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Soundscape approach integrating noise mapping techniques: a case study in Brighton, UK

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Abstract: In the guidelines about the management of areas of good environmental noise quality recently published by the European Environment Agency (EEA) it is suggested to combine different methodologies, like noise mapping, sound level measurements and the soundscape approach. Such a recommendation has started to be recognised by a number of local authorities in Europe that are gradually integrating a holistic concept into their environmental noise policies. This research aimed to explore and demonstrate the possibility to integrate conventional noise mapping methods and soundscape methods in an actual urban redevelopment project. A case study was made using the Valley Gardens project in Brighton & Hove (UK). Different scenarios of sound-pressure level distributions were simulated for both traffic sound sources (i.e. noise maps) and natural sound sources (i.e. sound maps). Additionally, individual responses about the sound environment of the place collected during an on-site question survey were used to implement soundscape maps.

The overall picture revealed that the road traffic noise should be reduced, but also it is feasible that preferred sounds like water features or birdsong could be introduced to make the sound environment more appropriate for the place. Generally, within the framework of this research, noise maps, sound maps and soundscape maps were used together to "triangulate" different layers of information related to the acoustic environment and the way it is perceived, providing a possible working procedure to consider for planners and policy-makers in the future.

Keywords: Urban sound planning; Noise Mapping; Urban soundscape; Landscape management

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1 Introduction

The Directive 2002/49/EC of the European Parliament and of the Council, more commonly known as the Environmental Noise Directive (END), relates to the assessment and management of environmental noise [1]. Noise mapping is certainly one of the most relevant operational tools that the END relies on, providing visual representations of the yearly average noise levels in a selected area. Within the framework of the END, noise maps are useful to assess easily the populations' noise exposure and consequently to spot areas where noise action plans are required [2]. They can also inform more widely urban sound planning, supporting the land-use definition and assessing possible environmental impacts beforehand. Since the implementation of the END, noise maps have always played a fundamental role in a strategic noise management process. They are useful operative tools in pointing out issues related to community noise exposure. Therefore, much attention has been given in research as well as in policy-making to their development and accuracy (e.g. [3, 4]).

After identifying areas where the noise levels should be reduced, the END also urges the Member States to "preserve environmental noise quality where it is good". Such areas are often referred as "quiet areas"; although the definition of "quiet" provided by the END is limited and it granted the Member States with ample discretion for the interpretation of this concept, which occasionally led to disagreements. Therefore, in order to provide further indications to local authorities, the European Environment Agency (EEA) recently published some guidelines on how to identify and preserve areas of good environmental noise quality [5]. Four complementary methods are there reported and their combined use is recommended: (1) noise mapping, (2) sound level measurements, (3) the soundscape approach, and (4) expert assessments. Similarly, the EAA in its annual report on noise in Europe specified again that "*effects of noise upon the wider soundscape, including wildlife and quiet areas, need further assessment*" [6]. Furthermore, recently, methods and guidelines have been proposed regarding the identification, characterisation, enhancement and management of quiet areas in urban context, as required by the END [7–9].

The acknowledgement of the need for a methods' integration by researchers and stakeholders represents a turning point in the traditional approach to urban sound planning, for which the attitude has mainly been "reactive" to unwanted noise until now. The soundscape approach is playing a relevant role within such an integration process. Soundscape has recently been defined as the "*acoustic environment as perceived or experienced and/or understood by a person or people, in context*" [10]. Research is progressing in this field, as demonstrated by the increasing number of publications investigating perceptual aspects of the acoustic environments in urban and peri-urban contexts [11–13], as well as studies more concerned about how to position the soundscape approach into a broader planning and policy making agenda [14]. Within a design framework, the soundscape approach requires a differentiation between sound sources other than those commonly considered in noise maps (e.g. traffic noise). Even though sound sources might be wanted or unwanted, the noise control approach usually assimilates contributions across all sound sources, whereas the soundscape approach imposes a quality paradigm.

