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Integrating acoustics engineering and soundscape design for an urban park: a case study

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ABSTRACT

A new urban park is proposed in the centre of Stockton-on-Tees, England. One of the design's features is the incorporation of a road, which will be converted from a dual to a single-carriageway. How will the road traffic noise affect the soundscape for the users of the various park spaces? A combination of methods such as noise propagation modelling and newly developed soundscape assessment and analysis tools, were used to answer this question. This approach identified the most significant acoustic risks for the current design and proposed improvements for the sonic environment.
The challenges encountered with this novel practical application of the soundscape method in a commercial context are discussed.

Keywords: *soundscape, urban park, acoustics.*

1. INTRODUCTION

This paper presents a combined soundscape and acoustic engineering approach to evaluate the sound environment for the proposed Stockton Urban Park and Waterfront. The park will feature event areas for concerts with amplified sound. Part of the existing Riverside Road (A1305) will be reduced from a dual to a single carriageway, and the existing Castlegate shopping centre and Swallow Hotel will be demolished. To support a planning application, Apex Acoustics previously conducted a noise impact assessment for the site to identify the noise risks for existing sensitive receptors from proposed activities within the park [1]. The portion of work reported here concerns the acoustic characteristics of the future park. A soundscape survey was carried out at two locations near the development site, and the data was analysed to provide insight into the future soundscape of the park and mixed-use spaces.
Since there are no standard guidelines for a soundscape consultation, this paper outlines the discussions, analysis, and considerations made to develop a soundscape-focused assessment and design for the Stockton Waterfront project.

Figure 1. Site location outlined in red

2. METHODOLOGY

The soundscape assessment survey was carried out on November 23rd and 24th of 2022. The survey was guided by ISO 12913:2-2018 [2] and the SSID Protocol [3], with adjustments made to accommodate the site's limitations and the project's practical constraints.

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2.1 Technical framework for assessing soundscape

ISO/TS 12913-2:2018 [2] is a reference document for soundscape studies' data collection and reporting. It covers two main approaches: soundwalks with questionnaires (Methods A and B) and narrative interviews (Method C). Part 3 of ISO 12913 [4] provides guidelines for analysing data from these methods. The SSID Protocol [3], developed by UCL's Soundscape Indices Group, is another method for soundscape surveys. It consists of a Recording Stage and a Questionnaire Stage.
For this assessment, only the Questionnaire Stage is used. The goal was to collect enough responses per location to assess the soundscape's 'collective perception' [5]. Details about the protocol and questionnaire are in the SSID Protocol [3]. An example questionnaire can be found here.

2.2 Perceptual Attributes and the Soundscape Circumplex

The soundscape circumplex, as initially proposed by Axelsson et al. [3], is the primary tool for characterising a soundscape using a quantitative approach. It comprises two main dimensions of perceptual attributes: pleasantness and eventfulness. These are distinct from the physical properties of the acoustic environment and are used to appraise the quality of sounds. The common model representing these dimensions is a bi-dimensional circumplex model with pleasantness on the X-axis and eventfulness on the Y-axis. In addition to the primary dimensions, there is a set of additional axes rotated 45° from the main axes containing additional attributes: 'vibrant', 'chaotic', 'monotonous', and 'calm'.
This results in eight descriptors [3], or Perceptual Attributes (PA), which together describe a soundscape: pleasant, vibrant, eventful, chaotic, annoying, monotonous, uneventful, and calm. The soundscape questionnaire collects these PAs through a series of questions with 5-point Likert-type responses as this scale is commonly used in questionnaires and can be easily interchanged.

2.3 Soundscape circumplex coordinates

A new soundscape analysis method summarises perception within one coordinate point on an XY plane formed by pleasant and eventful axes. This is achieved by projecting the eight individual PA responses onto these axes and plotting each survey response as a scatter point for comparison, as shown in Figure 3. The advantage of using the scatter plot is that allows direct and simple comparisons between measurements with different attributes.

The derived coordinate points are called ISOPleasant and ISOEventful values [9][4]. This projection method was originally proposed in ISO/TS 12913-3 [3], although it was originally intended to be used only with the median PA value; the projection of each individual response as done here was further proposed in [9].

