The influence of vegetation and surrounding traffic noise parameters on the sound environment of urban parks

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1. Introduction

Traffic noise has been closely related to health issues (Bodin et al., 2009; Fyhri & Klæboe, 2009; Pirrera, De Valck, & Cluydts, 2010; Selander et al., 2009). In particular, according to the review report from the Environmental Burden of Disease (EBD) (Hänninen et al., 2014) noise was ranked second among the selected environmental stressors evaluated in terms of their public health impact in six European countries.

The Environmental Noise Directive (END) (2002/49/EC) - through the Noise Action Plans - has made an attempt to quantify the percentage of people living within critical areas of high noise levels. However, the noise levels reported in the END are based on the results of traditional noise mapping methods based on simulations of annual average traffic data and refer to a strategic level. Moreover, in practice, measurement campaigns found significant deviations between measured and calculated acoustical indicators (De Coensel et al., 2015), especially in shielded zones or quiet areas (Wei et al., 2016).

At the same time the technological boost in acoustic measurement devices has made the acquisition of real-time noise data much easier either through mobile phones (D'Hondt, Stevens, & Jacobs, 2013; Guillaume et al., 2016; Maisonneuve et al., 2009; Murphy & King, 2016; Rana et al., 2015) or through the use of portable devices (Can & Gauvreau, 2015; Filipan et al., 2014). These methods can be used in the production of the so-called "dynamic noise maps" with various models being proposed (Can et al., 2010; Cho, Kim, & Manvell, 2007; De Coensel et al., 2005; Gereb, 2013; Ma & Cai, 2013; Szczodrak et al., 2013; Wei et al., 2016;). The increased accuracy of dynamic noise mapping in shielded or quiet areas makes this method more appropriate in noise level calculation within green areas and parks, the importance of which has also been highlighted in the "*Good Practise Guide on Quiet Areas*" (EEA Techical Report, 2014) and other studies (De Ridder et al., 2004; Gidlöf-Gunnarsson & Öhrström, 2007).

From the noise perspective, previous studies pointed out the importance of vegetation on traffic noise mitigation through the use of trees, tree belts, plants or hedges (Aylor, 1972; Huddart, 1990; Jang et al., 2015; Kragh, 1981; Van Renterghem, Botteldooren, & Verheyen, 2012). The above references provide general guidelines or refer to the specific experimental conditions.

On a broader scale, the latest studies assessing noise level distribution have applied regression models using morphological and land use parameters (Aguilera et al., 2015; Margaritis & Kang, 2017; Ryu et al., 2017). The same regression-based approach has also been applied in soundscape mapping with physical, acoustic and perceptual data using different interpolation techniques (Hong & Jeon, 2017). Complementary to these tools, clustering techniques are also important in the identification of "cold" and "hot" spots in large noise datasets. Such tools are provided in ArcGIS (v.10.3.1) and belong in the category of local spatial pattern analysis tools (Hot Spot Analysis-Getis-Ord Gi*, Local Moran's I). In this study the Hot Spot Analysis tool was used, which is able to identify whether features with either high or low values cluster spatially. Since the main interest lies in the identification of the regular patterns, the use of the Local Moran's I tool was avoided, as it is appropriate for the detection of spatial outliers. The latter are just a few points throughout the parks and comprise the exception cases.

Especially for noise distribution in parks, most of the studies have dealt with a combination of measured noise levels (Zannin, Ferreira, & Szeremetta, 2006) and perceptual parameters based on users' experience (Aletta et al., 2015; Brambilla & Maffei, 2006; Filipan et al., 2014; Liu et al., 2014a; Nilsson & Berglund, 2006; Szeremeta & Zannin, 2009). In particular, Brambilla et al., (2013) found that non acoustical parameters, such as vegetation and natural sounds improve the soundscape quality of parks, even when these sites exceed the objective acoustic threshold of "quiet" areas (50 dBA). A similar study in Milan by Brambilla, Gallo, & Zambon, (2013) revealed that "soundscape quality" prevailed over "quietness", confirming that the latter parameter is just one aspect of soundscape appraisal. These examples led Brambilla & Gallo, (2016) to develop a new index for assessing the environmental quality of urban parks using the perceived overall quality and objective noise indices. In the same wavelength, Cohen et al., (2014) used in-situ noise levels as one of the proposed elements of a methodological framework for the assessment of the environmental quality of urban parks. Finally, other authors (Kang et al., 2013; Schulte-Fortkamp & Jordan, 2016) have included noise levels in parks as part of various active soundscape interventions in order to mask the unwanted traffic sounds.

However, very few studies have tried to describe the perception of tranquility in green areas based exclusively on physical parameters related to green space features. For example, González-Oreja, Bonache-Regidor, & De La Fuente-Díaz-Ordaz (2010) used the park size and the tree canopy as predictors for noise levels, while Pheasant, Horoshenkov, & Watts (2010) introduced the "Tranquillity Rating Prediction Tool" (TRAPT), which predicts perceptual tranquillity based on the sound pressure levels and the ratio of natural features in the scene. Although this tool has been validated, it is designed to assess specific sceneries within a restricted visual depth. Nevertheless, the assessment of tranquillity and noise distribution when investigating parks as entities needs to be broader, considering also the urban morphology of the surrounding environment.

Consequently, the main aim of this study is to investigate the influence of vegetation and traffic-related parameters on the sound environment in urban parks based on physical data. This aim is achieved through the following objectives: (1) investigation of noise level distribution in the park scale caused exclusively by the simulated surrounding traffic, (2) investigation of noise level distribution in point scale according to the recorded noise levels inside the parks, (3) identification of possible patterns in the noise measurements based on the inside-outside relationship and (4) identification of possible correlations between the green space attributes of the parks and other morphological parameters, 5) presentation of noise level differences based on vegetation coverage parameters analysed in a park and index-based scale.

2. Methods

2.1. Case study sites

The data presented in this study were collected in eight urban parks in Antwerp, Belgium. Antwerp is the largest city in Flanders and the second largest city in Belgium. A big part of the city's economy is a major European harbour, which has its incoming and outgoing traffic routes along the city. Additionally, Antwerp's ring road is integrated in the Trans-European Traffic Network (TENtec). Therefore, traffic creates substantial noise problems for the surrounding urban areas.

All data were collected in cooperation with the Environmental Authority of Antwerp’s City Council. The investigated parks shown in Fig.1 spread over the whole city and are accessible to a large number of people. Additionally, they present significant variations in the distance from the Ring or the National road, as well as the variability in size and green space coverage, which renders them representative for the whole study area. Details are provided in Table 1, while the location of the parks within the city can be seen in Fig.1.

