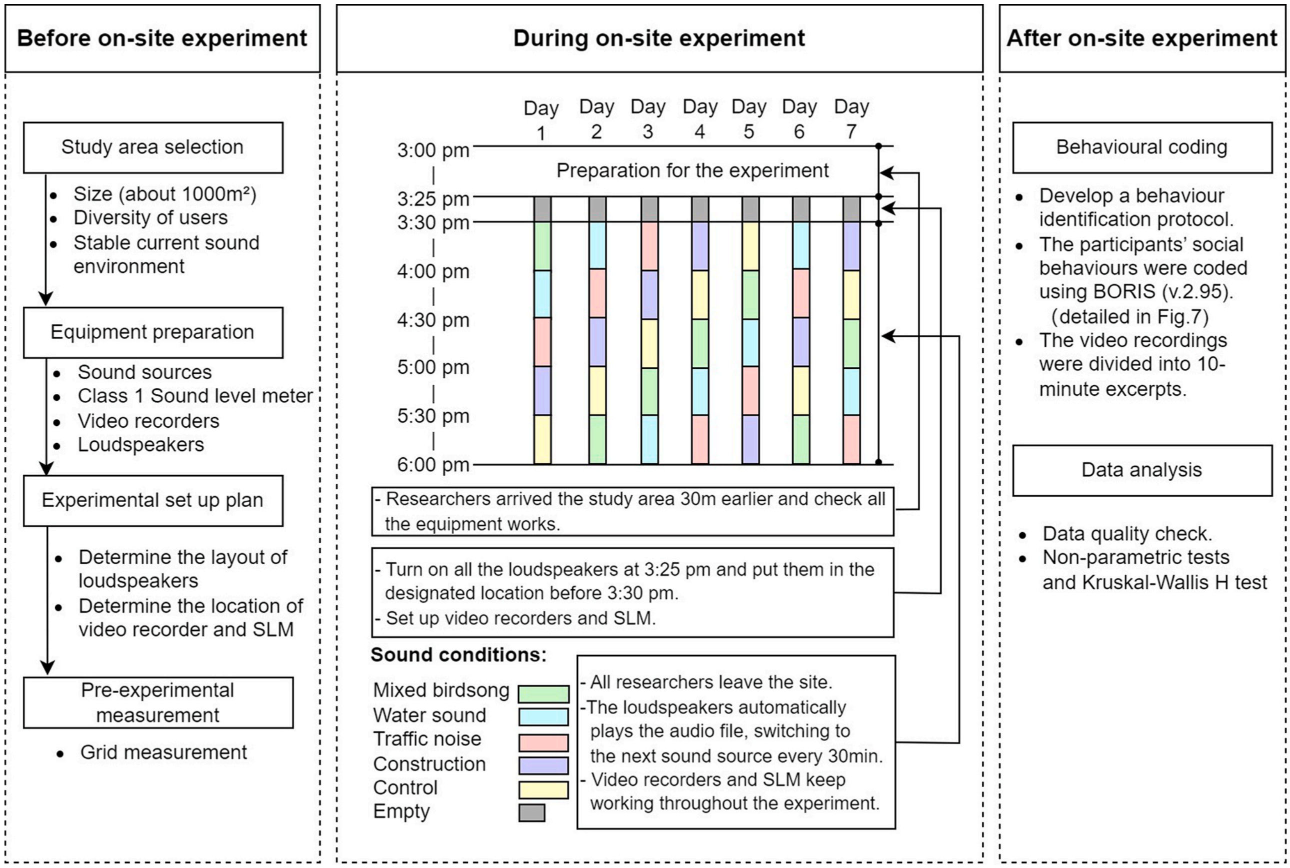

Fig. 1. The procedure of the sound intervention experiments.

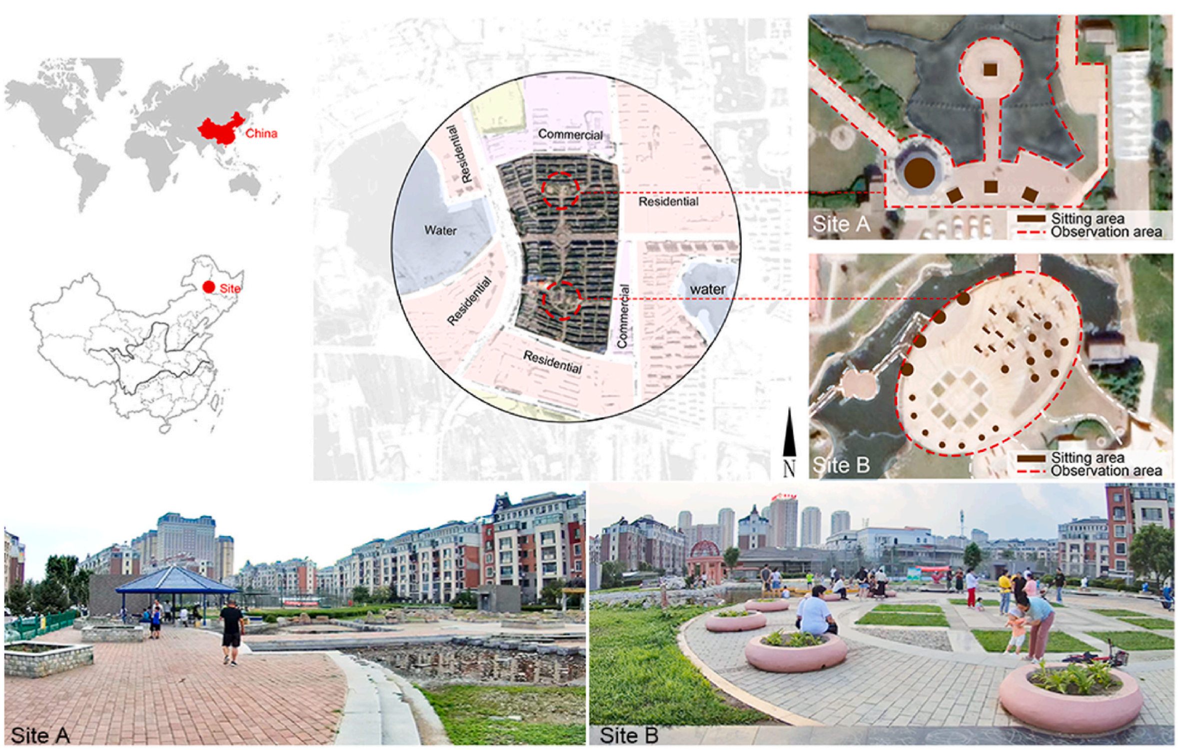

Fig. 2. The Location of the YinYi community and the study areas, with on-site pictures.

Table 1
Demographic information of residents in Area A and Area B in YinYi community (Data source: Yinyi Community Neighbourhood Committee).