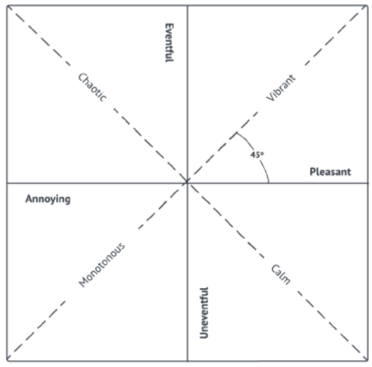

Figure 2. The soundscape circumplex as originally derived by Axelsson at al. (2010) and updated in ISO/TS 12913-2:2018.

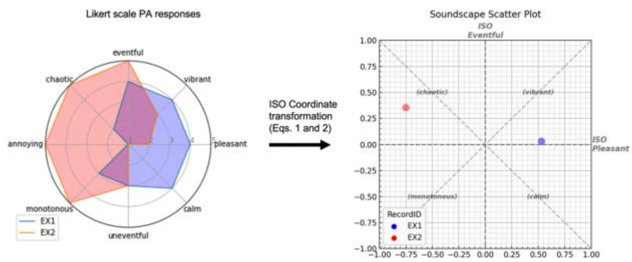

Figure 3. Example of representations of two soundscape assessments. Left: Radar plot of two example perceptual attributes (PA) ratings on the Likert scale (1-25). Right: Scatter plot of the same assessments on the soundscape circumplex, transformed according to ISO 12913 Part 3. Reproduced with permission from [6].

3. DATA COLLECTION AND ANALYSIS

A survey was carried out to collect questionnaire responses and psychoacoustic measurements at two locations, labelled P2 and P6, in Figure 4. The questionnaire was adapted from ISO 12913-2, and participants were chosen randomly. A total of 32 participants submitted responses. To enable a potential analysis and a before-after comparison of the site soundscape, binaural recordings were made using a HEAD Acoustics binaural sensor unit (BSU) connected to a Head Acoustics data acquisition system SQobold. These recordings were cross-referenced with the questionnaire responses to obtain psychoacoustic indicators. Additional binaural recordings were taken using the APEAL Method developed by Apex Acoustics [10]. The APEAL Method is a form of binaural audio with point of view video recording. The video was captured with an iPhone, and the binaural audio with a Soundman OKM-II studio set. These recordings were used to offer additional elucidation and insight into the questionnaire answers, as well as to aid readers in grasping the context in this document.

Figure 4. Soundscape assessments positions (P2 and P6).

3.1 Location P2

Location P2 was chosen to assess the soundscape along Stockton's High Street, near the proposed development. The High Street will remain unchanged after the development, so its soundscape and impact on the development's west end should be considered.
A survey was conducted on November 24th 2022, from 11:00 to 13:00 hrs under cloudy conditions with no precipitation and an average temperature of 5°C. Minor demolition works were happening during the survey. The site was busy with pubs, casinos, charity shops and a bus stop. The survey resulted in 11 questionnaire responses and 9 binaural recordings; however, only 5 recordings were included in the analysis after data validation, due to contamination with speech from the participants.

3.2 Location P6

Location P6 was chosen to represent the potential soundscape of the proposed development's waterfront side. A survey was conducted on November 23rd 2023, from 14:00 to 16:00 hrs under partly cloudy conditions with no precipitation and an average temperature of 7°C. The site is a relatively tranquil area used by dog walkers, near a dual carriageway with constant traffic noise. The survey resulted in 18 questionnaire responses and 13 binaural recordings; however, only 6 recordings were included in the analysis after data validation.

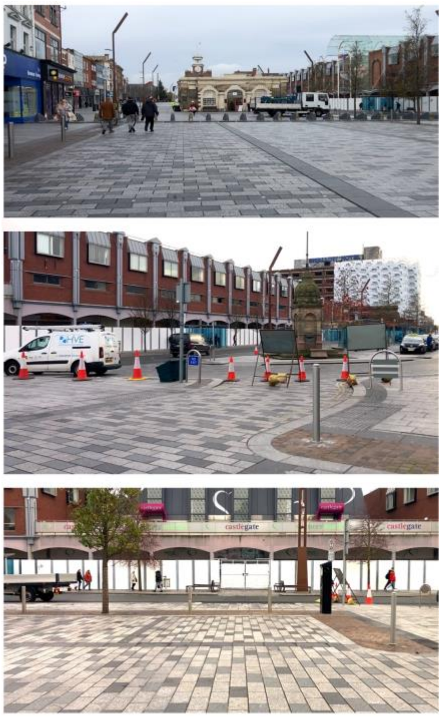

Figure 5. Street view of Location P2, click here to see a video with binaural sound.