Table 1

Fig.1

2.2 Green space and morphological data

The green space data for this study were selected from tree and grass coverage in dichotomous terms rather than interval since it is expected that at the urban level this would provide enough information about the vegetation coverage. Green space features were identified from the World Imagery basemap available by ESRI. This layer provides an imagery resolution of “0.3m” regarding Western Europe and at least “1m” in many parts of the world (ESRI, 2016a). The green space characteristics were recognised for each park using the ArcGIS software (v. 10.3.1) and the Maximum Likelihood Classification tool (ESRI, 2016b).

At first, all park images were imported in Photoshop (v.CS5), where certain steps were followed to facilitate the classification process in ArcGIS. Specifically, the tools of “Brightness” and “Contrast” were used to make the differences between the shadows and the canopy more evident. A slight increase of the green colour in the “Colour Balance” menu was used to further highlight these differences in some parks. All images were then georeferenced in ArcGIS in accordance with the vector park borders.

In the next step, the green space classes were distinguished along with the results of the supervised classification process, which involved the collection of training samples for each category. The ultimate recognised classes were formed as follows: “trees”, “grass” and “other” all built in a raster of 30cm x 30cm in order to comply with the basemap resolution. In the final step, the new dataset was converted from a raster to a vector format, which allowed the calculation of additional parameters. An example of the classification process can be seen in Figs 2a,2b, while the green space coverage for each class per park can be seen in Fig.2c. Finally, although the classification process yields small errors among the three classes, the final accuracy is high and did not affect the proportions of green space coverage as shown in Fig. 2c.

Fig.2

2.3 Green space and morphological indicators

The indicators presented in Table 2 refer to vegetation-related and morphological variables relevant to the parks themselves or their surrounding environment. The first three indicators refer exclusively to park features, namely: park size (*CA*), tree coverage (*Tree_COV*) and grass coverage (*Grass_COV*). The road (*RCOV_100*) and building coverage (*BCOV_100*) within a buffer zone of 100m around the borders of the parks were also calculated. The 100 m distance was chosen according to the studies by Tompalski & Wężyk, (2012) and M'Ikiugu, Kinoshita, & Tashiro, (2012). In particular, all buildings whose centroids satisfied the 100-meter buffer criterion were selected. Road surfaces were digitized in Google Earth, since the road width is easily recognisable. The distance of 100m was selected as the zone that can directly influence the sound environment of the parks. Other indicators used to describe the surrounding sound environment of the parks were: mean distance from major roads (*Mean_dist_major*) and maximum simulated traffic volume in the adjacent streets of each park (*Max_veh*). Particularly, "*Mean_dist_major*" was calculated by averaging the distances (*d1, d2, d3, d4*) from all four sides of each park (Eastern, Western, Northern, Southern). However, roads had to be classified in one of the following categories: motorway, ring road or national road. The road classes and the speed data were retrieved from the traffic count database based on the Flemish Traffic Centre (Flemish Traffic Centre, 2015).

Table 2

2.4. Noise levels data

2.4.1 Noise mapping

Noise levels were both simulated and measured. In the first case, the impact of the roads adjacent to the parks was simulated using CadnaA sound propagation software (v. 4.5). The UK Calculation of Road Traffic Noise (Department of Transport, Welsh Office, 1988) and ISO 9613-B:1996 were used to select the parameters of traffic characteristics and outdoor sound propagation respectively. Traffic data were based on origin-destination matrices built upon automatic and manual traffic counts simulated for the entire road network of Flanders. The final data refers to the number of vehicles per hour (veh/h) for day, evening and night over every road segment of Antwerp's network, during weekdays (Flemish Traffic Centre, 2015).

In the simulation, the surrounding environment of the parks was considered as totally reflective with a zero Ground Factor (G_{out}=0), while for the surface area inside the parks four different cases were tested as a sensitivity analysis. In the first case, the Ground Factor (G_{in}) was kept constant (G_{in}=1) and noise levels were calculated - with and without the effect of terrain - using elevation data. In the second case, noise levels were calculated with and without elevation - in order to test the actual effect of terrain - with G_{in}=0.5 for grass areas and G_{in}=1 for areas covered with trees. No barriers were present around any of the measured parks during the measurements campaign period, therefore they were not included in the simulation. Finally, receivers in CadnaA were placed every five meters at a height of two meters above the ground, since the aim was to capture the noise variation close to the human scale and not in the building facades.

Fig.3

2.4.2 Noise measurements

In the second case, portable devices were used to capture the sound variability in the parks, using the approach similar to Schnell et al. (2013). Measurement devices were custom-made Linux-based sensor network nodes created to incorporate both sound and location recordings. Hardware consisted of a single board computer (Alix 3D3 system board) with the connected 0.1 in microphone (Knowles FG-23329-P07) and a GPS receiver (Haicom HI-204III). The approach of using a small microphone for environmental noise monitoring was verified in a previous study (Van Renterghem et al., 2011). Three of the measurement devices were assembled using the same type of components and placed into the backpacks. Each day before the measurements the devices were calibrated to 94 dB SPL output level with a class 1 calibrator (Svantek SV 30A). The used software was in-house made (Botteldooren et al., 2013; De Coensel and Botteldooren, 2014; Domínguez, et al., 2014), and it included recording of the audio and calculation of 1/3-octave band levels, eight times per second. Moreover, GPS positions were recorded once each second. The data were saved on a USB card during the walks and transferred to the database after each day of the measurements.

Two to three participants - depending on the size of the park - used mobile recording devices carried in the backpacks. The participants were University researchers of the acoustics group and therefore thoroughly aware of the measurements caveats. Moreover, all of them were additionally trained to carefully mind their way of walking in order not to intervene in the recorded sonic environment.

The walks were made with a common starting point on the existing paths within the parks, while no specific directional guidelines were given in order to provide the participants with the freedom to move arbitrarily. Additionally, the participants were asked to make stationary recordings with 10-minute stops every half an hour by placing the backpack on the bench. Finally, to measure the surrounding sound environment, recordings were also performed by walking along the closest roads outside the parks as shown in Fig.4.

All noise measurements were performed during August and September 2013 between 11:00 a.m. and 19:00. The total amount of points per park during one day varied between 2,800 and 3,800 depending on the park size. For the current analysis, all levels recorded in a single day within the borders of a park were taken into consideration by accumulating all the measurements points from the corresponding devices.

Fig.4

In the final stage, all measurement points were intersected with the two green space classes (*Tree_COV*, *Grass_COV*). Most of the paths in the parks were not recognisable in the image classification; however, the points intersected with the main ones were classified to the closest green space class. Water features, buildings and main paths were easily recognisable and did not affect the accuracy of the final classification. On average 2,056 points were attributed in the tree coverage class and 513 in the grass coverage class per park.

