Effect of visual characteristics of residential areas on soundscape in high density cities in China

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ABSTRACT

Taking residential areas with different floor area ratios as an example, this study investigated the effect of visual changes in building floor area ratios and surface colour on sound attention, satisfaction, and the correlation between attention and satisfaction. Results were as follows: First, a change in the visual building floor area ratio affected birdsong attention (*p* = 0.043), wind satisfaction of sound (*p* = 0.028), and the correlation between attention and satisfaction for the sounds of birdsong and traffic. With an increase in the floor area ratio, the correlation coefficients between attention and satisfaction increased for the sound of birdsong but decreased for the sound of traffic. Second, a change in building surface colour affected the satisfaction of wind sound (*p* = 0.047) and footstep sound (*p* = 0.032) under different building densities, and the change in colour also affected the correlation between attention and satisfaction. The correlation between attention and satisfaction for the sounds of birdsong and traffic became irrelevant after a change in building colour, and a change in building colour caused a shift in people's attention from hearing to vision. These results indicate that the urban sound landscape can be improved by changing the colour of residential buildings.

Keywords:residential areas, floor area ratio, sound, building colour

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1. INTRODUCTION

Currently, the increasing number and scale of cities have resulted in a continuous flow of people into cities. Thus, with the increasing new urban population, the housing problem in cities needs to be resolved. The floor area ratio is a major indicator used to evaluate environmental quality and comfort, and it also reflects the intensity of land use and development. The floor area ratio is calculated using the following formula (1)

$$R = \frac{C}{H} \tag{1}$$

Where C is the product of building density and H is the average number of floors. A high floor area ratio often reduces living comfort while resulting in high land use intensity. Kang (2014) confirmed that the noise sound pressure level (SPL) in the residential areas of Hong Kong, which has a high floor area ratio, was 3 – 5 dB higher than that in Sheffield, which has a low floor area ratio, when the SPL of noise sources was the same, and this difference increases with an increase in building height. Furthermore, Yu and Kang (2006) confirmed that SPL in Taipei streets was approximately 10 dB higher than that in Sheffield, and that Taipei residents had lower satisfaction of sound ratings and poorer health. More than 150 million urban residents are exposed to an SPL of 65 dB, which causes discomfort to people and exerts a negative effect on their health. Therefore, it is important and urgent to determine methods to use the audio-visual interaction to improve the sound landscape of residential areas.

Studies have shown that vision plays a major role in hearing. Viollon et al. (1998) could demonstrate significant differences in the evaluation of bird twittering, if in addition to the acoustic stimuli on the one hand the picture of an urban environment and on the other hand the picture of a forest were presented. Viollon and Lavandier (1999) examined the effect of images of natural and urban environments on the ratings of sound quality; they found that viewing natural images and hearing natural sounds, such as those of singing birds, were rated as pleasant, whereas viewing urban environments was rated as unpleasant. Thus, the more urban-oriented the visual environment, the poorer the evaluation of sound. Studies on the audio-visual interaction have mostly focused on urban parks, streets, and natural landscapes; however, studies on the audio-visual interaction in residential areas are lacking.

The type, distance, and presence or absence of objects in the field of vision may also affect people's judgment of the soundscape. Ren (2016) pointed that acoustic comforts of sounds relating to people’s participation are increased by artificial landscape objects compared with natural landscape objects. Regarding the effect of the distance to water edge, the acoustic comfort score (based on a five-point scale) of children frolic was found to be higher by 1.06 with a closer view of a waterscape. In city parks, landscapes can be divided into visual and functional landscapes. Liu (2013) indicated that the effects of a visual landscape on the perception of individual sounds can be more important in natural sounds than in artificial sounds. Ke (2017) have also confirmed that the subjective loudness of the greening area in winter is higher than that of an area without greening. The difference in subjective loudness increases with an increase in SPL. In addition, the difference in acoustic comfort and pleasantness is smaller between different greening conditions in spring and summer. However, additional studies on the effect of a change in the volume ratio of residential buildings on the soundscape need to be conducted.