Current research is indeed promoting a holistic rather than a mitigation approach to urban acoustics (e.g. [15–18]) and local authorities are increasingly committed to implement qualitative strategies to noise-related issues into their policies (e.g. [19–21]). This is commonly considered to be the most effective and practical way to achieve better urban acoustic environments [22]. Nevertheless, there is still an ongoing debate about suitable methodologies to integrate quantitative and qualitative approaches for urban sound planning [23]. Several attempts have been made to apply methods that are typical in noise control engineering (i.e. noise mapping) to soundscape studies.

A number of studies have tried to use sound maps, rather than noise maps, by investigating the contribution of specific sound sources (e.g. birdsong) that are not usually considered in noise control policies to the urban acoustic environments [24, 25]. Liu *et al.* [26] used maps to represent the spatial and temporal distribution of sound sources –other than traffic sources– defining the urban soundscape and also investigated the relationships between such distributions and landscape spatial pattern indices [27]. Hong and Jeon [28] analysed physical and perceptual soundscape data collected in a case study area to develop soundscape maps, which were created based on Geographical Information System (GIS) techniques.

The aim of this research is to explore and demonstrate the possibility to integrate conventional mapping methods for soundscape design in actual urban redevelopment projects. In this paper the Valley Gardens project in Brighton & Hove (UK) is analysed as a case study site. For this purpose, a noise mapping package was used to simulate possible scenarios of sound-pressure level distributions for both traffic sound sources (i.e. noise maps) and natural sound sources (i.e. sound maps). Moreover, soundscape maps related to the perceived overall sonic quality and pertinence of the sonic environment to the place were also produced through a GIS-based procedure, according to subjective data collected on site.

2 The case study area

The case study site, the Valley Gardens Park in Brighton & Hove, is located in the city centre, starting from the seafront with an extension of approximately 1.5 Km into the City. The area is a main spot for entering and leaving the City and also for accessing the seaside. Therefore it is currently affected by high traffic noise levels. The green areas along the site are scarcely used by either residents or tourists. The Council has put in action a project to improve the area, the Valley Gardens scheme, that consists of a complete redesign of the site, for which more detailed information can be found at the ref. [29]. Figure 1 shows the layout of the current proposal for which works will start by September 2015. Sound is a relevant component of the redevelopment project and its main aims are "*using sound as a valuable resource rather than a waste product of poorly designed areas*" and "*minimising intrusive/unwanted noise whilst at the same time introducing positive sounds*" [29]. Within the framework of the Valley Gardens scheme, the City Council defined an overall strategic approach for the sound environment of the area, relying on four key areas for potential proposals in support of the project: (1) analysing/recording current conditions of the acoustic environment, (2) reducing noise generation opportunities, (3) proposing noise deflection/absorption interventions and (4) providing positive soundscapes. The present study is one of the outputs resulting from the collaboration between the research group and the Brighton & Hove City Council.

3 Noise maps

Noise maps were calculated using the noise-mapping package CadnaA (version 4.4.145, DataKustik GmbH, http://www.datakustik.com), according to the CRTN stan-

Figure 1: Layout of the redevelopment proposal (courtesy of Untitled Practice LLP and Brighton & Hove City Council)

Table 1: Traffic input data used for the simulation (courtesy of Brighton & Hove City Council). All vehicles were assumed to have a speed of 32 mph.

Road section ID	Notes	Veh/h	% Heavy veh
1	*(North bound and South bound)*	368	11
2		641	2
3	*(East bound and West bound)*	620	2
4a	*(Bus lane)*	90	100
4b		1729	2
5a	*(Bus lane)*	94	100
5b		1750	2
6a	*(Bus lane)*	92	100
6b		1697	2
7	*(North bound) (Bus lane)*	49	100
7	*(South bound)*	1550	2
8	*(East bound and West Bound)*	544	3
9	*(North bound)*	114	100
9	*(South bound)*	974	3
10a	*(Bus lane)*	101	100
10b		1034	3

dard [30]. A detailed three-dimensional model of the area, as well as traffic data (actual counting), were considered for the purpose of simulation. Traffic data used as input for the simulation are reported in Table 1. The high amount of vehicles is due to the fact that the Valley Gardens represent one of the main access points to the City from the national road network. Information about the ground surfaces and buildings' façades were obtained on-site. Fifty-five point receivers were randomly located within the study area at a fixed height of 1.7 m. Figure 2 shows the noise map of the current situation, before any intervention is considered. As expected, most of the study area results to be exposed to more than 65 dB with a few spots falling in the 60–65 dB range.