	Area A	Area B	Total
Number of Residents			
	7627	8097	15724
Age			
0-14	876 (11.5 %)	939 (11.6)	1815 (11.5 %)
15-19	360 (4.7 %)	388 (4.8 %)	748 (4.8 %)
20-59	4821 (63.2 %)	5139 (63.5 %)	9960 (63.3 %)
60+	1570 (20.6 %)	1631 (20.1 %)	3201 (20.4 %)
Gender			
Male	3793 (49.7 %)	4032 (49.8 %)	7825 (48.8)
Female	3834 (50.3 %)	4065 (50.2 %)	7899 (50.2 %)

the similarities in the environment and population compositions, data from both experimental sites were combined. The experiment involved adult participants who were treated uniformly. Observations of their social behaviours indicated the impact of environmental factors on their interactions. Notably, although the target participants of our experiment were intended to be community residents, it is inevitable that some participants were not actual residents. To emphasize that our research site is a community activity space, we broadly refer to its users as “residents."

2.2. Interventional sound resources

During the sound intervention experiment, four distinct types of sounds were used to create varied community sound environments: mixed birdsong, water sound, traffic noise, and construction noise. Traffic and construction noises are common in urban residential areas. Given the site’s vegetation and pond, birdsong and water sounds were also appropriate. To avoid creating a discordant experience, contextually suitable sounds were selected for the community setting. The mixed birdsong comprised various bird songs recorded in urban parks, and the water sound was derived from natural streams, matching the community’s artificial stream. Traffic noise was recorded from the road near Yinyi Community, and construction noise consisted of electric drills typically heard at construction sites.

Fig. 3 presents the spectrograms of the four intervention sounds. These sounds were edited to achieve the same equivalent sound pressure level (SPL). The original sound files were at least 10 min long, with any prominent segments removed to ensure the looping sounds went unnoticed. Unlike urban public open spaces, the community’s original sound environment is relatively quiet. Therefore, the volume of the intervention sounds was controlled to significantly alter the sound environment without impeding normal conversation and activities (see more detail in 2.4).

2.3. Equipment and layout for experimental setup

The equipment used in this experiment comprised three main components: an array of loudspeakers to modify the acoustic environment, two video cameras to record human activities, and a Class 1 sound level meter to monitor the site’s acoustic conditions. Several loudspeakers were modified by placing multidirectional wireless speakers (SAST T39, 5W) into rock-shaped outdoor speaker enclosures (20 × 30 × 40 cm). This type of enclosure is widely used for lawn speakers in parks, allowing the speaker to blend into the surrounding environment. The enclosure has sound holes around it to ensure that the sound can be transmitted in all directions. The frequency response of the modified loudspeakers was measured, and seven with the best and most similar frequency responses were selected as sound input devices. As shown in Figs. 4 and 5, the loudspeakers were evenly distributed on the ground around and within the study area, with the middle of each speaker positioned 20 cm above the ground, maintaining an approximate distance of 15 m between each to ensure a uniform acoustic impact. During the experiment, two miniature video cameras (M980, 93 × 36 × 15 mm, 170°) recorded human behaviour from different angles to eliminate visual blind spots. Additionally, a Class 1 sound level meter (BSWA 801, BSWA-Technology) was used to record the SPL of the site every 30 s throughout the experiment.

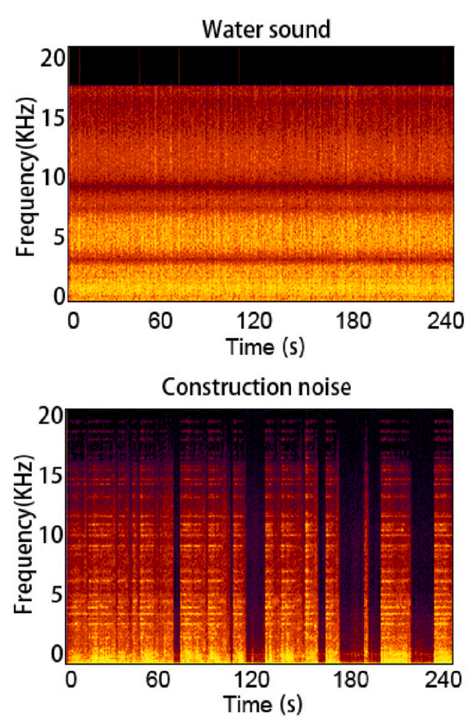

Fig. 3. The spectrograms of sound sources in intervention experiments (50 ms time resolution, 50 % overlap, 48.0 kHz sample frequency, 24 bits).

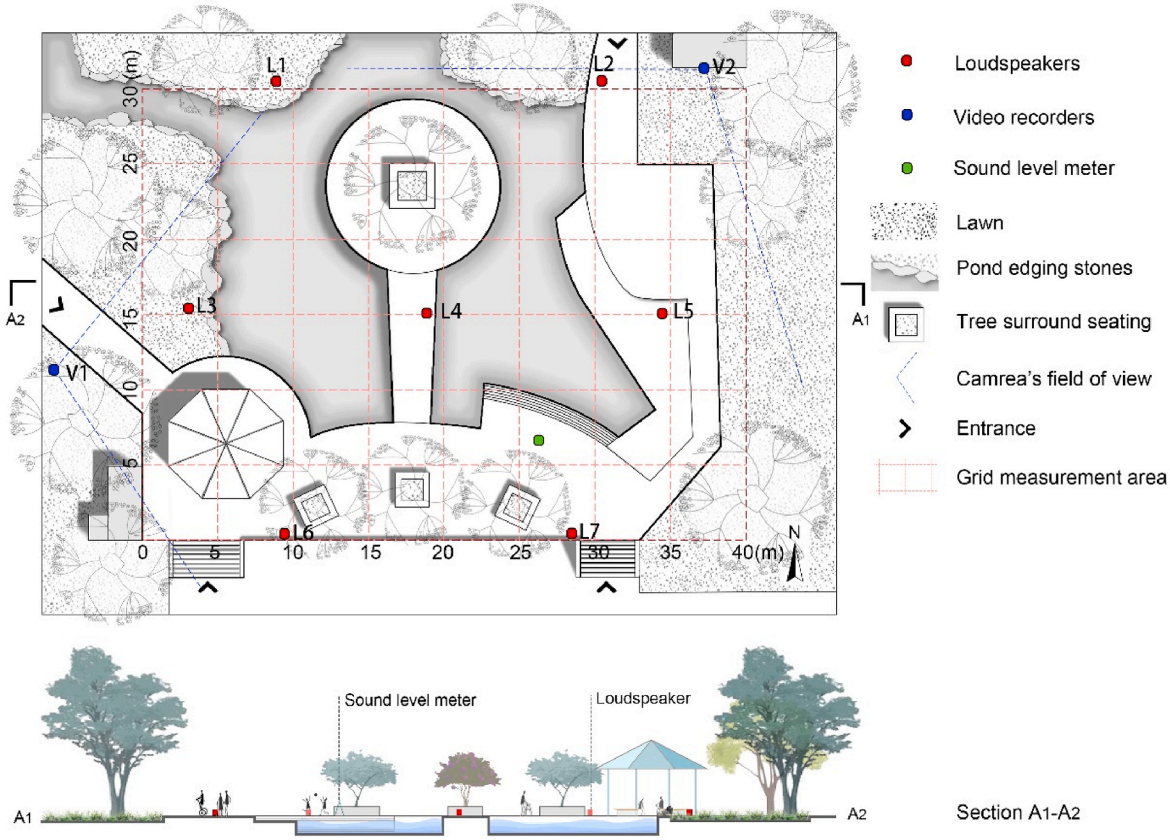

Fig. 4. Layout plan and a section for experimental equipment in community activity space, Site A.