Some previous studies indicated that people's judgement of the soundscape can also be effected with different colour of objects. The effect of different colours on loudness judgements was first examined by Patsouras et al.(2002) they found that the images of red trains caused an increase in the loudness judgement compared with the images of pale green trains. In addition, Menzel (2007) confirmed that some colours can increase or reduce the loudness judgment; however, the effects showed a large inter individual variability. Some participants were apparently not affected by the presented visual stimulus, whereas some participants overestimated or underestimated loudness by approximately 1%–5% with the maximum being up to 9%. Colours such as red and pink appear to cause an increase in loudness, whereas grey and pale green reduced loudness. The effect of colour on the soundscape has been thoroughly studied. However, studies evaluating the effect of the colour of residential buildings with different floor area ratios on the soundscape are lacking.

Therefore, taking residential areas with different floor area ratios as an example, this study investigated the effect of visual changes in building floor area ratios and surface colour on sound attention, sound satisfaction, and the correlation between attention and satisfaction.

2. Methodology

2.1. Auditory and visual materials

The sound used in the experiment was recorded in a typical Community in Harbin city, China, as shown in Figure 1. The district is back to the main road of traffic. The recording place is in the courtyard of the residential area, 30 m away from the road and free of obstacles. The traffic noise is obvious, and fountains are present in the courtyard of the district. With many pedestrians and children often playing in the downstairs square, the sound source is rich. We recorded one minute of sound, which included the sounds of traffic, children's noise, wind, birdsong, footsteps, and water.

The experimental picture is taken from the Bund capital community of Harbin City, Heilongjiang Province, China. The location is shown in *Figure 2*. The north part of the district has high-rise buildings, whereas the south part has multi-storey buildings. Both the north and south parts have the same building shape and colour, but the floor area ratio is considerably different. We selected a location in the middle of the road in the area with multi-storey buildings, the intersection area of areas with high-rise and multi-storey buildings, and the high-rise building area, so that most of the buildings appear on both sides of the field of view, with few buildings in the front. This ensured that only the height of the building changes, not the position of the building. Pictures were taken 1.6 m above the ground, buildings on both sides were 13 m away from the shooting site, and the horizon was a quarter of the picture below. Finally, three pictures were screened out. These three pictures respectively showed low residential density (floor area ratio 1.2, 5-story building), medium (floor area ratio 3.0, two buildings with 20 and 5 stories in the site,), high (floor area ratio 4.2, 20-story building), marked as LOW, MID,and HIG.

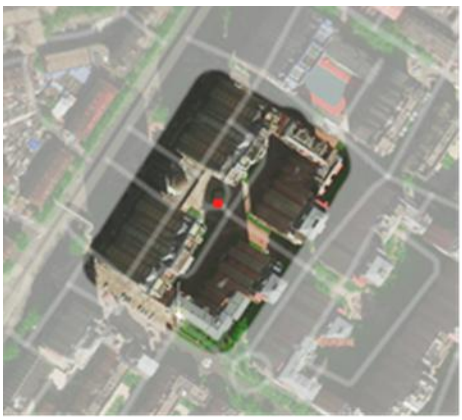

Figure 1: Location of sound collection

Figure 2: Location of image collection

2.2. Post processing

Adobe Photoshop CC 2016 was used to postprocess photos; adjust colour levels and curves; adjust the position of the horizon; unify the sky; and make the light and shade of photos, the position of the horizon, the colour of the sky, and other factors consistent. These photos were shot in early spring when plants are not budding; thus, the plant density would not be a variable of visual characteristics.

Because residential buildings are equally spaced (30 m), an increase in the floor area ratio indicates an increase in building height and a higher amount of sky obscurity. We used ‘Class percentages in the Picture’ (CP_Sky) to represent a visual change in the floor area ratio. Photoshop2016 was used to change the architectural colour of the three pictures from H: 45, S: 10, B: 90 (white) to H: 0, S: 15, B: 50 (dark red) to create three new pictures. Finally, six pictures were obtained, and the recorded sound was processed using Premiere CS4 software for video production, producing six 50-second videos. The video had the same sound but different pictures and were named as L (white, CP_Sky = 31.8%), M (white, CP_Sky = 17.4%), H (white, CP_Sky = 3.6%), l (red, CP_Sky = 31.8%), m (red, CP_Sky = 17.4%), and h (red, CP_Sky = 3.6%) in the order shown in *Figure 3*.

LOW MID HIG

Figure 3: Pictures used in the survey

2.3. Questionnaire survey

In the questionnaire survey, the participants were told to watch only one of the six videos and completed a questionnaire every day for six days, to avoid the possible influences of remembering the sound. First, participants were asked to write down their gender, age, educational background, and occupation. We included a total of 29 participants (17 men and 12 women). Of 29 participants, 25 were undergraduate or graduate students with different educational backgrounds and were aged between 20 and 29 years. The remaining participants were aged between 40 and 49 years.