Afterwards, a hypothetic scenario was simulated, considering a one-meter absorbent barrier parallel to all road segments used for computation, located one meter off the road, towards the park side. Figure 3 shows that under such conditions most of the study area results to be exposed to a range of 60–65 dB, while few spots fall in the 55–60 dB range.

The rationale for such a simulation was that the noise barrier was never considered as an actual design intervention by the City Council, but it was meant to point out that even such an invasive noise mitigation action would not provide substantial beneficial effects for the study area. Assuming that the traffic flows should not change, the noise mitigation action proposed for the simulated sce-

Figure 2: Noise map of the current scenario, before any intervention is made (L_{day})

Figure 3: Noise map of the simulated scenario with a one-meter barrier one meter off the roads (L_{day})

nario is not likely to be an option that most of local authorities would go for, due to the obvious impacts and costs that a one-meter barrier all around the park would imply. Indeed, taken together, the two computed scenarios show that even an invasive noise control solution applied in the study area might not lead to a "quiet" urban context with low noise levels overall. Such a circumstance urges to consider different elements other than traffic noise, like sounds that might be "wanted" rather than "unwanted". Indeed, a previous study by Oldoni *et al.* [31], raised the question that soundscape design should aim at composing acoustic environments that are as pleasant as possible. Such a process relies on creating contexts where the sounds that the listener identifies as desired in a space are audible, while unwanted sounds (i.e. "noises") remain mostly not noticed by the listener.

Table 2: Octave band spectra (dB) of the water features sound sources used for simulation

Sound source	Frequency (Hz)					
(dB)	125	250	500	1000	2000	4000
Rill	70	70	70	70	70	70
Fountain	50	55	50	52	55	52

Figure 4: Sound map calculated for water feature sound sources' spatial distribution (L_{day})

4 Sound maps

Within the urban realm, traffic noise is only one of the sound sources composing the acoustic environment. Noise maps are largely used to assess exposures to unwanted sounds (i.e. community noise). Conversely, the assumption made in this research is that noise mapping could also be used as a tool to monitor the spatial distribution and audibility of preferred sounds and to investigate the variation of such sources. For the purpose of this study, two sound sources were selected, namely water features and birdsong. Both these sources were located within the study area according to the design layout, so to simulate their possible distribution in the next future. The maps were again calculated in CadnaA.

4.1 Sound map of water features

The design layout of the Valley gardens includes two main water features' types: a programmable fountain in front of St Peter's Church and a rill (small stream) going through the park. The selection of the water features was led by functional and socio-cultural reasons promoted by the City Council and the landscape consultants. The fountain in front of St Peter's Church is meant to create a new "focal point" for people to aggregate and it is also expected to improve the soundscape by providing energetic and attentional masking for the traffic noise. On the other hand, the rill is related to an historical meaning for the reference to the valley's alluvial soil and the seasonal Wellesbourne (a winterbourne stream) running below the surface.

In order to model such sources an octave band spectrum was retrieved from a previous research [32] for the fountain, while a generic flat spectrum was considered to be representative for the rill, for the sake of convenience. Table 2 shows the spectra used for the two sources that were considered to be both active in the simulation. The rill and the fountain proposed in the design layout were treated as a linear and surface source, respectively, with a continuous operating time.

Figure 4 shows the spatial distribution of water sounds, considering the combined effect of the fountain to be located in front of St. Peter's Church and the rill to

Table 3: Octave band spectrum (dB) of the birdsong sound source used for simulation

Sound source	**Frequency (Hz)**					
(dB)	125	250	500	1000	2000	4000
Birdsong	28	53	54	41	61	86

Figure 5: Sound map calculated for birdsong sound sources' spatial distribution (L_{day})

go through the whole Valley Gardens site. The map mainly shows that the fountain is likely to have a significant area of influence in the northern part of the study area, while the rill is mostly relevant for the paths it runs parallel to.