2.5. Noise indicators

The noise level indicators were divided into two categories as displayed in Table 3; simulation-based and measurement-based. The first category includes indicators that describe the entire sound environment according to the simulated traffic conditions around them. The second one encompasses widely adopted indicators (Hao et al., 2015; Wang & Kang, 2011) referring in detail to the noise levels recorded with the portable devices in each park. The indicators were calculated for each 10-second time step by accounting for the 1/3-octave band spectrum values within a moving time window of one minute. Finally, location data (GPS positions) was included and related to the acoustic indicators by interpolating the dataset to the same 10-second division period.

Table 3

In the first category, one indicator refers to the minimum and maximum levels of L_d using the noise mapping results, while the other calculates the average value of $L_{d(avg)}$ per park using a Matlab code. The reference area for this calculation is the area only within the park borders. The code was set to recognise the colour range for each noise band and transform the RGB (Red-Green-Blue) values in noise levels. Noise levels were simulated based on a grid of 5x5 m in order to capture also small noise variations in the study areas.

On the contrary, the second category uses detailed percentiles weighted sound levels (Table 3). It consists of the following indicators: L_{A10}, L_{A50}, L_{A90}, *and* L_{Aeq}. All of them were initially calculated from the stored measurement data and extracted on the same selected time steps by taking the 1/3-octave band values of one-minute duration.

In order to guarantee a representative sampling strategy in the measurement data, a grid-based approach was also applied. The aim of this approach was to aggregate the measurement values within the same grid so as to avoid any possible bias from the fact that smaller parks are expected to have more sampling points within the same sampling period. The applied grid was 20x20 m covering the maximum possible width of a single path among the eight parks. The grid size in this case was defined based on specific criteria relevant to the area size of the parks and the paths width. As a result, it had to be bigger than the one of 5x5 m applied in the simulated noise levels. An identical grid size for both cases would end up in significant increase in calculation time without improving the accuracy of the final results. Furthermore, it would cause unclassified points in the case where all points would have to be attributed to a single vegetation-related class.

In both cases the percentile indicators were used to get the dynamic characteristics of the sonic environment: L_{A50} illustrates the average, L_{A90} the background noise and L_{A10} the highest values or peaks. Finally, A-weighted equivalent levels (L_{Aeq}) were used due to their overall relationship with the human hearing characteristics.

2.6 Noise clusters identification

An additional indicator was extracted to identify possible spatial relationships of the noise levels exhibited inside the parks. The calculation of this indicator was performed in two steps. At first, the “Hot Spot Analysis” tool was used to calculate the Getis-Ord (Gi) index (ESRI, 2016c) for each feature in the dataset. The subsequent *z*-scores and *p*-values provided information on whether there are spatial clusters between points of low or high noise levels.

The tool works by examining each point within the context of neighbouring points. A point with a high noise level value can only be considered statistically significant ($p \geq .90$) when surrounded by other points with high values as well. The tool was set to run under the “inverse distance” option; where nearby neighbouring features have a larger influence on the computation than features that are far away. The threshold distance was calculated by the system each time in order to ensure that each point has at least one neighbour. The output feature class giving the confidence level is represented by the “Gi_Bin” field and identifies statistically significant hot and cold spots. It ranges between -3 and +3. Features in the (±3) bins reflect statistically significant spots with a 99% confidence level; features in the (±2) bins correspond to a 95% confidence level and features in the (±1) bins reflect a 90% confidence level. Zero bin values refer to non-statistically significant points.

In the second step, the spatial distribution of the points was measured, since the aim was to detect to what extent the difference in sound sources inside and outside the parks can have an effect on the recorded noise levels. In this case the distance from all points to the park's centroid was used as an objective method able to yield comparative results among all parks. Centroid-based solutions are common in spatial analysis with representative examples provided by Jerrett et al. (2004) and Talen (1997).

For this analysis, only points of marginal values were used (Gi=-3, Gi=+3, p<.01), since they represent the most significant clusters. For simplification reasons, the possible exhibited clusters were divided into three categories: "introverted", "extroverted" and "random", with an example of the first two to be given in Fig 5. An "extroverted" cluster (Fig.5a) denotes a positive correlation between the distance of each measurement point from the park centroid and the respective noise levels. Practically, this means that higher noise levels have been identified on the borders of the park and there is a decreasing tendency as somebody moves towards the park centroid. On the other hand, an "introverted" pattern (Fig.5b) presents a negative correlation with higher noise levels close to the centroid and a decreasing tendency as somebody moves towards the borders. It should also be made clear that the algorithm can also recognise the cluster of points created by the stationary recordings; however the number of points in this category is small and does not affect the overall correlations.

Fig.5.

3. Results

3.1 Noise distribution at point scale

Initially, the simulated noise data as presented in Section 2.4.1 showed that the distinction of ground absorption between areas of trees and grass had an additional effect between 0.3

and 1.1 dB(A), while the presence of terrain had an effect between 5 and 6.2 dB(A). Contrary to these simulated results that investigated the influence of traffic noise from the adjacent roads, measurement noise levels refer to the indicators extracted from the data recorded in each park. For this analysis, L_{A10} and L_{A90} were used to represent the marginal cases of peaks and background noise respectively. Therefore, Figs 6a,6b represent the frequency of occurrence of noise levels between 40 and 75 dB(A) for each of the two indicators (99% of measurement points). The same analysis using the grid approach presented in Figs 6c,6d showed that although the curves were quite different, noise levels were similar in average values with the initial frequency approach and only differ by 0.1 to 2 dB(A) for both indicators.

Fig.6.

It can be seen that each park follows a different bell-shaped distribution in both approaches. Using the quartiles for the specific dataset as a reference it is evident that the distribution of L_{A90} is mostly skewed to the left with maximum noise levels around 60 dB(A) for all parks apart from Rivierenhof. On the contrary, the L_{A10} distribution presents a higher degree of normality in the curves with values that exceed 70 dB(A) in all parks apart from Domein. From both approaches, it is clear that the background noise (L_{A90}) presents more fluctuations than L_{A10}, which further provides an evidence that this can probably be related to traffic.

Two groups of parks can be distinguished according to the grid approach for L_{A90} (Fig.6c). The first group (Sorghvliedt, Nachtegalenpark, Te Boelaerpark and Rivierenhof) contains a maximum number of measurement points between 586 and 1,500. On the contrary, the second group (Domein Hertoghe, Den Brandt, Bisschoppenhof and Stadspark) with smaller parks has a maximum frequency of 100 points. The frequency difference between the two groups can be attributed both to the park size, since bigger parks are expected to have higher noise variability and to the proximity to busy roads around the parks.

A further comparison between the measurements inside the parks and the ones recorded in the surrounding roads is shown in Fig.7. In all cases and for both indicators noise levels were higher outside the parks. These differences ranged between 0.5 and 5.9 dB(A) for L_{A90} and between 1.8 and 14.3 for L_{A10}. The average difference for L_{A90} was 3.2 dB(A), while the corresponding value for L_{A10} 8.5 dB(A). This shows that L_{A10} was much more diversified outside the parks and L_{A90} in terms of background noise inside the parks. Possible reasons for this divergence can be attributed to various sound sources; however traffic is the most probable. Actually passing-by cars can produce short events with high dynamic range, which influence the L_{A10} levels.