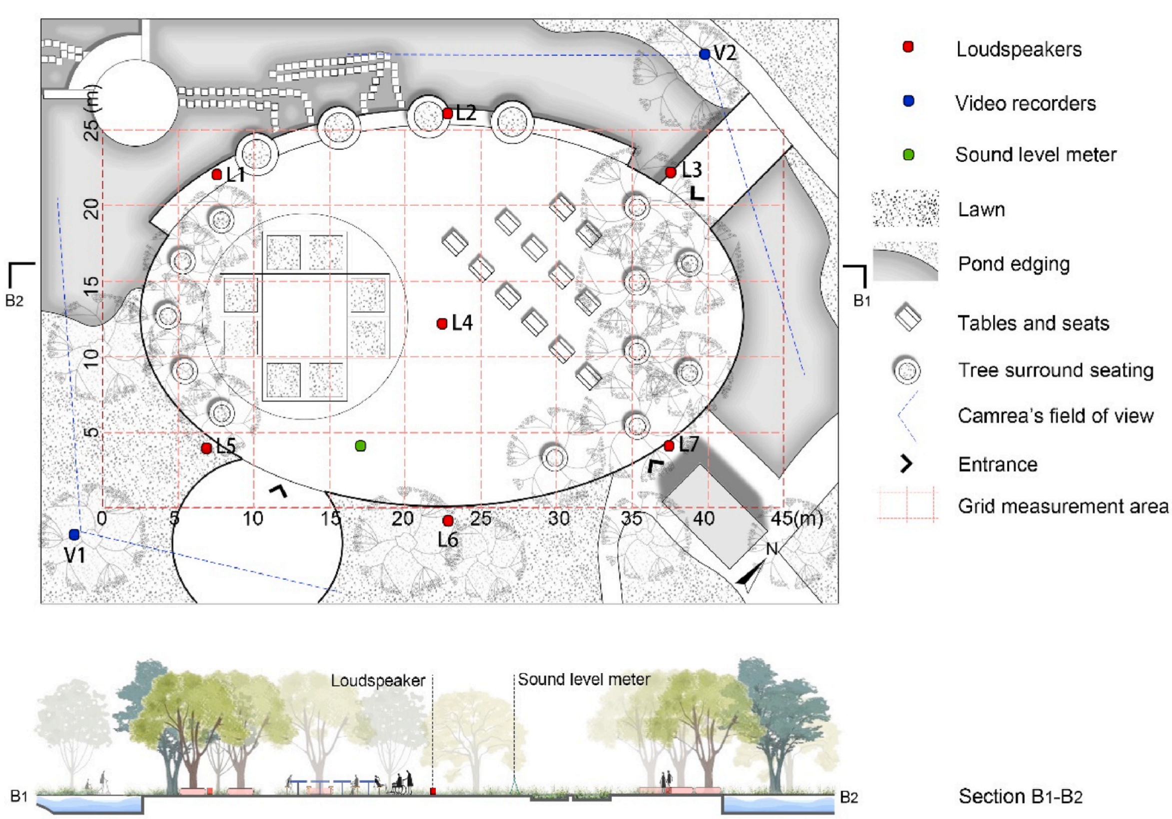

Fig. 5. Layout plan and a section for experimental equipment in community activity space, Site B.

2.4. Sound environment description

Before the sound intervention experiments, grid measurements were conducted to understand sound propagation. The activity areas in Sites A and B were divided into 5m × 5m grids (Figs. 4 and 5). Each grid centre was a measurement point where the equivalent sound pressure level was measured three times for 10 s each, and the average value was recorded. The sound level meter was mounted on a tripod to keep the microphone no less than 1.5 m away from the ground and other objects to avoid sound reflection [45]. The average background noise level (L90) was measured at Sites A and B between 3:30 p.m. and 6:00 p.m., resulting in 46.3 dB(A) and 49.4 dB(A), respectively. Intervention sounds were set to exceed these levels by 5–10 dB to ensure perceptible changes without affecting behaviour.

Fig. 6 visualizes the grid measurement results. Under quiet conditions, the equivalent sound pressure levels in Site B were 46.3 dB and 43.2 dB, respectively (Fig. 6, A0, B0). Sound interventions significantly affected the sound environment (Fig. 6, A1-A4, B1-B4), but the environment across most activity areas remained uniform. The interventions aimed to influence the overall sound environment rather than create specific sound zones.

2.5. Experiment procedure

The soundscape intervention experiment was conducted over 14 days, from July 11 to July 25, 2022, with the first 7 days in Site B and the subsequent 7 days in Site A. The weather was clear, with daily temperatures ranging from 21 °C to 31 °C. The intervention was scheduled from 3:30 p.m. to 6:00 p.m., the period with the highest number of users.

The intervention sound files consisted of five 30-min segments, including four intervention sounds and one silent audio (control group). Each sound was edited for repetition and looping, with 15-s fade-ins and