Participants were asked to complete a seven-level scale describing the source of attention. The scale included sounds of traffic, wind, birdsong, footsteps, water, and children's playing noises. In addition, scale items could describe people's attention to sound sources, ranging from ‘total lack of impression’ to ‘my mind is full of this sound’. Finally, participants were asked to complete a seven-level scale describing satisfaction for the aforementioned six sounds, ranging from one to seven to express dissatisfaction to satisfaction.

2.4. Data analysis

The reliability of the questionnaire was test using Cronbach's alpha coefficient. Differences among groups were compared with the Shapiro–Wilk test, since the sample size was less than 50. Because of the skewed distribution of questionnaire data, the independent-sample Mann–Whitney non-parametric test was used to compare differences between groups, and finally, Spearman analysis was performed.

3. RESULTS

3.1. Effect of CP_Sky on the Soundscape

3.1.1. Effect of CP_Sky on sound attention and satisfaction

First, participants watched L, M, and H (three) videos, and the video mainly contained 6 types of sound. Based on data provided by participants in the seven-level scale to describe the source of attention, a box diagram was plotted (*Figure 4*). We used the independent-sample Mann–Whitney nonparametric test to compare the difference in sound attention among L, M, and H groups. The p value of the test result is shown in *Table 1*.

The sounds of traffic, wind, footsteps, water, and children's voices shown in Figure 5 were not significant.

The effect of CP_Sky on sound attention was not strong. As shown in Figure 4, the highest score for attention to children's playing noise in the L group was 7 (the sound occupies my entire brain), which was the same as in the other two groups, whereas the first quartile(4) was significantly different from that in the other two groups. Some participants indicated that a high CP_Sky reduced attention to children's loud sounds, and there was little change in traffic, wind, water, and footstep sounds.

According to the results of the non-parametric test, significant differences were observed only in the group comparisons for the sound of birdsong, as shown in Figure 5. As determined using the Mann–Whitney test, the p value was 0.043 for both L and M groups, which was significantly different. The median value of concern was 4.9, which was 0.9 higher than that in the M group, and the upper and lower quartile numbers were 6 and 4, respectively, both higher by 1 than that in the M group. The overall decline in the M group compared with the L group suggests that birdsong was significantly more visible and more audible in the visual environment of low-density buildings.

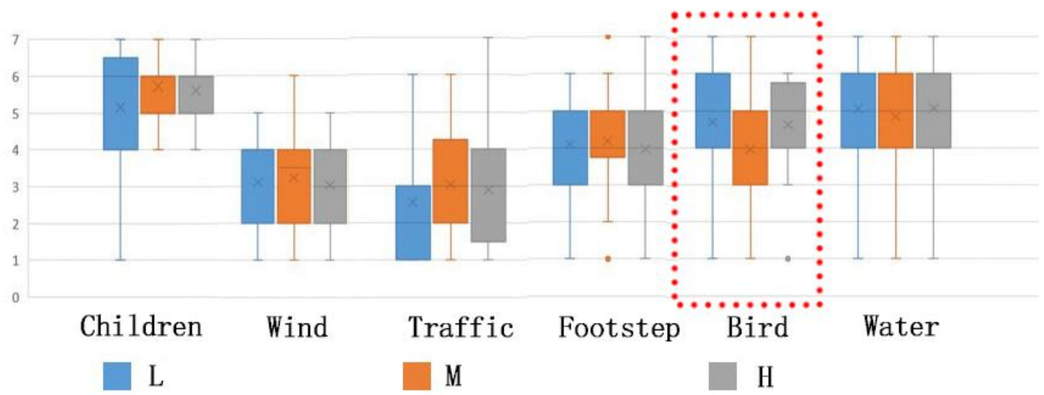

Figure 4: Box Chart Describing attention of sound

Table 1: The influence of CP_Sky on sound attention of sound

Sound source/Group	L-M	L-H	M-H
Traffic	0.318	0.554	0.655
Wind	0.900	0.827	0.695
Bird	0.043	0.241	0.388
Footstep	0.430	0.691	0.258
Water	0.607	0.960	0.587
Children	0.823	0.328	0.389

In the second step, participants watched three videos, L, M and H, and completed the seven-level scale to describe their satisfaction with the sound source; by using the scale's data, a box diagram was plotted. As shown in *Figure 5* the Mann–Whitney non-parametric test was performed to compare the difference in source satisfaction among L, M, and H groups. the mean value of satisfaction of wind was 4.2, 0.6 and 1 less than the other two groups. The p value of the test result is shown in *Table 2*.