Fig.7

It was also shown that both $L_{A90(avg)}$ and $L_{A10(avg)}$ differ by almost 9 dB(A) between the quietest and the noisiest park, while the $L_{A90(SD)}$ ranged between 2.2 and 5.2 dB(A) and changed independently from the $L_{A90(avg)}$.This happened for various reasons not always related to traffic. For example in some parks such as Bisschoppenhof, Te Boelaerpark, Den Brandt, and Sorghvliedt there were a few points with high levels of L_{A90} close to their borders. Yet, the majority of peak L_{A90} values were clustered close to park centres (Nachtegalenpark, Sorghvliedt), usually in short distance from architectural or water features.

Human sounds can have a potential contribution in the peak levels of L_{A90}, since traffic noise close to the borders of the parks reduces the acoustic comfort evaluation (Tse et al., 2012) and prompts people’s gatherings close to the centres of the parks. Similar differences concerning the acoustic environment of parks and the plurality of soundscapes have previously been reported by Jeon & Hong, (2015). Vegetation-related parameters can also affect noise levels in an indirect way, since large unparticioned grass areas tend to accumulate human activities according to the behavioural mapping outcomes of Goličnik & Ward Thompson, (2010). For tree areas this is less expected, since a minimum distance of 5 meters was observed between users and tree-lined paths in the above-mentioned study.

Out of the eight parks, Bisschoppenhof, Te Boelaerpark, Den Brandt and Sorghvliedt presented the lowest proximity to the ring road or any other national road with an average value of 48.7 dB(A) for L_{A90} and 51.8 dB(A) for L_{A10}. The range for $L_{A10(SD)}$ inside the parks was between 4.8 and 6 dB(A). As expected, L_{A10} had a smaller range than L_{A90} and also smaller variations, since it represents the peak values in the percentile scale and was less susceptible to big fluctuations. The only exception was Rivierenhof park, where the range of values was higher in both noise indices.

3.2. Noise distribution at parks scale

Noise levels inside the parks as presented in Fig.8 varied between 43 and 78 dB(A) in terms of $L_{d(min)}$ and $L_{d(max)}$, while the range for $L_{d(avg)}$ was restricted between 48.2 and 65 dB(A) as shown in Table 4. The aim of this Table is to mainly highlight the differences among the variations of measured and simulated values, which is more representative than comparing the actual values themselves. Based on these noise levels, Te Boelaerpark was found to be the quietest park, while Rivierenhof the noisiest. Also the noise range presented a great variability among the case study areas ranging between 14 dB(A) in Bisschoppenhof and 23 dB(A) in Te Boelaerpark.

Fig.8

Table 4

Once the parks were sorted in an ascending form for $L_{d(avg)}$ (Fig.8), two groups were distinguished. The first one involved the first four parks, which presented low noise levels combined with high noise range. The common characteristic among them is that three out of four

(Den Brandt, Sorghvliedt and Te Boelaerpark) are located far from the Ring road or any other National road by at least 370 m. The effect of location on noise levels for these three parks was also depicted in the structure of the box plots (Fig.8), where the minimum noise levels coincided with the 1st quartile (Q1). Practically this suggests that noise variability in these places was very low with high noise levels to appear locally, probably due to the increased traffic volume in one of the surrounding local roads.

The second group of parks (Bisschoppenhof, Nachtegalenpark, Rivierenhof and Stadspark) was found to be the noisiest from the traffic perspective with few outliers and a smaller noise range. In all cases, their borders were very close either to the ring road or any other road belonging to the national network. Finally, for all parks the standard deviation (SD) ranged between 2.8 and 5.4 dB(A).

3.3 Cluster analysis inside the parks

Additional analysis was performed to emphasize the possible patterns exhibited in the measurements data within each park. The pattern investigation was performed only for L_{A90}, firstly because as an indicator it presents the greatest variation compared to the others and secondly in order to capture the background noise from traffic, whenever this was possible. In order to account for Type I error and spatial dependency, the False Discovery Rate (FDR) option was activated in the Hot Spot analysis options. According to Table 4 there was only one case (Te Boelaerpark), where the $L_{A90(avg)}$ was higher (+3 dB) than the $L_{d(avg)}$. Based on these results the expected cluster at this stage would have to be “introverted” in this park and “extroverted” in the other seven cases.

However, the results from “Hot Spot” analysis as presented in Fig.9 revealed that the observed cluster for L_{A90} is quite different from the expected one. In particular, all the three types of clusters (“introverted”, “extroverted” and “random”) were detected. The correlation coefficient *(r)* in the eight parks ranged between 0.13 and 0.66 in absolute values. Positive correlations denoting an “extroverted” cluster were detected in four parks, namely: Domein Hertoghe (r = 0.47), Nachtegalenpark (r = 0.58), Rivierenhof (r = 0.59) and Stadspark (r = 0.66). Negative correlation coefficient denoting an “introverted” cluster were found in Sorghvliedt (r = -0.63) and Te Boelaerpark (r = -0.36). Finally, weak correlations were detected in Den Brandt (r = -0.13) and Bisschoppenhof (r = -0.38), which can be considered as random.

Fig.9

These results confirm to some extent the hypothesis that the sound environment inside the parks is affected by traffic noise. Nevertheless, a holistic approach of the topic should consider the entire sound sources that can be encountered in the parks (human, natural, mechanical). Currently, it was shown that parks with low simulated noise levels such as Te Boelaerpark and Sorghvliedt (“introverted”) were little or not affected at all by the outside traffic conditions. In the case of Park Den Brandt, the absence of clustering can be attributed to the sound sources distribution, since the park is conceivably divided in two parts with all the “hot” points clustered to the right and all the “cold” to the left. On the contrary, parks with higher simulated noise levels (“extroverted”) were found to be affected by traffic to a lower or higher extent, since the Pearson correlation coefficient ranged between 0.47 and 0.66.

The observed cluster confirmed the hypothesis in four out of eight cases. For the rest of the parks three possible reasons for the divergence can be assumed. First of all, some information is lost when values are averaged to a single number representing each park. Secondly, the results can be affected by the other sound sources found in the parks (human, natural) as well as by the physical characteristics of the environment. For example, in Sorghvliedt, the lake in the centre of the park attracts both human and natural life, making this part more vibrant.