4.2 Sound map of birdsong

A set of 280 new trees is included in the design scheme to complement the existing elms in the park. One of the aims of such actions is to enhance biodiversity and attract birds' populations. Therefore it seems fair to assume that birdsongs will be a relevant sound source in the future Valley Gardens acoustic environment.

In order to implement the birdsong source in the software, a typical octave band spectrum was retrieved from previous research [25] to associate it to the surface of the trees. The rationale for performing such a simulation was achieving a reasonable birdsong's spatial distribution according to the trees' design layout in the area. Table 3 shows the birdsong spectrum used for the simulation. Since the distribution of the sound sources (i.e. localisation of the birds on the trees) represented a substantial issue, a number of assumptions were made for the purpose of simulation. The A-weighted sound power level of 87 dB derived from the spectrum in Table 3 was considered to be the reference power per tree unit area associated to a single birdsong source, and the trees were treated as single surface sources, according to their size and height (consequently: the bigger the tree, the more birds on it, the higher the emission). Since it was considered unrealistic that all birds would sing continuously and simultaneously, an operating time of one minute was set for such sources over the day reference period (780 minutes). This resulted in a time correction of 28.9 dB [33] that was added to the calculated level (L_{day}).

Figure 5 shows a higher exposure to birdsong in the middle part of the study area and few spots close to St. Peter's Church. This is possibly due to a combined effect of a higher trees' density in those areas and a small distance between the opposite buildings' front facades of the park.

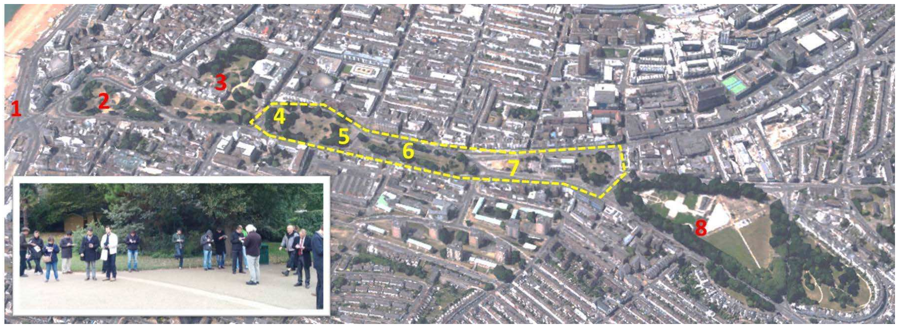

Figure 6: Study area (dashed line), the 8 points of the soundwalk (reference points in red) and some participants

5 Soundscape maps

Within the framework of this research, soundscape maps are meant to provide visual representation of perceptual attributes related to the sonic environment. In order to produce viable information for such individual aspects, survey data was collected on site through a soundwalk and individual responses where afterwards implemented into a Geographical Information System (GIS) software.

5.1 Soundwalk and data collection

The soundwalk is a very common method for collecting individual responses about the sonic environment in soundscape studies (e.g. [34, 35]). In order to characterise the soundscape of the study area before any intervention is made, a soundwalking session was organised in October 2014 (also see [36]).

A group of 21 people composed of acousticians, architecture/planning professionals and officers from Brighton & Hove City Council took part. In the literature, there is still no clear indication about the selection criteria for the soundwalks' participants. A number of studies tended to select residents and non-experts as more suitable participants. However, within the framework of this study, experts on soundscape and people involved in the decision-making process were invited to participate in order to reflect possible outputs of the investigation into urban planning and design [35]. Participants were led by an experimenter who walked across the study area and stopped at eight selected locations: (1) Seafront, (2) The Old Steine, (3) Royal Pavilion, (4) Victoria Gardens South – Victoria Statue, (5) Victoria Gardens South – Mazda Fountain, (6) Victoria Gardens North, (7) St Peter's Church and (8) The Level (the toponyms are not actual: they were used as "tags" for the purpose of soundwalk). Locations (1), (2), (3) and (8) will not be affected by any intervention at this stage of the project and were considered as reference points, as shown in Figure 6. For each location, participants were required to listen to the acoustic environment for two minutes and to fill in a structured questionnaire. The questionnaire [36] included questions about: demographic information of the participant, suitability of the location for social or recreational activities, noticeability of different sound sources' types, perceptual attributes' semantic scales related to the sound environment and overall quality and appropriateness of the sound environment [26]. Two questions were selected for the purpose of this study: (Q1) "Overall, how would you describe the present surrounding sound environment?" and (Q2) "Overall, to what extent is the present surrounding sound environment appropriate to the present place?". For both questions, a ten point continuous scale was used, ranging from "very bad" (0) to "very good" (10) for Q1, and from "not at all" (0) to "perfectly" (10) for Q2. During the soundwalk, a non-participant operator carried out some sound-pressure level measurements by means of a calibrated sound level meter.