As shown in *Table 2*, the Mann–Whitney test results for the sounds of wind, traffic, footsteps, water, and children's voices were not significant. The effect of CP_Sky on satisfaction of sound was not strong, and satisfaction with the sounds of birdsong, underwater, and traffic showed almost no change. According to the results of the non-parametric test, significant differences were found only in the comparisons of wind satisfaction of sound among the groups. The p value between groups M and H was 0.028, and the median value of group H was 0.9 higher than that of group M. The overall distribution of wind satisfaction of sound data in group M decreased.

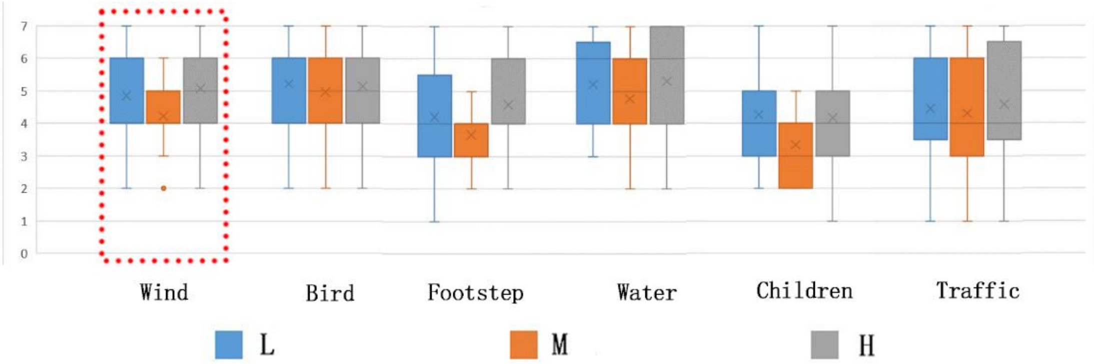

Figure 5: Box chart describing satisfaction of sound

Table 2 : The influence of CP_Sky on satisfaction of sound

Sound source/Group	L-M	L-H	M-H
Traffic	0.700	0.816	0.567
Wind	0.456	0.538	0.028
Bird	0.348	0.637	0.637
Footstep	0.542	0.324	0.105
Water	0.313	0.701	0.146
Children	0.154	0.902	0.252

3.1.2. Effect of CP_Sky on the correlation between sound attention and satisfaction

The results of Spearman analysis for satisfaction of sound and attention in groups L, M, and H are shown in *Table 3*. A significant positive correlation was observed between the degree of attention and satisfaction for the sound of water in the three groups. The *p* value was <0.05, indicating that the more obvious the sound of water, the more comfortable the residents feel. The correlation among the three groups was maintained at a *p* value of approximately 0.55, indicating that the correlation between satisfaction and attention was not affected by vision, and people's love of underwater sound was not affected by CP_Sky in the residential area.

Regarding the correlation for the sound of birdsong, correlation coefficient values were 0.039, 0.002, and 0.0003 for L, M, and H groups, respectively, which showed a significant positive correlation among the three groups. This finding indicates that the more obvious the sound of birdsong, the happier the residents feel. The correlation coefficient increased with an increase in the floor area ratio of residential buildings, which was 0.397, 0.520, and 0.775 for L, M, and H groups, respectively. This suggests that the higher the density of the residential area, the more people like the birdsong. This may be because the higher the building, the more urbanised the visual sensation and the more people yearn for the natural environment; thus, the birdsong is particularly sensitive.

We then tested the correlation for the sound of traffic among the three groups. The *p* values were 0.001, 0.006, and 0.039, for L, M, and H groups, all of which showed significant negative correlations. This finding indicates that the more obvious the sound of traffic, the more irritable it becomes. The correlation coefficients decreased with a decrease in CP_Sky to −0. 550, −0.526, and −0.386 in L, M, and H groups, respectively. This shows that the lower the building height, the greater the area of exposed sky and the lower the people's tolerance to traffic noise. This may be because the height of buildings is reduced, and the visual environment tends to be closer to the natural environment. People find it difficult to bear the noise of traffic in the natural scenery. By contrast, the dense building mass makes people feel that there should be more vehicles in the city; thus, their tolerance for traffic noise becomes higher.