3.4 Relations between noise levels and morphological features

At this level the parks were investigated as single entities. Possible correlations between the green space or morphological features (Table 2) and recorded noise levels (Table 3) were investigated through the Pearson product-moment correlation coefficient. Out of the five measured noise indicators, three were found to be statistically significant and negatively correlated with “tree coverage” as shown in Fig.10. The first was $L_{A10(avg)}$ (r =-0.68, n=8, p<.01), the second one was $L_{A90(avg)}$ (r =-0.74, n=8, p<.01) and the third one was L_{Aeq} (r=-0.66), n=8, p<0.1). Results are depicted in Fig.10 with the corresponding R^2 values. It was shown that more variance is explained when “Tree_COV” is used as a predictor for L_{Aeq} (F1,6)=4.8, p=0.07, R^2=0.45) compared to $L_{d(avg)}$ (F1,6)=3.7, p=0.1, R^2=0.28).

Fig.10

Practically, these results reveal that an increase in the tree coverage can potentially reduce noise levels in the parks both for the background noise (L_{A90}) and the high peaks (L_{A10}). Similar outcomes have been found in previous studies (Fang, Ling & Kuntze, 2003; McPherson et al., 1997), which show that vegetation and particularly trees can be a substantial parameter in noise distribution. From a perceptual viewpoint, Kuttruff (2006) has mentioned that vegetation has a more psychological than physical effect on sound attenuation. This depicts the multiple effects of vegetation at different levels that can be taken into consideration. Taking this into account, the relationship between vegetation and noise can further be explored in landscape and park design.

Apart from the green space parameters, additional correlations were also detected between the $L_{A90,max}$ and the road coverage, (r=0.89, n=8, p<.01), as well as between the $L_{A10,min}$ and the building coverage (r=0.73, n=8, p<.01). In relation to the building coverage similar results have also been identified by Liu et al., (2014b) and Margaritis & Kang (2016). These correlations provide an evidence base for the importance of the surrounding environment on the overall noise distribution in the parks. Finally, as far as traffic is concerned, a strong positive correlation was detected (r=.94) between $L_{A90,max}$ and the maximum traffic volume in the roads adjacent to the parks. This is also evidence that despite the possible presence of human or natural sounds in the parks, background noise from traffic significantly contributes to the maximum levels of L_{A90}. Additional important indicators, such as the mean distance from major roads were found to be correlated with the measured noise at this level of analysis. The overall conclusion of the detected correlations could therefore be that the noise level distribution in the parks can be affected both by green space characteristics and morphological attributes from the surrounding environment.

3.5 Noise level comparisons using a park-based and index-based approach

The final step of analysis dealt with the possible effect of tree or grass areas in noise indices. This analysis was performed in two levels in order to capture the effect of vegetation in different scales and to account for the possible spatial dependence among the points. The park-based approach refers to the analysis performed per park, while the index-based approach refers to the analysis performed per noise index for all parks.

3.5.1 Park-based approach

In the park scale, a simple linear regression analysis was conducted to predict each noise index (L_{A10}, L_{A50}, L_{A90}, L_{Aeq}) based on two predictors: a) the distance of each measurement point from the park centroid and b) the binary variable of grass or tree coverage per point. The first predictor can account for the noise variability with respect to the centre of each park, while the second one for the variability referring to the vegetation type of each point. The regression models were checked for residual spatial autocorrelation using the Global Moran's I tool in ArcGIS. It was found that in all cases the z-scores were high ($60<z<1{,}975$) and statistically significant ($p<0.001$), which denotes a bias in data independence. Practically this means that there are unexplored predictors that need to cover the remaining variance. The effectiveness of the current predictors is presented in Table 5 using the coefficient of determination (R^2).

Table 5

From Table 5 it can be seen that there was a very low coefficient of determination (R^2) ranging mostly between 0% and 17%. However, there were particular cases (Stadspark, Rivierenhof), where a higher amount of variance between 20% and 32% was explained. In these parks, it was found that the distance from centroid managed to explain more variance than the vegetation coverage (grass, trees). These results are consistent with the respective findings in Fig.10 and denote that the further a person moves away from the centre of these parks, the higher the noise levels are (L_{A50}, L_{A90}). For the vegetation coverage the coefficient of determination (R^2) showed that it was not possible to use it as a predictor for noise levels in a park-based analysis.

3.5.2 Index-based approach

In order to overcome the issue of spatial dependence in the residuals as recognised in the park-based analysis, a second index-oriented approach was investigated. In this approach, the spatial scale covers all the eight parks at the same time providing a minimum of 1,000 neighbours per point from the eight case studies. In that way data independence was secured supported also by the fact that the Global Moran's index was not possible to be calculated with such a high number of neighbours per point. In total, four datasets were created, one per noise index including all the corresponding data and an average of 30,504 records per index.

An independent sample t-test was then conducted to find out whether the difference between the average noise levels detected in tree areas was significantly different from the noise levels within the grass areas. At first, outliers were removed using the box-plot graph for each park and normality was checked using the frequency distribution and the normal Q-Q plots. The homogeneity of variances was checked with Levene's test and it was found that in all cases it was violated, since equal variances were not assumed. Noise levels for the two groups (grass, trees) differed significantly according to Welch's unequal variances t-test ($p<0.001$). In all cases, as shown in Fig.11, levels in grass areas were slightly higher than the respective ones in areas covered by trees. The minimum difference detected between grass and trees points was 0.99 dB(A) for L_{A10}. (Fig.11a) and the maximum 1.17 dB(A) for L_{A90}, (Fig.11b).

Fig.11

4. Discussion and conclusions

The effect of vegetation and traffic-related parameters on the sound environment was investigated in the eight representative parks of Antwerp. Results were investigated in two different scales using the most appropriate calculation method in each case. Simulated traffic noise levels with higher variation were calculated in park scale and sound recordings of high spatio-temporal resolution and smaller variation at point scale.

The results showed that the noise levels in grass areas were slightly higher than the respective values in the areas covered by trees. Similarly, Papafotiou et al.(2004) found that dense vegetation could add 2 to 4db(A) of extra noise reduction compared to areas with grass or bedding plants. From a different viewpoint, Peschardt, Stigsdotter & Schipperrijn (2016) found that "green features" do not seem to be significant for "socialising", but mainly for restoration in urban parks. Finally, from a health perspective, Schnell et al. (2016) recognised the valuable effect of green spaces on stress level reduction.

From the morphological viewpoint, tree coverage was also found negatively correlated with noise levels. This comes to confirm previous studies where vegetation was used as a predictor for noise levels in land use regression models coupled with variables related to road or building attributes (Xie, Lu and Chen, 2011; Goudreau et al. 2014). Overall, a next step would be to try and correlate the spatial indicators used in this study with perceptual parameters obtained for the same noise environment as Kothencz and Blaschke (2017) have done.