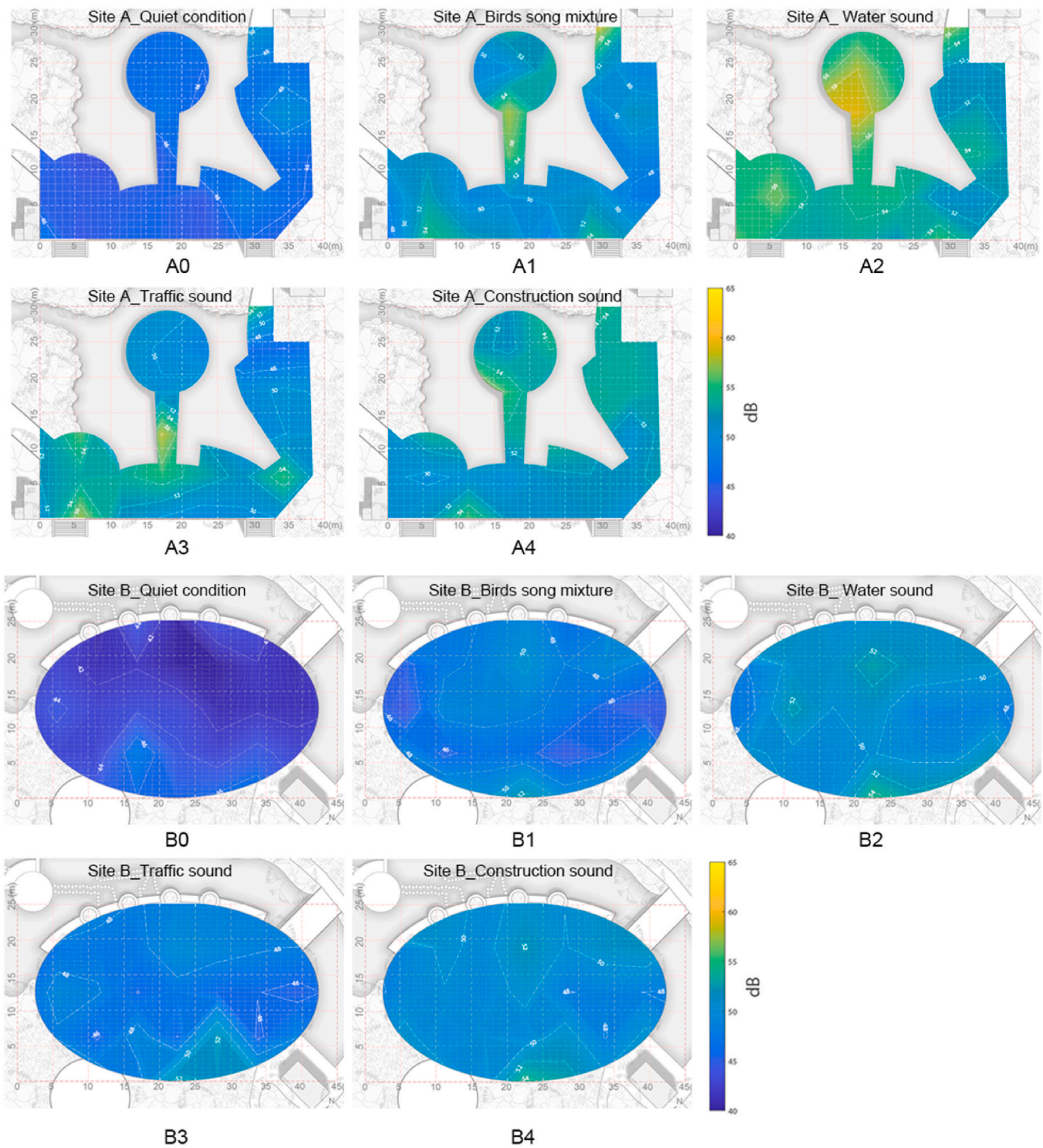

Fig. 6. Characteristics of the sound environment in two study areas under quiet and four intervention conditions based on grid measurements.

fade-outs during transitions. The order of the five sound conditions varied daily to ensure each was tested at different times. Each sound condition played for a total of 210 min over the 7 days at each site. To minimize the impact on social interactions, the experiment operators left the site after setting up the equipment.

The SPL in two study areas under different sound intervention conditions over the 7-day experiment were recorded. In Site A, the average SPL in the control group was 54.6 dB, with a maximum of 3.8 dB lower than the sound intervention conditions. In Site B, the average SPL in the control group was 58.8 dB, with a maximum of 0.6 dB lower than the sound intervention conditions. These results indicate that the sound interventions had a minor effect on sound pressure levels, primarily enriching the sound environment.

2.6. Identification and analysis of social interaction behaviours

The Behavioural Observation Research Interactive Software (BORIS, v.2.95) from the University of Turin was used to analyze muted video recordings of social interactions. The BORIS software assists researchers in recording subjects' behaviours in real-time from video files. It was used in this study to record the start and end times of each social behaviour during the experiment. Its visualization and data analysis tools provided statistics on social behaviours over a given period, including the number of participants, the frequency of interactions, and their duration. Fig. 7 outlines the procedure of video recording analysis, which consists of two parts: object identification and behaviour recording. During object identification, children and passersby who stayed less than 30 s were excluded. Interactions between subjects and their family members were also not recorded.

In the behaviour recording stage, interactions were firstly identified by signs such as waving, and then categorized as paired (two people) or grouped (more than two people) based on the number of participants. If no clear signs were observed, social interaction was determined by social distance [46,47], duration, and participant number. Intimate space (0–45 cm) interactions over 10 s were recorded based on the number of participants. Interactions in personal space (45–120 cm) involving more than two people for more than 10 s were recorded as group interactions. Each social interaction's start and end times were noted, with short leaves (under 1 min) not ending interactions to avoid overestimation.

Evaluating social interactions within experimental sites is critical to comparing social interactions across various sound environments. This study assesses social interactions from participation, occurrence, and depth dimensions adapted from the three indicators measuring objective social interactions in urban parks [36]. From the participation dimension, the social participation indicator (SP) reflects the proportion of socially interactive residents, indicating the site's attractiveness. From the occurrence dimension, the occurrence of social interaction indicator (OSI) measures interaction frequency, revealing the intensity of social interactions. Interactions are further classified into brief (OSI-B) and prolonged (OSI-P) based on a 30-s threshold. From the depth dimension, the depth of social interaction indicator (DSI) measures residents' time spent on social interactions, ensuring a comprehensive assessment of the site's social functions. Higher values for each indicator suggest better social interaction conditions. Given the complexity of social interactions, such as brief greetings, intimate conversations, and group activities, different interactions hold different meanings. Therefore, to better understand the impact of the sound environment, social interactions are categorized into paired social interactions between two people (P) and grouped social interactions involving more than two people (G).

The SPSS(version 29) software was used to conduct statistical analyses after behavioural data were all coded. Each intervention lasted 210 min in the experiment and was divided into 10-min excerpts. A quality check process was carried out to exclude excerpts that were affected by abnormal noises or had fewer than 5 subjects, resulting in 182 valid excerpts. Non-parametric tests and the Kruskal-Wallis H test were used to analyze the data.