Figure 7 shows the mean individual assessments for Q1 and Q2 submitted to participants during the soundwalk (standard deviations were overall small, approximately ±1.7 for both questions and were therefore not represented on the graph) and the sound-pressure levels recorded over the same time interval, at the corresponding locations.

It is possible to observe that, regarding the eight sampling locations, Q1 and Q2 follow the same spatial pattern and the peaks of the individual assessments correspond to the lows of the sound levels (and vice versa). This fact suggests that in this case soundscape appreciation is being affected by sound levels.

5.2 Mapping process

The individual responses collected for Q1 and Q2 at the eight selected locations were averaged over the 21 sound-

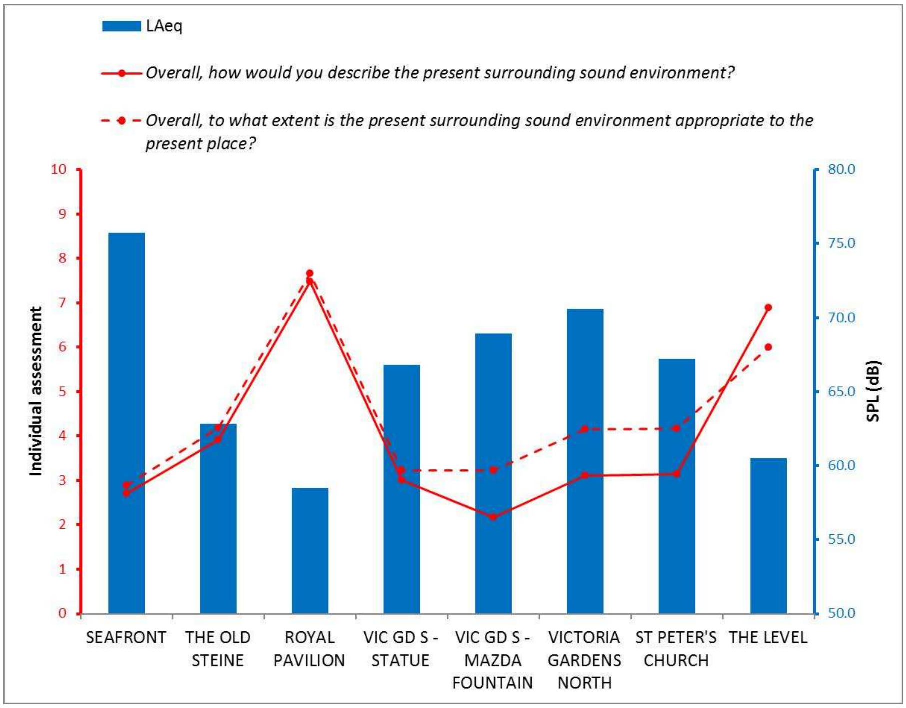

Figure 7: Mean individual assessments (red lines) and SPLs (blue bars) as collected and measured during the soundwalk

walk's participants. Those values were then uploaded to a GIS software (ArcGIS, v.10.1) and used to generate a prediction surface based on a "kriging" interpolation method. Kriging has previously been used for noise mapping and soundscape purposes (e.g. [37]). In the present application, the surfaces were created based on the "ordinary kriging" method and the spherical semivariogram model, considering all the eight sampling points. A cross-validation process was used to evaluate the performance of the interpolation process. A data point was omitted consecutively and the predicted values at the location of the omitted point were compared with the actual values using the remaining points. In order to check the degree of bias and uncertainty in the data, the mean standardised error (MSE) and the Root-Mean-Square-Standardised-Error (RMSSE) were used, respectively. The MSE is equal to the prediction error divided by the prediction standard error. According to the MSE results, all the values in the cross-validation had a small positive or negative variation very close to 0.00 (unbiased result). The RMSSE values were also close to the 1.00 (ideal value). This led to the conclusion that the current sample size (8 points) could be considered adequate for the purpose of soundscape mapping in the investigated area.