The innovative feature of this approach was the combination of measurement noise data with advanced GIS and statistical tools. Possibly a different way of quantifying the distance between each point and the traffic sources might yield better results compared to the centroid approach. Also, this study focused exclusively on the effect of traffic sources and traffic noise within the eight parks. However, from a realistic viewpoint it is difficult to end up in a solid conclusion without taking into consideration all the active sound sources (human, natural) - apart from traffic - that were recorded within the parks. An automatic source recognition tool can help in the future towards this direction.

There were also differences between the simulated (L_d) and measured values (L_{Aeq}) showing that the noise maps are good for an overall estimation of the actual environment, but present errors when it comes to the dynamic acoustic environment within the urban parks. As a limitation of the simulation approach, noise sources did not include the water features which are relevant local noise sources

As regards the noise distribution in the parks taking into account only the simulated traffic conditions from the adjacent roads, it was found that parks closer to the Ring or National Roads present higher noise levels compared to parks further away. Also, In six out of eight cases the simulated noise levels were higher than the average L_{Aeq} showing that the actual noise map could not effectively capture the instantaneous noise levels. The differences ranged between 0.63 and 8.27 dB(A) in absolute values. The comparison between the inside and the outside environment showed that L_{A90} was lower inside the parks by 3.2 dB(A) compared to 8.5 dB(A) for L_{A10}, on average values. For the measured noise levels in the roads around the parks the overall comparison revealed that L_{A10} presented higher variability than L_{A90} concluding that the surrounding environment was noisier as expected. Furthermore, in four out of eight parks an "extroverted" cluster was recognised for L_{A90} showing that noise levels were higher close to the borders of the parks and lower towards their centre. This further signifies that traffic sources had indeed a significant effect on the sound environment inside the parks.

The correlations between morphological and green space attributes of the parks with noise indicators showed that out of all the variables tested, tree coverage was found to be negatively correlated with $L_{A90(avg)}$, $L_{A10(avg)}$ and L_{Aeq}. Additional correlations were also detected between the $L_{A90(max)}$ and the road coverage as well as between the $L_{A10(min)}$ and the building coverage showing that noise level distribution in the parks can be affected both by green space characteristics and morphological attributes from the surrounding environment.

Finally, in the park-based approach it was found that the distance from the park centroid had a higher effect than vegetation coverage in noise level prediction for some parks. Consequently in these cases, the further a person moves away from the park centroid, the higher the noise levels are. In the rest of them both predictors presented very low correlations with noise levels. On the other hand, the index-based approach showed that noise levels differed significantly between tree and grass areas. However, in the best case (L_{A90}) this difference did not exceeded 2 dB(A). At first stage, the results of this study can provide evidence on the understanding of the noise environment within the parks and the extent of differences between the inside and the surrounding environment. In a second stage, they can be taken into account in the design of parks' acoustic environment coupled with landscape design principles and sound masking tools. If these elements are further combined with automated source identification algorithms so as to have an estimation of the contribution of each source on the overall sound pressure level, this would further reinforce the design process on making parks more pleasant and attractive to the public.

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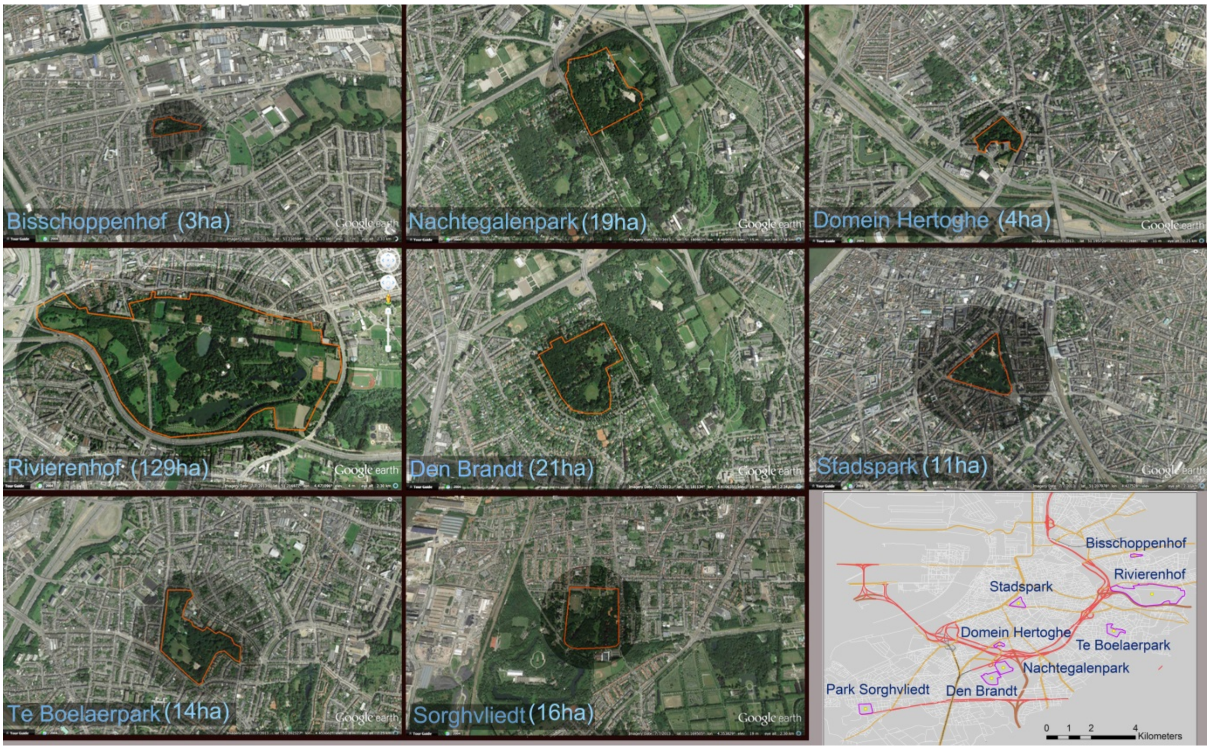

Fig.1. Aerial images of the eight investigated parks in Antwerp, Belgium, from an altitude of 2km above ground. The size of the parks is listed next to their names. In bottom right map, the spatial distribution of the eight parks relatively to the city's road network.