No significant correlation was observed between the perception and satisfaction of children's noise. However, the H group's *p* value (0.079) was very close to 0.05; thus, the irrelevance may have been due to the low sample size. We also interviewed participants of different ages, many of whom were aged more than 50 years; older participants indicated that in the third group, the level of boredom caused by children's noise decreased significantly compared with the first two groups.

The correlation between attention and satisfaction for the sound of wind was not significant. The *p*value was considerably higher than 0.05, and similar findings were found for footsteps. This finding suggests that changes in CP_Sky in the residential area do not affect the relationship between sound attention and satisfaction.

Table 3: Effect of CP_Sky on the correlation between attention and satisfaction of sound

Sound source	**Group**	**L**	**M**	**H**
Traffic	Correlation coefficient	-0.390*	-0.213	-0.125
	p	0.030	0.306	0.518
Wind	Correlation coefficient	-0.269	0.081	0.320
	p	0.144	0.699	0.091
Bird	Correlation coefficient	0.529**	0.364	0.347
	p	0.002	0.074	0.065
Footstep	Correlation coefficient	-0.136	-0.295	-0.350
	p	0.465	0.153	0.063
Water	Correlation coefficient	0.155	0.428*	0.432*
	p	0.405	0.033	0.019
Children	Correlation coefficient	0.038	-0.221	0.112
	p	0.840	0.289	0.562

3.2. Effect of building colour on the soundscape

3.2.1. Effect of Building Colour on Attention and Satisfaction of Sound

Contrast the attention of group L with group L, group M with group M, group H with group H. The results of the Mann–Whitney test are shown in *Table 4*. The results of the non-parametric test were not significant, and the building colour exerted no effect on sound attention.

Table 4: Effect of Building Colour on attention of sound

Sound source/Group	Traffic	Wind	Bird	Footstep	Water	Children
L-i	0.820	0.784	0.179	0.705	0.460	0.787
M-m	0.111	0.250	0.275	0.587	0.477	0.871
H-h	0.843	0.654	0.495	0.151	0.144	0.741

Contrast the satisfaction of group L with group L, group M with group M, group H with group H. We used the Mann–Whitney non-parametric test to determine the change in satisfaction of sound with a change in building colour. The results are shown in *Table 5*.

Table 5: Effect of Building Colour on satisfaction of sound

Sound source/Group	Traffic	Wind	Bird	Footstep	Water	Children
L-i	0.846	0.716	0.937	0.793	0.645	0.383
M-m	0.352	0.047	0.069	0.032	0.282	0.593
H-h	0.631	0.046	0.401	0.150	0.102	0.136

When the floor area ratio was L, test results were not significant, and satisfaction of sound was not affected by building colour. When the floor area ratio was M, the non-parametric test results for the sounds of wind and footstep were 0.047 and 0.032, respectively, which were significantly different.

As shown in *Figure 6*, when the colour changed, the number of selection 4 (no sensation) on the seven-grade scale for the sound of wind decreased from 13 to 9, the number of selection 7 (very satisfactory) increased from 0 to 6, and the average level increased from 20.02 to 27.50, and participants felt more satisfied with the wind sound as a whole. When the colour changed, the number of selection 4 on the seven-grade scale for the sound of footstep decreased from 13 to 10, the number of 7 selection increased from 0 to 4, and the average level increased from 20.79 to 29.04. Participants felt more satisfied with the overall sound of footsteps.