3.3 Data analysis

The primary tool used for data analysis and visualisations was `soundscapy`, an open-source soundscape analysis package specifically developed to process data collected according to either the ISO 12913 or SSID Protocols [2][3].

3.4 Psychoacoustic Measurements

There is currently no agreed-upon suite of metrics or standardised approach to link metrics to soundscape perception without survey responses. ISO/TS 12913-2 recommends measuring and reporting classical acoustic indicators such as $L_{Aeq,T}$ and $L_{Ceq,T}$, reported to be in conformance with ISO 1996-1 [12][13].

Psychoacoustic loudness and additional psychoacoustic parameters (e.g., sharpness, tonality, roughness, and fluctuation strength) can be reported, but ISO/TS 12913-2 does not provide a recommended strategy for assessing their outcome.
The binaural recordings taken during the soundscape survey were processed using soundscapy to calculate psychoacoustic metrics. Within the SSID Protocol, these measurements are intended to be compared to questionnaires to determine the relationship between sonic characteristics and soundscape perception.
Direct comparisons between psychoacoustic features and survey results cannot be made, but the sound environment can still be documented per ISO/TS 12913-2.

Figure 6. Street view of Location P6, click here to see a video with binaural sound.

4. RESULTS AND RECOMMENDATIONS

The following Sections present the results of our analysis of the soundscape survey data.

4.1 Psychoacoustic Results

The results of the psychoacoustic measurements in each location are presented in Tables 1 and 2.
The average dB(A) level between the two locations is not significantly different ($L_{Aeq,P2}$ = 68.4 dB, $L_{Aeq,P6}$ = 66.7 dB). However, their psychoacoustic loudness levels differ greatly ($N_{5,P2}$ = 29.0 dB, $N_{5,P6}$ = 20.5 dB).
The difference between foreground and background levels at P2 is also much higher than at P6, indicating a more variable sound environment. Sharpness and Roughness are reported as per the Standard but are not used to draw conclusions.

4.2 Soundscape perceptual attributes

Figure 7 shows the Likert analysis of the perceptual attributes from the questionnaires. Each attribute is displayed as a stacked bar chart centred on the neutral response.
The attributes follow a circumplex arrangement and show a consistent pattern with an identifiable peak indicating the general character of the soundscape. For example, Location P2 has a peak at 'chaotic' while Location P6 peaks at 'calm/pleasant' with strong disagreement for 'Annoying/Chaotic'. P6 also has a lower proportion of neutral responses indicating stronger agreement that it is calm.

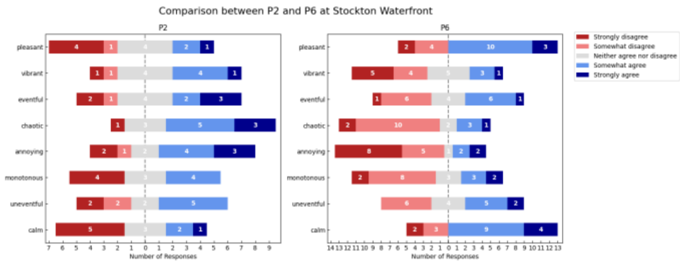

Figure 7. Likert scale counts for the Perceptual Attributes

Table 1. Location P2 Psychoacoustics results.

Recording	L_{eq}	L_{Aeq}	L_{A10}	L_{A90}	L_{Ceq}	N_5	S	R	L_C-L_A	L_{A10}-L_{A90}
P2TK01	78.0	72.5	75.8	63.2	77.2	39.3	1.1	0.1	4.8	12.6
P2TK04	77.8	68.2	72.1	62.4	77.1	31.4	1.0	0.1	8.9	9.7
P2TK05	79.8	69.0	71.1	65.8	78.2	29.4	1.1	0.1	9.3	5.4
P2TK06	75.9	65.5	67.1	63.3	74.7	21.5	1.0	0.1	9.2	3.8

P2TK09	76.4	66.9	69.0	63.8	74.3	23.6	1.1	0.1	7.4	5.2
MEAN:	77.6	68.4	71.0	63.7	76.3	29.0	1.1	0.1	7.9	7.3

Table 2. Location P6 Psychoacoustics results.