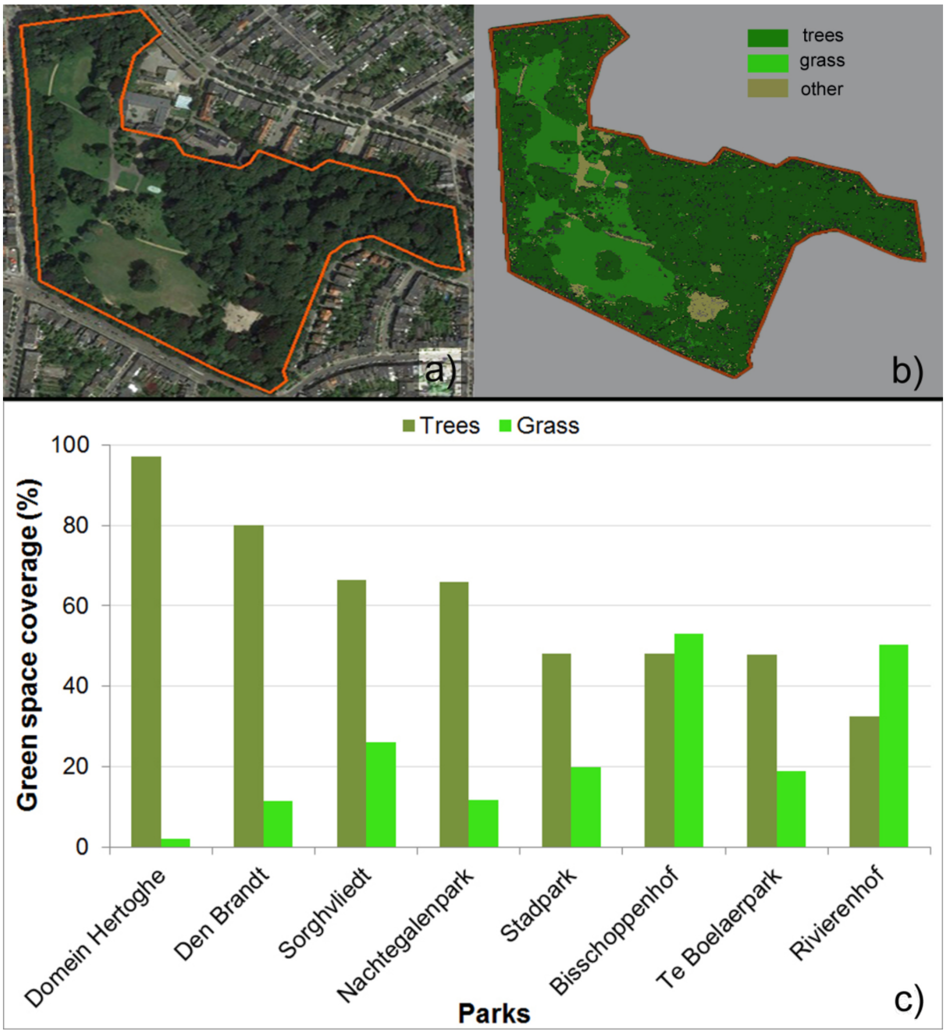

Fig.2. a) Initial satellite image from Imagery basemap (ESRI) for Te Boelaerpark, b) Corresponding results after the Maximum Likelihood classification, c) Green space coverage (ratio) for trees and grass in all parks.

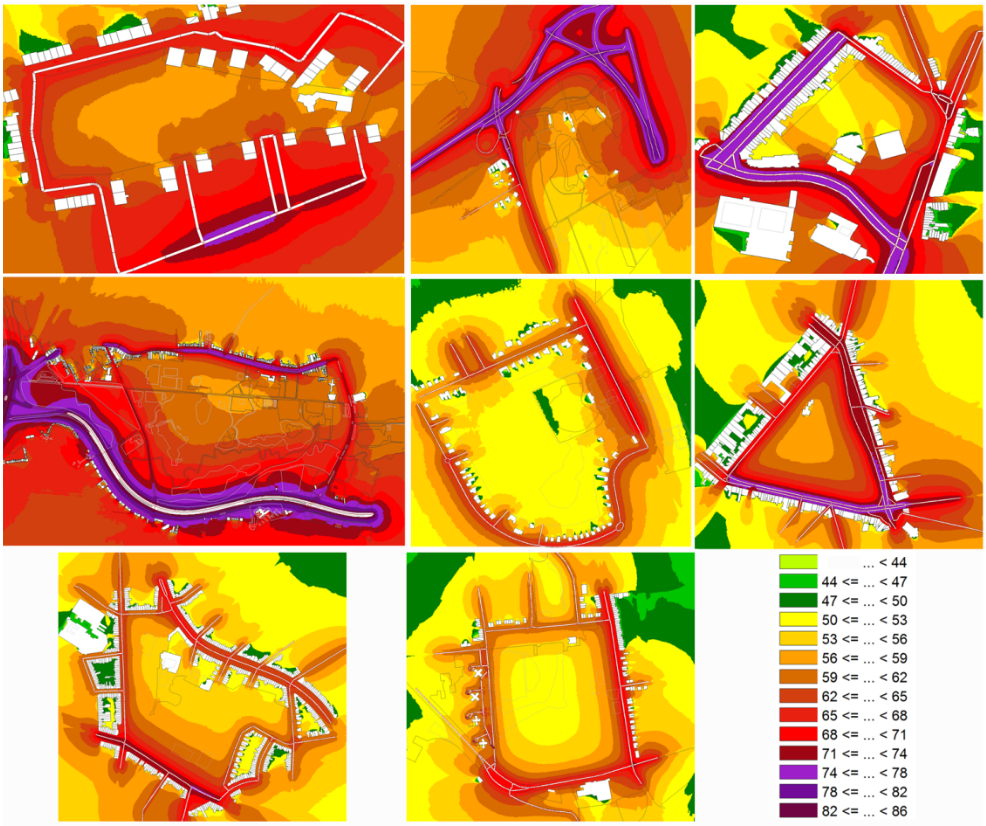

Fig.3. Noise level distribution in the parks and their direct vicinity simulated in CadnaA. The traffic data are based on origin-destinations matrices built upon traffic counts (automatic & manual) with the traffic to be finally simulated over the idealized traffic network. All data have been retrieved from the Flanders Traffic Centre. Source: http://www.verkeerscentrum.be/verkeersinfo/verkeerscentrum/vc_wie_vc