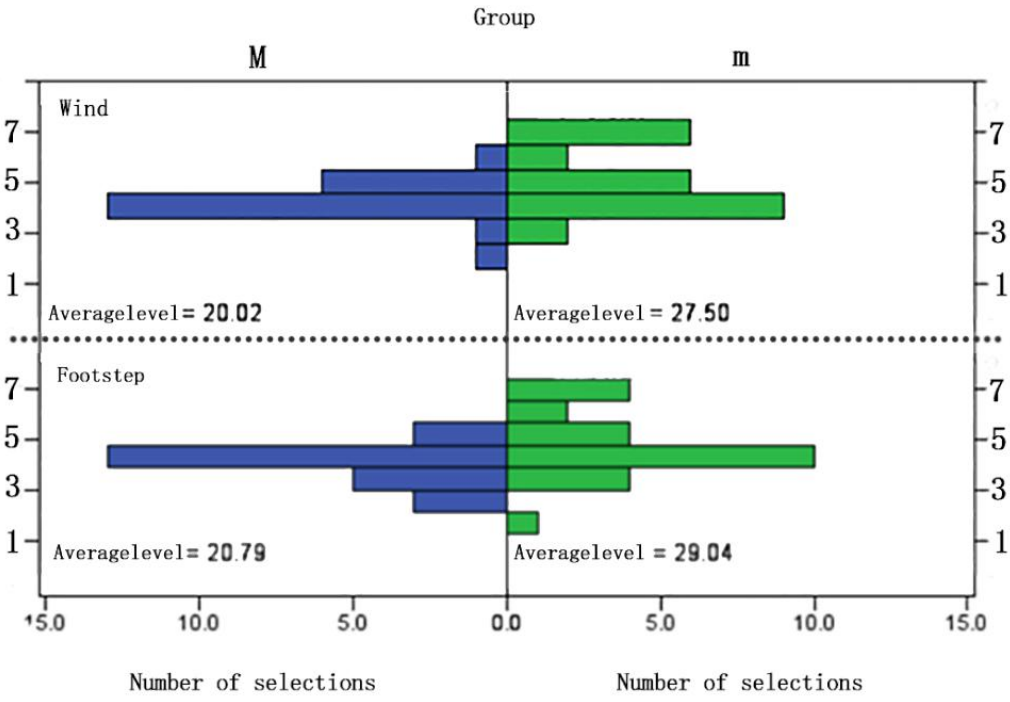

Figure 6: Selection of seven-grade scale of satisfaction

When the floor area ratio was H, the non-parametric test result for the sound of wind was 0.046, as shown in *Figure 7*. When the colour changed, the number of selection 4 on the seven-grade scale for the sound of wind increased from 16 to 17, and the number of selection 7 decreased from 6 to 0. The average level decreased from 32.33 to 24.39, and participants' satisfaction with the sound of wind decreased after a change in colour.

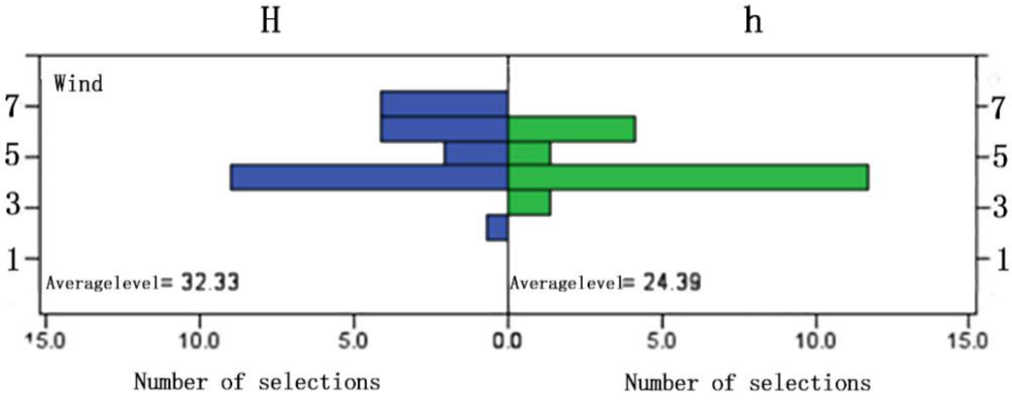

Figure 7: When the floor area ratio was H, selection of seven-grade scale of satisfaction

3.2.2. Effect of Building Colour on Correlation BetweenAttention and Satisfaction of Sound

After changing the colour of the building, the correlation between attention and satisfaction for the sounds of traffic noise, birdsong, and water changed, as shown in *Table 6*.

The correlation between attention and satisfaction for the sound of traffic decreased with a change in the colour. The correlation coefficient decreased from −0.550 to −0.390 when the floor area ratio was LOW and changed from significant correlation (p = 0.006 and 0.039, respectively) to no correlation (p = 0.306 and 0.518, respectively) when the floor area ratio was MID and HIG.