Recording	L_{eq}	L_{Aeq}	L_{A10}	L_{A90}	L_{Ceq}	N_5	S	R	L_C-L_A	L_{A10}-L_{A90}
P6TK03	71.9	66.5	68.0	64.7	70.3	19.6	1.1	0.1	3.8	3.4
P6TK04	72.2	66.2	67.9	63.7	70.9	20.0	1.0	0.1	4.7	4.2
P6TK06	73.0	66.8	68.5	64.2	71.8	21.9	1.0	0.1	5.0	4.4
P6TK07	72.6	66.8	67.6	65.7	70.8	19.9	1.0	0.1	4.1	1.9
P6TK08	72.0	66.6	68.4	64.2	70.9	20.7	1.0	0.1	4.3	4.2
P6TK12	72.1	67.2	68.9	64.3	70.9	20.9	1.0	0.0	3.8	4.6
MEAN:	72.3	66.7	68.2	64.5	70.9	20.5	1.0	0.1	4.3	3.8

4.3 Perceived loudness

Figure 8 shows the Likert-scale responses to the question of how loud the sound environment is. P2 is considered generally loud, while P6 has a balance of responses. Figure 9 shows a relationship between increased perceived loudness and decreased pleasantness for P6 only. This indicates that P6 indeed benefits from a decrease in perceived loudness and that the threshold for pleasantness (i.e. where the ISOPleasant score crosses 0) occurs at a perceived loudness level of 3 ('very loud').

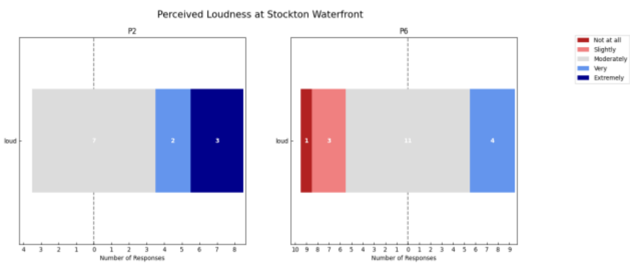

Figure 8. Likert scale analysis of perceived loudness responses

As previously mentioned, we are currently unable to reliably link psychoacoustic measurements with their corresponding surveys. This means we cannot establish a specific objective threshold for what is considered 'very loud' in this situation. However, the average L_{Aeq} values for both locations are similar, while the N_5 for P2 is significantly higher, which aligns with the perceived loudness.

When considering noise reduction measures, the emphasis should be on reducing the psychoacoustic loudness level rather than the L_{Aeq}. This is likely to have a greater effect on improving the pleasantness of the soundscape.

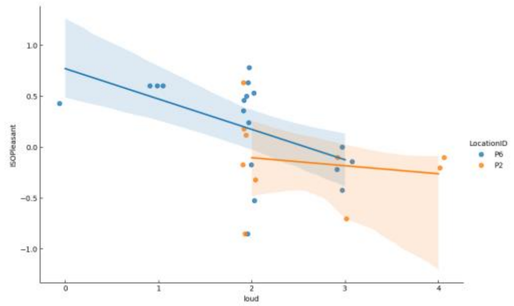

Figure 9. Likert scale analysis of perceived loudness responses

4.4 Sound source dominance analysis

Figure 10 shows the relative dominance of four types of sound sources: traffic noise (e.g. cars, buses, trains, airplanes), other noise (e.g. sirens, construction, industry, loading of goods), human sounds (e.g. conversation, laughter, children playing, footsteps), and natural sounds (e.g. birds singing, water flowing, wind in vegetation).

In locations P2 and P6, traffic noise is similarly dominant. However, P2 has high levels of other noise and human sounds, while other sound types are barely present in P6. Despite the high perceived dominance of traffic noise at P6, the soundscape is still considered pleasant and calm. This indicates that the carriageway does not have a significant negative impact on the waterfront soundscape.

The consistent background sound of traffic noise at P6 is not perceived as annoying at the observed sound level. During our site visit, subjective perception indicated that the area around P6 was the calmest part of the site, which may have influenced this result. However, if quieter locations are accessible, such as in the proposed park, the perception of noise may vary.