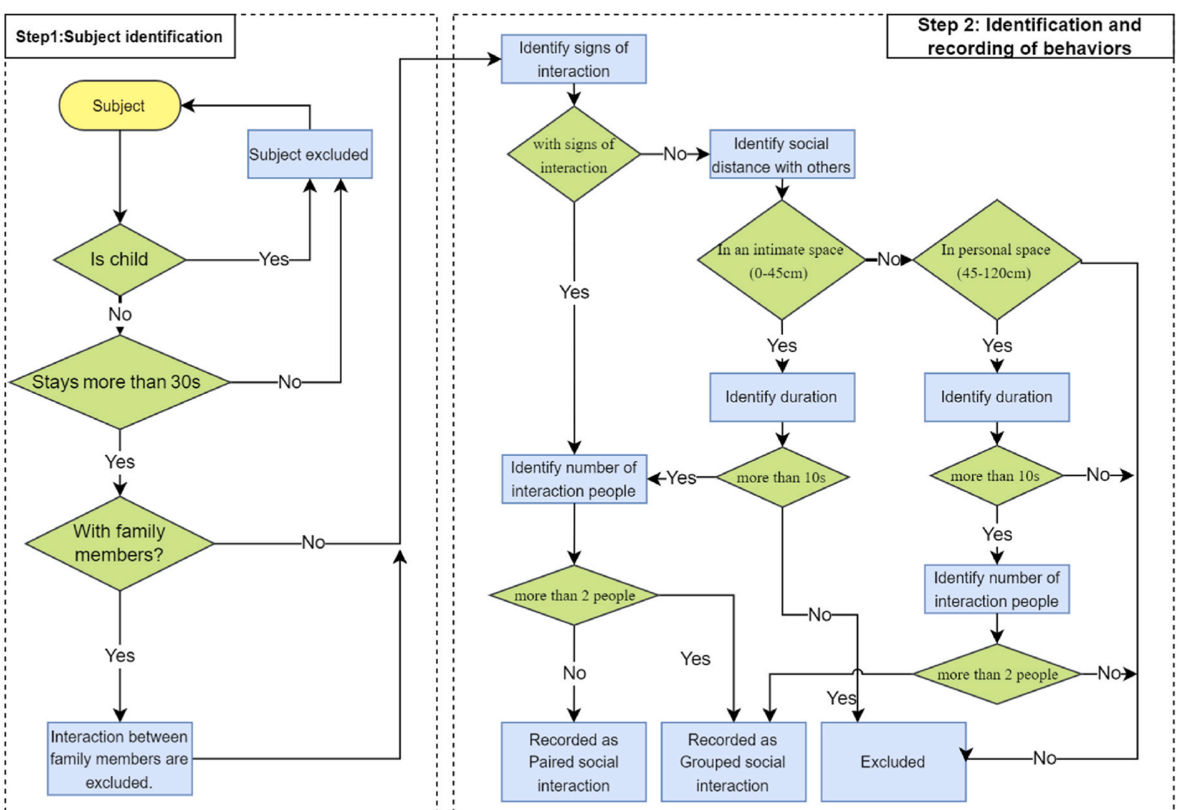

Fig. 7. The procedure of behaviour identification and recording based on video recordings.

3. Results

3.1. The sound environment's influence on social interaction participation

This study investigates whether changes in the sound environment affect the proportion of socially interactive residents. This involves identifying and counting the number of all users and adults that participated in social interactions. During the experiment, variations in the number of socially interactive residents under different sound intervention conditions did not accurately reflect the acoustic environment's impact on social interactions. This discrepancy may also occur because the number of individuals present in the area varies across different time periods, influencing the number of social interactions. For example, a higher population density in the area naturally leads to more social interactions. Therefore, social participation indicator (SP) in this study capture the proportion of socially interactive residents which is the ratio of residents that participated in the social interactions to the total number of subjects [36]. A higher SP value indicates that the environment more effectively encourages social interactions. Table 2 presents the descriptive statistics of the video excerpts, total subjects, socially interactive residents, and mean SP(P/G) values for paired and grouped social interactions. The average SP(P) ranged from 34.94 % (traffic noise) to 51.21 % (mixed birdsong), whereas the average SP(G) varied from 11.11 % (control) to 27.66 % (water sound).

Nonparametric tests were utilized because SP (P) and SP (G) values did not follow a normal distribution across different sound conditions. Kruskal-Wallis H tests were applied to assess if significant variations existed in SP (P/G) scores among the five sound condition groups: "Mixed Birdsong" (N = 37), "Water Sounds" (N = 36), "Traffic Noise" (N = 39), "Construction Noise" (N = 34), and "Control" (N = 36). Boxplot visualizations showed that SP (P) and SP (G) score distributions varied among the groups (see Figs. 8 and 9). The analysis revealed significant differences in the mean rank of SP (P) scores among the groups, $\chi2$ (4) = 14.324, p = .006, as well as significant differences in SP (G) scores, $\chi2$ (4) = 10.623, p = .031. This indicates significant variability in the proportion of socially interactive residents across different sound conditions. Follow-up pairwise comparisons using Dunn's (1964) procedure with a Bonferroni correction identified significant differences in SP (P) mean rank scores between the "Traffic Noise" group (69.91) and the "Mixed Birdsong" group (113.58) (p = .003) and exhibited a medium to large effect size (r = 0.41) (J. [48]). However, no other group combinations showed significant differences (see Table 3). For grouped social interactions, the follow-up pairwise comparisons indicated significant variations in SP (G) mean rank scores between the "Control" (75.94) and "Water Sounds" (110.79) groups (p = .024) and exhibited a medium to large effect size (r = 0.36), without significant differences in other pairings (see Table 4).

These results indicated that the intervention of natural sounds contributes to greater participation in social interactions within community activity spaces. Notably, under the condition of bird song intervention, a significantly higher proportion of residents were observed to engage in paired social activities than in traffic noise intervention. For grouped social activities, the presence of water sound significantly increased the proportion of socially interactive residents compared to the control group.

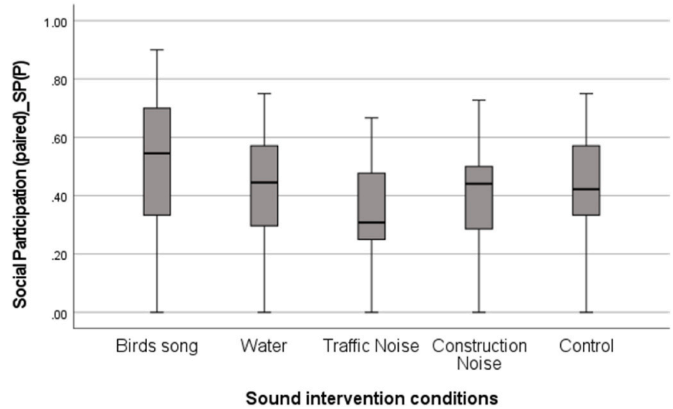

Fig. 8. Boxplot for SP(P) under five sound intervention conditions.

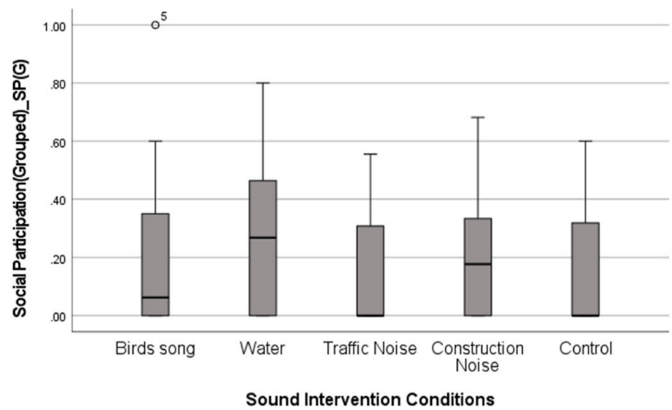

Fig. 9. Boxplot for SP(G) under five sound intervention conditions.

3.2. The sound environment's influence on the occurrence of social interactions

This study also explores the type of acoustic environment that promotes social interactions, measured by the Occurrence of Social Interactions (OSI). This involves identifying and counting the total number of subjects and social interactions on the site. Adults are continuously monitored to determine their engagement in social activities. Social interactions are categorized as brief (under 30 s) or prolonged. Due to the complexity of social activities, exclusions are made for non-interactive situations, such as individuals sitting back-to-back without communication. Given the varying number of site users over time, OSI-B

Table 2
Number of total subjects and socially interactive residents under five sound conditions, SP(P/G): Social Participation (Paired/Grouped).