Figure 8 shows the soundscape maps for Q1 and Q2. From the maps' observation, it emerges that the central part of the Valley Gardens (points 4, 5 and 6) is characterised by a poor individual assessment, for both the overall sound environment (Q1) and the appropriateness of the sound environment to the place (Q2). This is likely due to the high volume of traffic related to the crossroad, leading to higher sound levels that result in contrast with the visual scenario (greenery).

6 Discussions: towards an integrated approach

This research aimed to explore the possibility of using conventional noise mapping methods under a soundscape perspective and three different types of maps were proposed; namely the noise maps (vehicles' traffic), the sound maps (water features and birdsong) and the soundscape maps (individual responses on overall sound quality and appropriateness). A noise mapping package was used for (1) assessing the short-term effect on traffic noise distribution of a noise control measure and (2) investigating the spatial distribution of sound sources other than traffic (i.e. water features and birdsong) according to the design layout of the area. On the other hand, due to the qualitative nature of the individual responses, those were mapped differently through a GIS-based implementation.

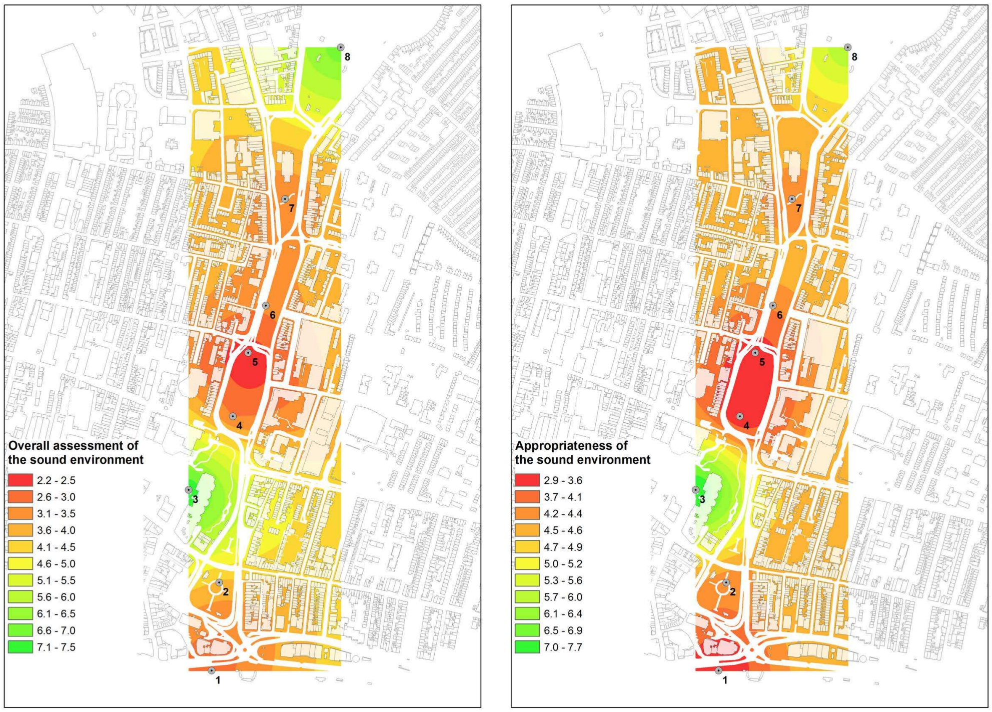

Figure 8: Soundscape maps for the overall assessment of the sound environment (left) and the appropriateness of the sound environment to the place (right)

The simulations of traffic noise distribution performed for the Valley Gardens in Brighton pointed out that even an invasive noise mitigation action like a barrier would not prevent from having relatively high noise exposures within the study area; therefore different issues should be addressed.