Comparing the two locations suggests that the negative perception of P2 is driven by other noise sources and human sounds rather than traffic noise. Removing the existing shopping centre is expected to improve the soundscape in the western part of the park.

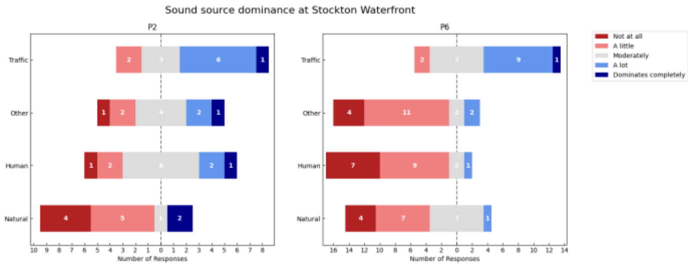

Figure 10. Dominance of various sound source types in locations P2 and P6.

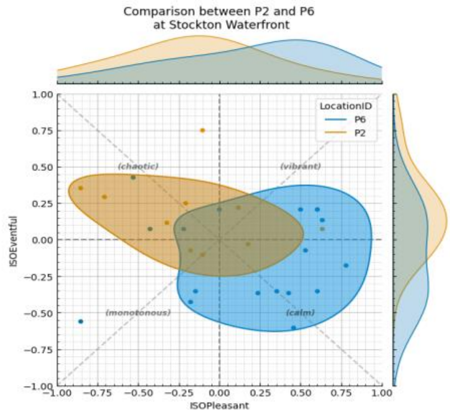

Figure 11. Soundscape distribution plots for locations P2 and P6. Generated using Soundscapy.

Table 3. Summary of survey results. ISOPleasant/ISOEventful column reports the mean coordinate value for all responses. 'pleasant' and 'eventful' report the percentage of responses which fall on the pleasant or eventful half of the circumplex. 'vibrant', 'chaotic', 'monotonous', 'calm' report the percentage of responses which fall within the given quadrant.

Location		Mean Response		% in half-plane		% in quadrant			
ID	Count	ISO-Pleasant	ISO-Eventful	Pleasant	Eventful	Vibrant	Chaotic	Monotonous	Calm
P6	18	0.188	-0.117	0.611	0.444	0.222	0.167	0.167	0.389
P2	10	-0.155	0.185	0.300	0.700	0.200	0.500	0.200	0.100

4.5 Soundscapy-style analysis

The distribution of responses within the soundscape circumplex is summarised in Table 3. Figure 11 presents these results graphically. Given the limited number of survey responses that could be collected, these results should be interpreted cautiously.

As shown in Figure 11, P6 is predominantly considered 'pleasant' and 'calm', with occasional 'vibrancy'.

Figure 9 analysis suggests that reducing loudness near the waterfront park areas could increase the ISOPleasant score. The activities introduced by these park areas may also increase vibrancy. While we cannot quantify the benefits of reducing traffic noise, an increase in ISOPleasant score is expected, making these park areas better suited for their intended purpose. P6 represents the waterfront areas within the development, raising the question of whether this is the desired soundscape for these spaces. As shown before, a 'vibrant' soundscape may be more beneficial than a 'calm' one from a soundscape perspective.

This assessment focused on users' sonic experiences during late autumn midweek daytime. Users' aspirations and expectations may vary at different times, potentially leading to different results.

5. MODELLED SOUND ENVIRONMENT

One of the main concerns with noise is excessive levels in certain areas. According to the noise modelling in Figure 12, the area between the roadway and the waterfront experiences the highest impact. The dB(A) noise map and results from P6 suggest that traffic noise from the single-carriageway may not affect the western half of the development. However, this area is currently the only tranquil space for dog walkers and other recreational activities, making it more pleasant compared to other available spaces. Once more tranquil space is available in the newly developed park, road traffic noise may make this area less convivial.

Reducing traffic noise near the waterfront could improve the soundscape quality for park users by making it morepleasant. Potential mitigation solutions are presented in the next Section. Alternatively, making the area more vibrant could also improve its pleasantness.
An alternative to mitigating noise is incorporating features to make the waterfront more vibrant. If this space is intended to be a vibrant area with walkways and human activity, then a louder soundscape may be perceived as appropriate, as suggested by the analysis in Figure 11.