Types of social interaction	Sound interventions	Excerpts N.	Total subjects N.	Socially interactive residents N.	Mean SP (%)	Std. Dev. SP (%)
Paired (P)	Mixed birdsong	37	410	220	51.21	23.58
	Water sounds	36	417	184	43.60	18.85
	Traffic noise	39	457	156	34.94	16.67
	Construction noise	34	424	175	39.02	17.41
	Control group	36	352	153	42.88	18.62
Grouped (G)	Mixed birdsong	37	410	81	19.16	24.75
	Water sounds	36	417	128	27.66	25.46
	Traffic noise	39	457	74	13.84	18.03
	Construction noise	34	424	103	18.88	20.87
	Control group	36	352	53	11.11	17.88

Table 3
The follow-up pairwise comparisons between groups regarding the proportion of socially interactive residents participated in paired social interactions.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Traffic-Construction	−13.560	12.345	−1.098	.272	1.000
Traffic-Water	25.368	12.161	2.086	.037	.370
Traffic-Control	−26.090	12.161	−2.145	.032	.319
Traffic-Birdsong	43.671	12.075	3.617	.000**	.003**
Construction-Water	11.807	12.582	.938	.348	1.000
Construction-Control	−12.529	12.582	−.996	.319	1.000
Construction-Birdsong	30.110	12.500	2.409	.016	.160
Water-Control	−.722	12.401	−.058	.954	1.000
Water-Birdsong	18.303	12.317	1.486	.137	1.000
Control-Birdsong	17.581	12.317	1.427	.153	1.000

The asymptotic significance values are displayed for two-sided tests, **p < 0.01 and * p < 0.05.

Table 4
The follow-up pairwise comparisons between groups regarding the proportion of socially interactive residents participated in grouped social interactions.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Control-Traffic	7.286	11.276	.646	.518	1.000
Control-Birdsong	17.799	11.422	1.558	.119	1.000
Control-Construction	18.644	11.668	1.598	.110	1.000
Control-Water	34.847	11.500	3.030	.002**	.024*
Traffic-Birdsong	10.512	11.197	.939	.348	1.000
Traffic-Construction	−11.357	11.448	−.992	.321	1.000
Traffic-Water	27.561	11.276	2.444	.015	.145
Birdsong-Construction	−.845	11.591	−.073	.942	1.000
Birdsong-Water	−17.048	11.422	−1.493	.136	1.000
Construction-Water	16.203	11.668	1.389	.165	1.000

The asymptotic significance values are displayed for two-sided tests, **p < 0.01 and * p < 0.05.

and OSI-P were calculated by dividing the occurrence of brief/prolonged social interactions by the total number of subjects [36]. Table 5 presents the descriptive statistics of the video excerpts, total subjects, brief/-prolonged social interactions, mean OSI-B, and mean OSI-P values for paired and grouped social interactions. The average OSI-B (P) ranged from 0.05 (traffic noise) to 0.10 (mixed birdsong), OSI-P (P) from 0.35 (traffic/construction noise) to 0.61 (mixed birdsong), OSI-B (G) from 0.01 (traffic/construction noise) to 0.03 (mixed birdsong), and OSI-P(G) from 0.11 (control) to 0.30 (water sound).

Nonparametric tests were utilized because OSI-B (P/G) and OSI-P (P/G) values did not follow a normal distribution across different sound conditions. Kruskal-Wallis H tests were applied to assess if significant differences existed in OSI-B (P/G) and OSI-P (P/G) scores among the five sound condition groups: “Mixed Birdsong” (N = 37), “Water Sounds” (N = 36), “Traffic Noise” (N = 39), “Construction Noise” (N = 34), and “Control” (N = 36). Boxplot visualizations showed that OSI-B (P/G) and OSI-P (P/G) score distributions varied among the groups.

For prolonged social interactions, the analysis revealed significant differences in the mean rank of OSI-P (P) scores among the groups, $\chi 2$ (4) = 16.224, p = .003, as well as significant differences in OSI-P (G) scores, $\chi 2$ (4) = 11.524, p = .021. This indicates significant variability in the occurrence of both paired and grouped social interactions among residents across different sound conditions. Regarding prolonged pair social interactions, the follow-up pairwise comparisons using Dunn’s (1964) procedure with a Bonferroni correction identified significant differences in OSI-P (P) mean rank scores between the “Traffic Noise” group (72.77) and the “Mixed Birdsong” group (115.01) (p = .005) with r = 0.40 showing a medium to large effect size, and between the “Construction Noise” group (75.63) and the “Mixed Birdsong” group (p = .016), with r = 0.37 showing a medium to large effect size. However, no other group combinations showed significant differences (see Table 6). Regarding prolonged group social interactions, the follow-up pairwise comparisons indicated significant variations in OSI-P (G)

Table 6
The follow-up pairwise comparisons between groups regarding the occurrence of prolonged pair social interactions.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Traffic-Construction	−2.863	12.347	−.232	.817	1.000
Traffic-Water	24.147	12.162	1.985	.047	.471
Traffic-Control	−24.425	12.162	−2.008	.045	.446
Traffic-Birdsong	42.244	12.076	3.498	.000**	.005**
Construction-Water	21.284	12.584	1.691	.091	.908
Construction-Control	−21.562	12.584	−1.713	.087	.866
Construction-Birdsong	39.381	12.501	3.150	.002**	.016*
Water-Control	−.278	12.403	−.022	0982	1.000
Water-Birdsong	18.097	12.319	1.469	.142	1.000
Control-Birdsong	17.819	12.319	1.447	.148	1.000

The asymptotic significance values are displayed for two-sided tests, **p < 0.01 and * p < 0.05.

Table 5
The occurrence of social interactions under five sound conditions, OSI-B (P/G): Occurrence of Brief Social Interactions (Paired/Grouped), OSI-P (P/G): Occurrence of Prolonged Social Interactions (Paired/Grouped).

Types of social interaction	Sound interventions	Excerpts N.	Total subjects N.	Brief social interaction N.	Mean OSI-B	Std. Dev. OSI-B	Prolonged social interaction N.	Mean OSI-P	Std. Dev. OSI-P
Paired (P)	Mixed birdsong	37	410	39	0.10	0.20	269	0.61	0.40
	Water sounds	36	417	28	0.06	0.10	195	0.46	0.24
	Traffic noise	39	457	24	0.05	0.09	155	0.35	0.21
	Construction noise	34	424	26	0.06	0.08	163	0.35	0.20
	Control group	36	352	28	0.07	0.14	170	0.47	0.32
Grouped (G)	Mixed birdsong	37	410	15	0.03	0.09	78	0.19	0.26
	Water sound	36	417	9	0.02	0.04	139	0.30	0.29
	Traffic noise	39	457	8	0.01	0.06	68	0.13	0.18
	Construction noise	34	424	6	0.01	0.03	114	0.20	0.24
	Control group	36	352	10	0.02	006	50	0.11	0.18

mean rank scores between the "Control" (76.11) and "Water Sounds" (1101.50) groups (p = .002) and exhibited a medium to large effect size (r = 0.36), without significant differences in other pairings (see Table 7).