The correlation coefficient for the sound of birdsong increased from 0.397 to 0.529 when the floor area ratio was LOW after a change in the colour, which was the only case where the correlation increased after a colour change. When the floor area ratio was MID and HIG, the correlation changed from significant (p = 0.002 and p = 0.000, respectively) to non-significant (p = 0.074 and 0.065, respectively).

When the floor area ratio was LOW after a change in colour, the correlation for the sound of water changed from significant (p = 0.002) to non-significant (p = 0.405). Furthermore, when the building volume ratio was MID, the correlation decreased from 0.671 to 0.428, and when the floor area ratio was HIG, the correlation decreased from 0.472 to 0.432. A change in building colour diminished the overall correlation for the sound of water.

Irrespective of conditions, the correlation between attention and satisfaction was not significant for the sounds of wind, footsteps, and children's noise, and the change in floor colour caused a shift in people's attention from sound to vision.

Table 6 : Effect of Building Colour on Correlation BetweenAttention and Satisfaction of Sound

Colour	**Traffic**	**LOW**	**MID**	**HIG**
Original (white)	Correlation coefficient	-0.550**	-0.526**	-0.386*
	p	0.001	0.006	0.039
Change colour (red)	Correlation coefficient	-0.390*	-0.213	-0.125
	p	0.030	0.306	0.518
Colour	**Wind**	**LOW**	**MID**	**HIG**
Original (white)	Correlation coefficient	0.196	0.047	0.117
	p	0.275	0.819	0.546
Change colour (red)	Correlation coefficient	-0.269	0.081	0.320
	p	0.144	0.699	0.091
Colour	**Bird**	**LOW**	**MID**	**HIG**
Original (white)	Correlation coefficient	0.397*	0.520**	0.775**
	p	0.045	0.002	0.000
Change colour (red)	Correlation coefficient	0.529**	0.364	0.347
	p	0.002	0.074	0.065
Colour	**Footstep**	**LOW**	**MID**	**HIG**
Original (white)	Correlation coefficient	-0.177	-0.083	-0.061
	p	0.324	0.688	0.753
Change colour (red)	Correlation coefficient	-0.136	-0.295	-0.350
	p	0.465	0.153	0.063
Colour	**Water**	**LOW**	**MID**	**HIG**
Original (white)	Correlation coefficient	0.527**	0.671**	0.472**
	p	0.002	0.000	0.010
Change colour (red)	Correlation coefficient	0.155	0.428*	0.432*
	p	0.405	0.033	0.019
Colour	**Children**	**LOW**	**MID**	**HIG**
Original (white)	Correlation coefficient	0.127	-0.220	-0.331
	p	0.480	0.281	0.079
Change colour (red)	Correlation coefficient	0.038	-0.221	0.112
	p	0.840	0.289	0.562

4. CONCLUSIONS

In this study, the effects of the change in surface colour on sound attention and satisfaction, as well as the correlation between sound attention and satisfaction were investigated in residential plots with different floor area ratios.

First, CP_Sky showed little effect on sound attention. The effect of CP_Sky on satisfaction of sound was also limited, except for sound of wind, and participants' satisfaction with the sound of wind satisfaction decreased slightly with an increase in the building floor area ratio. Furthermore, CP_Sky affected the correlation between attention and satisfaction for the sounds of traffic and birdsong. The correlation coefficient between attention and satisfaction for the sound of birdsong increased with a decrease in CP_Sky. The higher the floor area ratio, the more people like the sound of birds. This may be because the higher the building, the more urbanised the visual perception and the more people yearn for the natural environment. The correlation coefficient between traffic noise attention and satisfaction decreased with a decrease in CP_Sky, indicating that the higher the building, the stronger the tolerance to traffic noise.

Second, building colour exerted no effect on sound attention but some effect on satisfaction of sound. Furthermore, when the floor area ratio was L, building colour showed no effect. However, participants' satisfaction for the sounds of wind and footsteps improved when the floor area ratio was M. Colour also affected the relationship between satisfaction and attention. Under different floor area ratios, the correlation between satisfaction and attention for the sounds of traffic, birdsong, and water decreased after the building became brighter. This suggests that colour affects attention to sound, reduces boredom of negative sounds, and reduces the likeness of good sounds. Changes in building colour can shift people's attention from audio to vision, irrespective of whether the sound is good or bad. For residential areas where traffic noise is difficult to block, the colour of buildings can be changed and residents' attention can be diverted.

5. ACKNOWLEDGEMENTS

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