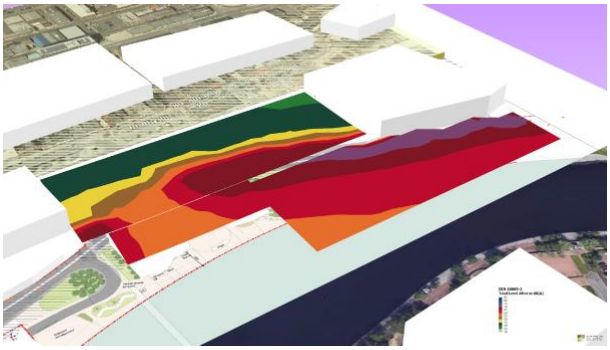

Figure 12. dB(A) Noise map of Stockton Waterfront development

6. RECOMMENDED MITIGATION

A potential solution to improve the soundscape near the waterfront and reduce noise levels at the amphitheatre is to implement a noise barrier 1.8 metres high, as shown in Figure 13. The predicted noise levels with the barrier in place are shown in Figure 14. The overall noise levels near the waterfront are expected to decrease by 7-15 dB(A), while noise levels in the amphitheatre area are expected to decrease by 10-12 dB(A).
These reductions would make the waterfront areas of the park substantially quieter and more pleasant and vibrant, depending on the activities in these areas. The estimated noise reduction in the amphitheatre area would significantly improve the signal-to-noise ratio (SNR) and speech intelligibility, mainly when used without sound amplification.
The perception that a soundscape is appropriate for its visual environment and intended use is crucial to users' overall impression and engagement. Improving the perceived soundscape quality without changing the sound environment or adding additional noise mitigation measures is possible but limited.

Figure 13. Proposed extension for the 1.8 metres height noise barriers (in red)

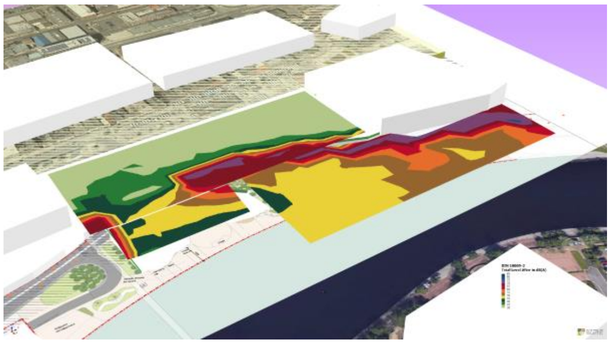

Figure 14. dB(A) Noise map of Stockton Waterfront development with the proposed 1.8 metres height barriers

7. LIMITATIONS AND FUTURE IMPROVEMENTS

As noted, there are currently no standardised or best practice methods for integrating acoustic engineering with a soundscape approach. This case study has attempted to demonstrate how these two disciplines may work in concert to inform a real-world planning project and to identify particular challenges which should be expected and addressed in future projects.
One quickly recognised challenge was that current soundscape assessment methods can only characterise spaces *as they currently exist*. This limited our ability to predict how the proposed design changes would impact the soundscape perception of the Stockton Waterfront. Instead, the results of the soundscape surveys conducted at the currently-existing sites were used to inform the design and cross-referenced with the acoustic modelling of the proposed barriers.
The existence of a model which could predict likely soundscape perception of new designs would allow greater integration of a soundscape approach and human-perception focus into the design process [12].

Although the SSID Protocol was designed to be more efficient and simple to conduct in new spaces than previous methods, the onsite survey proved fairly challenging and time-consuming, limiting the amount of survey data that could be collected. This limited data introduces uncertainty and caveats to interpreting the soundscape assessment results. Efficient data collection methods are needed to improve the application of soundscape methods to more projects.

8. CONCLUSION

The impact of the proposed Stockton Urban Park and Waterfront on potential users was analysed using standard and new acoustic engineering techniques. The study found that the western section may be affected by noise from High Street, but removing the shopping centre can enhance the soundscape. The new single-carriageway traffic noise is unlikely to impact the development negatively. Reducing road traffic noise at the waterfront can improve the perceived soundscape. The methods used can identify noise components other than L_{Aeq}, which can help with suitable design strategies. Future studies should plan well for site surveys and questionnaires to gather a high number of responses.

9. ACKNOWLEDGMENTS

We are grateful to our client for the opportunity to conduct this work.

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