For brief pair social interactions, the mean rank of OSI-B(P) scores rose from traffic (82.08) to water (86.76), construction (92.41), control (94.90), and birdsong (101.89). However, these differences did not reach statistical significance, χ^2 (4) = 3.998, p = .406. In the case of brief group social interactions, the mean rank of OSI-B(G) scores rose from traffic (84.58) to construction (89.82), control (92.11), water (94.31), and birdsong (97.01), but these differences also did not reach statistical significance, χ^2 (4) = 3.529, p = .473.

The results indicated that the intervention of natural sounds promotes more prolonged social interaction behaviours in residential community activity spaces. Specifically, for paired social interactions, the introduction of birdsong leads to a higher occurrence of social interactions compared to noise interventions, including traffic and construction noises. Regarding grouped social interactions, the introduction of the sounds of flowing water resulted in a higher occurrence of social interactions compared to the control group.

3.3. The sound environment's influence on the depth of social interactions

Another important question is whether changes in the sound environment affect the depth of social interactions (DSI), which is calculated as the ratio of the total duration of all social interactions to all subjects' total time spent in the area [36]. This indicator reflects the importance and proportion of social interactions in the overall use of the area. A higher DSI score indicates a more attractive and supportive environment for social interactions. Table 8 presents the descriptive statistics of the video excerpts, total time spent in the study area, total duration of social interactions, and mean DSI (P/G) values for paired and grouped social interactions. The average DSI (P) ranged from 20.15 % (traffic noise) to 29.54 % (mixed birdsong), while the average DSI (G) ranged from 5.68 % (control) to 12.71 % (water sound).

Nonparametric tests were utilized because DSI (P) and DSI (G) values did not follow a normal distribution across different sound conditions. Kruskal-Wallis H tests were applied to assess if significant variations existed in DSI (P) and DSI (G) scores among the five sound condition groups: "Mixed Birdsong" (N = 37), "Water Sounds" (N = 36), "Traffic Noise" (N = 39), "Construction Noise" (N = 34), and "Control" (N = 36). Boxplot visualizations showed that DSI (P) and DSI (G) score distributions varied among the groups. Although the mean rank of DSI (P) scores rose from traffic (77.76) to construction (86.06), water (89.76), control (95.42), and birdsong (108.86), these differences did not reach statistical significance, χ^2 (4) = 7.262, p = .122. In addition, the mean rank of DSI (G) scores rose from control (75.33) to traffic (85.19), birdsong (95.68), construction (98.26), and water (103.82), but these differences also did not reach statistical significance, χ^2 (4) = 7.823, p = .0.98. These results indicated that alterations in the acoustic environment did not significantly influence the residents' time spent on social interactions in the community activity spaces.

Table 7
The follow-up pairwise comparisons between groups regarding the occurrence of prolonged group social interactions.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Control-Traffic	6.299	11.216	.562	.574	1.000
Control-Birdsong	15.416	11.361	1.357	.175	1.000
Control-Construction	20.904	11.605	1.801	.072	.717
Control-Water	35.389	11.438	3.094	.002**	.020*
Traffic-Birdsong	9.117	11.137	.819	.413	1.000
Traffic-Construction	−14.604	11.387	−1.283	.200	1.000
Traffic-Water	29.090	11.216	2.594	.010	.095
Birdsong-Construction	−5.488	11.529	−.476	.634	1.000
Birdsong-Water	−19.973	11.361	−1.758	.079	.787
Construction-Water	14.485	11.605	1.248	.212	1.000

The asymptotic significance values are displayed for two-sided tests, **p < 0.01 and * p < 0.05.

4. Discussion

4.1. Sound environment's influence on social interactions in the community

There are several key findings based on sound intervention experiments in community activity spaces. Firstly, enhancing natural sounds in these spaces can foster social interactions among residents, encouraging greater participation in social activities and promoting more social interaction behaviours. This finding underscores the positive role of natural sounds, aligning with existing research on their benefits for physical and psychological health, such as stress relief and attention restoration [49,50]. Chen and Kang's sound experiment in urban parks confirmed natural sounds' effectiveness in improving social interaction [36]. This study extends these findings to community settings, demonstrating that a sound environment enriched with natural sounds is associated with an increased proportion of socially interactive residents and a higher occurrence of prolonged social interactions among community residents.

Despite findings that birdsong and water sounds facilitate social interactions, the lack of participant interviews in this study makes it difficult to determine the affective response of participants. One potential explanation is that natural sounds create a comfortable environment, fostering positive emotions and thus increasing social interactions. Another possible explanation is that the presence of natural sounds may attract additional attention from site users, becoming a topic of interest and discussion among residents. Similarly, noise can trigger social interactions, such as complaints or anger towards traffic and construction noise. Therefore, increased social behaviour does not directly equate to improved environmental quality.

Additionally, birdsong and water sounds facilitate social interactions, but their effects differ. Birdsong more significantly influences paired interactions within a community, whereas water sounds affect grouped social interactions. One possible explanation for this phenomenon is the differences in rhythm and melody between the two sounds. Research shows that human behaviour correlates with music tempo and pace [51]. Moreover, the type of music and its tempo can affect emotional responses and behaviours [52]. In this experiment, the livelier rhythm and melody of birdsong may promote a greater willingness for social interaction. Conversely, the facilitation of social interactions by flowing water sounds may arise from its function as white noise, which reduces cognitive load, aids concentration, and enhances cognitive performance [53,54]. In community settings, paired social interactions typically involve deeper personal exchanges and emotional connections, requiring a high level of attention and engagement between participants. Grouped social interactions, on the other hand, focus more on information sharing and collective activities, emphasizing the overall atmosphere and shared experience. The lively rhythm of birdsong may stimulate enthusiasm for interpersonal interactions, thereby facilitating paired communication. Conversely, water sounds, with their steady rhythm and calming effects, are more suitable for creating a relaxed environment that encourages grouped social interactions.

Although a previous study indicated that alterations in the acoustic environment within urban park activity spaces can affect the proportion of time spent on social interactions [36], this study did not find similar conclusions. This discrepancy may be attributed to differences in the environment and the relationships among people in urban parks compared to community activity spaces. The length of time residents use community activity spaces may largely depend on their daily habits,

Table 8
The total time spent in study areas and the total duration of social interactions under five sound conditions, DSI (P/G): Depth of Social Interaction (Paired/Grouped).

Types of social interaction	Sound interventions	Excerpts N.	Total time spent (min)	Total duration of social interactions (min)	Mean DSI (%)	Std. Dev. DSI (%)
paired (P)	Mixed birdsong	37	2472.0	743.0	29.54	16.78
	Water sounds	36	2390.9	574.1	23.74	17.57
	Traffic noise	39	2795.0	561.2	20.15	17.63
	Construction noise	34	2531.0	595.3	22.69	17.84
	Control group	36	2239.0	538.8	25.37	17.44
Grouped (G)	Mixed birdsong	37	2472.0	306.6	11.49	17.57
	Water sounds	36	2390.9	389.2	12.71	18.06
	Traffic noise	39	2795.0	284.8	8.50	14.37
	Construction noise	34	2531.0	401.3	11.81	15.48
	Control group	36	2239.0	165.4	5.68	12.09

making them less affected by changes in the sound environment. Moreover, the users of community activity spaces, especially those who have resided in the community for a long time, potentially form familiar neighbourly relations or even intimate friendships with each other. Therefore, environmental factors are less likely to influence their social activities. In contrast, in park activity spaces, individuals are mostly strangers without the influence of fixed daily routines, making their social interactions more flexible and more susceptible to environmental influences. In summary, while the intervention of natural sounds can generally promote social interactions, the specific impact varies depending on the environment.