Afterward, the noise mapping technique was used to generate sound maps, considering the spatial distribution of water features and birdsong, according to the proposed design layout of the study area. Previous research [25] reported that, when the reduction of unwanted sounds is not practically doable, energetic - as well as attentional-masking could be a suitable design strategy. Even though the presented analyses do not deliver specific information on energetic or attentional masking of unwanted sound sources, they provide additional insights on areas where the audibility analysis should be focused. Being able of mapping the spatial distribution of specific wanted sources is indeed important to define buffer and "transition" areas where they are more likely to become audible, since it has been previously endorsed that individuals are more sensitive to variations in the sound environments [38].

Individual responses collected on site revealed that the study area soundscape was dominated by the sound of road traffic, resulting in poor assessments of the overall sound environment quality and its appropriateness for the place. Such perceptual outcomes were reflected in the soundscape maps produced ad hoc through a GIS-based interpolation technique.

The above results overall show that the planned design intervention should aim at reducing the impact of road-traffic sources, but also introducing more positive sounds, like the sound of people and nature, in order to make the sound environment more appropriate for the place. This can be achieved through careful planning of the landscape and the social and recreational activities within the area.

Within the framework of this research, noise maps, sound maps and soundscape maps are supposed to be used together to "triangulate" all available information about the acoustic environment and the way it is perceived. Noise maps are used to characterise the current scenario and possible future scenarios related to sources that are conventionally unwanted (i.e. traffic noise). They are often used at an early stage of the design process to anticipate impacts related to changes in the investigated noise sources. On the other hand, sound maps, as described in the present study, should be used in an "explorative" stage of the process, when different design solutions are considered, in order to provide information about where to perform additional analyses on the noticeability of "desired" sound sources. Eventually, the soundscape maps should provide an overall description about the holistic perception of the acoustic environment. They are likely to be used at an early stage of the design in order to characterise the current perception and identify potential critical issues, as well as after the implementation of the designed interventions, so to monitor the achieved improvements.

Overall, those three outputs together are likely to inform in a better way planners and policy-makers, who should engage in the future with more effective tools and more detailed analysis about the acoustic environments towards a wider urban sound planning. Future working scenarios could include GIS platforms handling both objective and subjective data. Such a possibility could be relevant from the design perspective for building spatial queries with mixed objective-subjective criteria and identifying areas, for instance, of possible soundscape enhancement, leading towards "soundscape action plans" (rather than conventional noise action plans).

Soundscape studies usually investigate the relationships between the physical features and the individuals' perception of the sound environments, aiming to establish statistical correlations between acoustic metrics and perceptual ratings (e.g. [12, 13, 15, 36]). However, the focus of this study was on describing how the soundscape approach (i.e. the individual responses) could be integrated into a mapping process that conventionally refers to the noise control engineering domain. The main aim was to demonstrate the complementarity of three different tools (noise maps, sound maps and soundscape maps), suggesting at what stage of the design process they would be more suitable to be implemented, to provide viable inputs for the urban design development.

A technical limitation of the proposed methodology is the current lack of interface between the outcomes of the noise/sound mapping process and the GIS-based soundscape maps, but the main focus of this research was to provide different approaches to the same environmental context and its sound-related issues. To overcome such drawback, future research could consider the implementation of all available information in GIS platforms. This has already been attempted for noise monitoring purposes (e.g. [39]) and it has been proposed that it would be desirable to optimise noise mapping for GIS applications, as the process would benefit from better estimation of uncertainties [40].

7 Conclusions

This paper proposed and demonstrated a procedure to extend the conventional domain of noise mapping methods towards preferred sounds and soundscape in general. This is in accordance with the guidelines on the management of areas of good environmental noise quality provided by the European Environment Agency where it is recommended to integrate different methods to this purpose: noise mapping, sound level measurements, the soundscape approach, and expert assessments.

Considering a study area in Brighton & Hove (UK), within an actual urban regeneration scheme promoted by the City Council, the results showed that the proposed methodology is effective in deriving design-relevant information for the sound environment. The sound environment of the test site was indeed approached with three different perspectives (i.e. noise, sounds and perception) to provide new insights on the sound environment of the place and suggesting new methodologies that are likely to be used by stake-holders and practitioners in the future.

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