4.2. Optimization and implementation of sound environment design in communities

In recent decades, urban planning and environmental design have consistently aimed to create higher-quality living environments [55,56]. One key area of focus has been social interaction, due to its significant correlation with individual health [57,58]. Targeted psychological interventions, such as engaging in activities and maintaining social network connections, are commonly used to address social interaction challenges among socially isolated populations, especially the elderly [59,60]. It is important to note that psychological issues such as social isolation and loneliness result from long-term processes, such as prolonged exposure to environments lacking social interaction. From another perspective, everyone is at risk of experiencing insufficient social interaction in urban living. Therefore, while improving social interactions for isolated and lonely individuals is crucial, developing and constructing a socially interaction-friendly urban environment can benefit a wider population and prevent the onset of social isolation and loneliness at their source.

This study finds that creating a better sound environment, such as incorporating more natural sounds, can promote social interaction among residents. However, the introduction of certain levels of traffic and construction noise in community activity spaces during the sound intervention experiments did not negatively impact social interactions. This result aligns with the findings from Chen's sound experiments conducted in urban parks [36]. Excessively loud noise should be promptly reduced due to its significant adverse effects on human health. However, when noise levels are within a reasonable range, rather than solely focusing on further reduction, it is essential to also consider the potential positive effects of certain beneficial sounds. Research indicates that when the SPL is below a certain threshold, perceived acoustic comfort is not correlated with the sound pressure level [21]. Instead, the type of sound, characteristics of the listeners, and other factors may have significant impacts [61] Moreover, urban noise is a common sound in city life, and its presence in the community environment does not violate residents' expectations of the sound environment. Therefore, residents may have adapted to a certain level of these frequently heard urban noises [62].

From the perspective of leveraging the positive effects of sound resources, integrating natural sounds into community activity spaces can create environments that facilitate social behaviours. Additionally, since different types of sounds have varying effects on residents' social interactions, for example, bird songs promote paired interactions while the sound of flowing water tends to facilitate grouped social interactions, the design of the community acoustic environment should consider the user groups and the types of activities in certain spaces. Building on this study, further exploration of the relationships among the space, sound environment and user behaviours in the community will contribute to the development of theories and design methods for creating better sound environments in the communities and improving the overall quality of the living environment.

Moreover, the experiment in this study enhanced the sound environment of community activity spaces using electroacoustic equipment, a technique that has been used in many established soundscape intervention practices. Existing studies have summarized global soundscape intervention practices and identified recurring strategies, with the use of electroacoustic equipment to alter the acoustic environment being a widely adopted method [63]. However, there is currently a lack of evidence proving the positive effects of these devices on users. This study's results confirmed that employing electroacoustic equipment to modify the acoustic environment can have beneficial impacts on people. Especially in high-density urban communities with low green coverage, where creating natural habitats to introduce natural sounds through ecological methods is challenging, the implementation of electroacoustic facilities could be an efficient and controllable approach to creating a desirable sound environment.

4.3. Limitations

When applying the conclusions of this research to practical site design and the development of design theory, it is necessary to have a comprehensive understanding of the study's limitations. Firstly, the soundscape intervention experiments in this study utilized four types of sounds; however, a single sound source cannot represent an entire category of sounds. For instance, different species of birds produce sounds with varying frequencies and rhythms, which may have different impacts on people. Secondly, this study employed covert behaviour observation methods, ensuring that residents' normal use of the space was not disturbed. This approach avoided influencing the social activities of the observed subjects but made the collection of participants' demographic information unfeasible. Therefore, demographic data for the whole community was used, including the number of residents, gender ratio, and age distribution, to enhance the understanding of the characteristics of the experimental participants. According to the community demographic data, adults and elderly people account for 63.3 % and 20.4 % of the population, respectively, indicating a relatively young and vibrant community. Therefore, the conclusions of this study may not apply to communities with a unique demographic structure, such as those predominantly composed of elderly individuals. Furthermore, the experimental site was a typical urban residential community in China, characterized by high population density and a frequently used central public activity space. Consequently, the conclusions may not be applicable to low-density communities. Other factors, including geographic space, climate conditions, and local culture, may also influence the results of this study.

This study assessed social interactions in the space by investigating the objective social behaviours of users. However, the impact on residents' social health is not solely reflected in objective behaviour. For some residents, even without an actual increase in social behaviours, an improved community environment may positively affect their mental health, such as higher social participation willingness, perceived social support, and community belonging. This experiment focused on observable objective behaviour changes; thus, the psychological impact on residents was not within the scope of this study. Future research could further investigate the psychological impact of the acoustic environment on people's social behaviours. By comprehensively understanding the influences of the acoustic environment on individuals' social behaviours in various public spaces in urban context, it becomes feasible to develop detailed soundscape design strategies that utilize sound sources as tools to create more socially interactive urban environments.

5. Conclusion

This study investigated the impact of changes in the sound environment within community activity spaces on residents' social interactions. In this study's soundscape intervention experiment, the acoustic environment was altered by playing intervention sounds through loudspeakers. Residents' social behaviours were recorded using covert behaviour observation with video cameras. Based on the video recordings, the number of people using the space, the number of socially interactive residents, the occurrence of social interactions, and the start and end times of each social interaction were recorded for further data analysis.

The main findings are.

- Enriching the sound environment with bird songs and water sounds facilitates social interaction within the community. In this study, birdsong interventions increased paired socially interactive residents by about 11 %, while water sounds increased grouped socially interactive residents by about 12 %.
- Birdsong increases paired social interactions by about 0.2 occurrences for each person, while water sounds increase grouped social interactions by about 0.14 occurrences for each person.
- Different types of sounds have distinct effects on social interactions. Birdsong was found to foster paired social interactions, while water sounds tend to promote grouped social interaction.
- Prolonged social interactions among residents in the community are more likely to be promoted by natural sound interventions compared to brief social interactions.

This study suggests that creating a more natural sound environment in activity spaces is an effective way to encourage more residents to engage in social interaction and to promote prolonged social interactions in the community. Different sounds may have varying impacts on social interactions, and utilizing more positive sounds, such as natural sounds, can sometimes be more effective than simply reducing negative noise. The findings of this study could potentially contribute to developing theories and methods for sound environment design and encourage the incorporation of sound environments as crucial design elements in community space design for a more sustainable built environment.

CRediT authorship contribution statement

Xiaochao Chen: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jian Kang:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Mincong Wang:** Writing – review & editing, Data curation.

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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