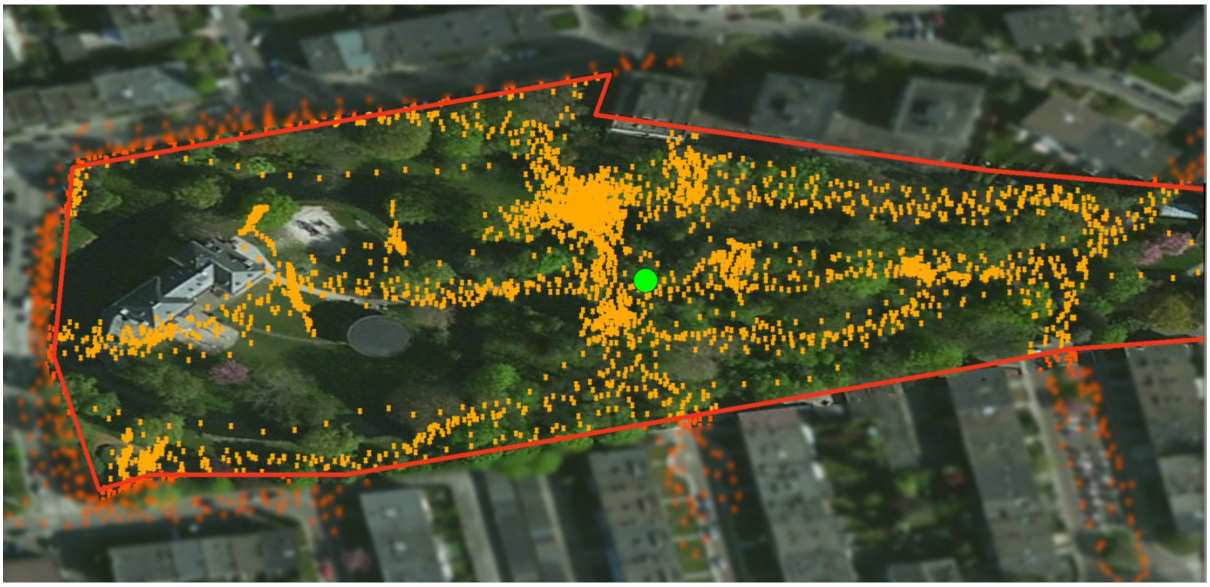

Fig.4. Measurement points distribution inside and outside Bischoppenhof park using an Imagery basemap background.

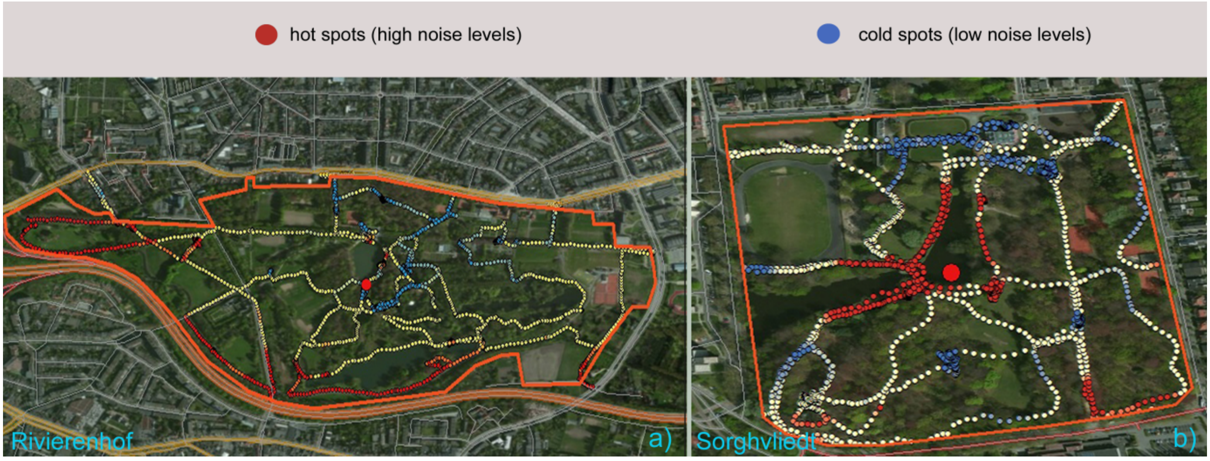

Fig.5. Noise clusters identification: a) “extroverted” and b) “introverted” noise clusters in Rivierenhof and Sorghvliedt respectively with the distribution of hot and cold spots.

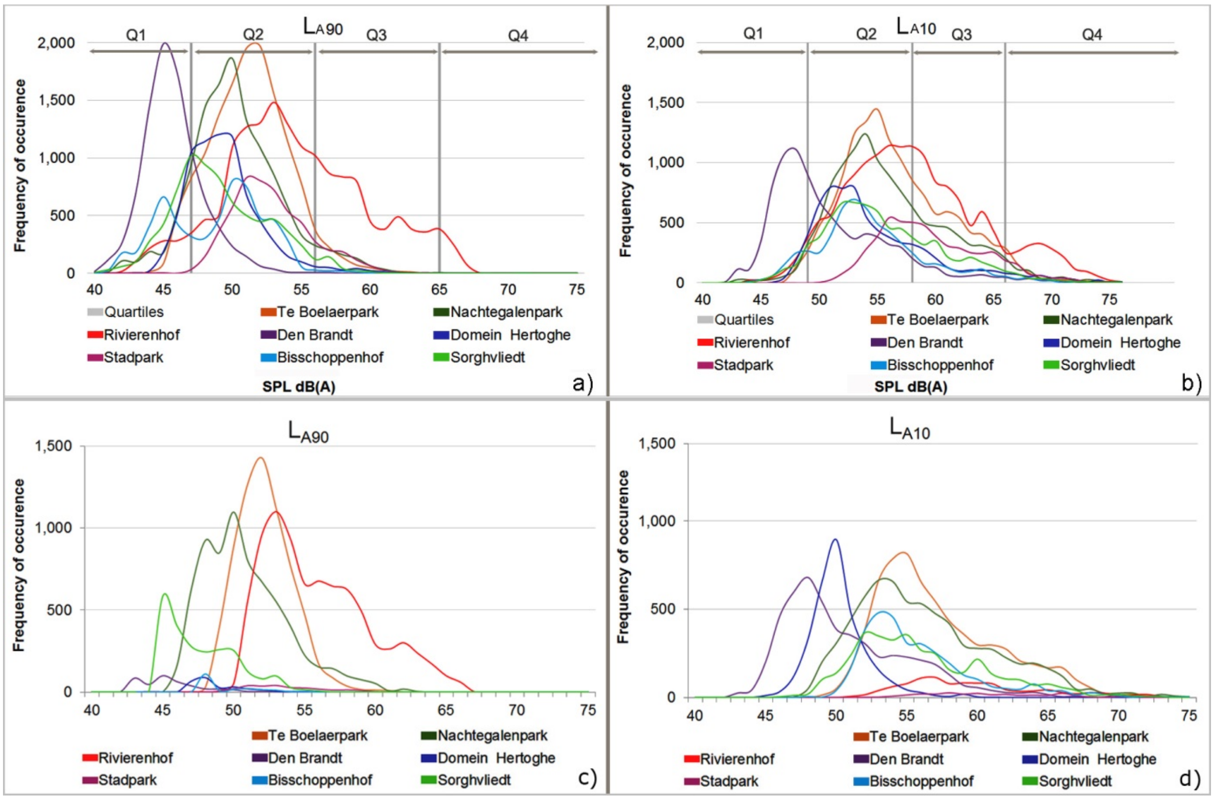

Fig.6. a,b) Frequency of occurrence for L_{A90} and L_{A10} based on values per measurement point, c,d) Frequency of occurrence for L_{A90} and L_{A10} based on the aggregated values per cell.

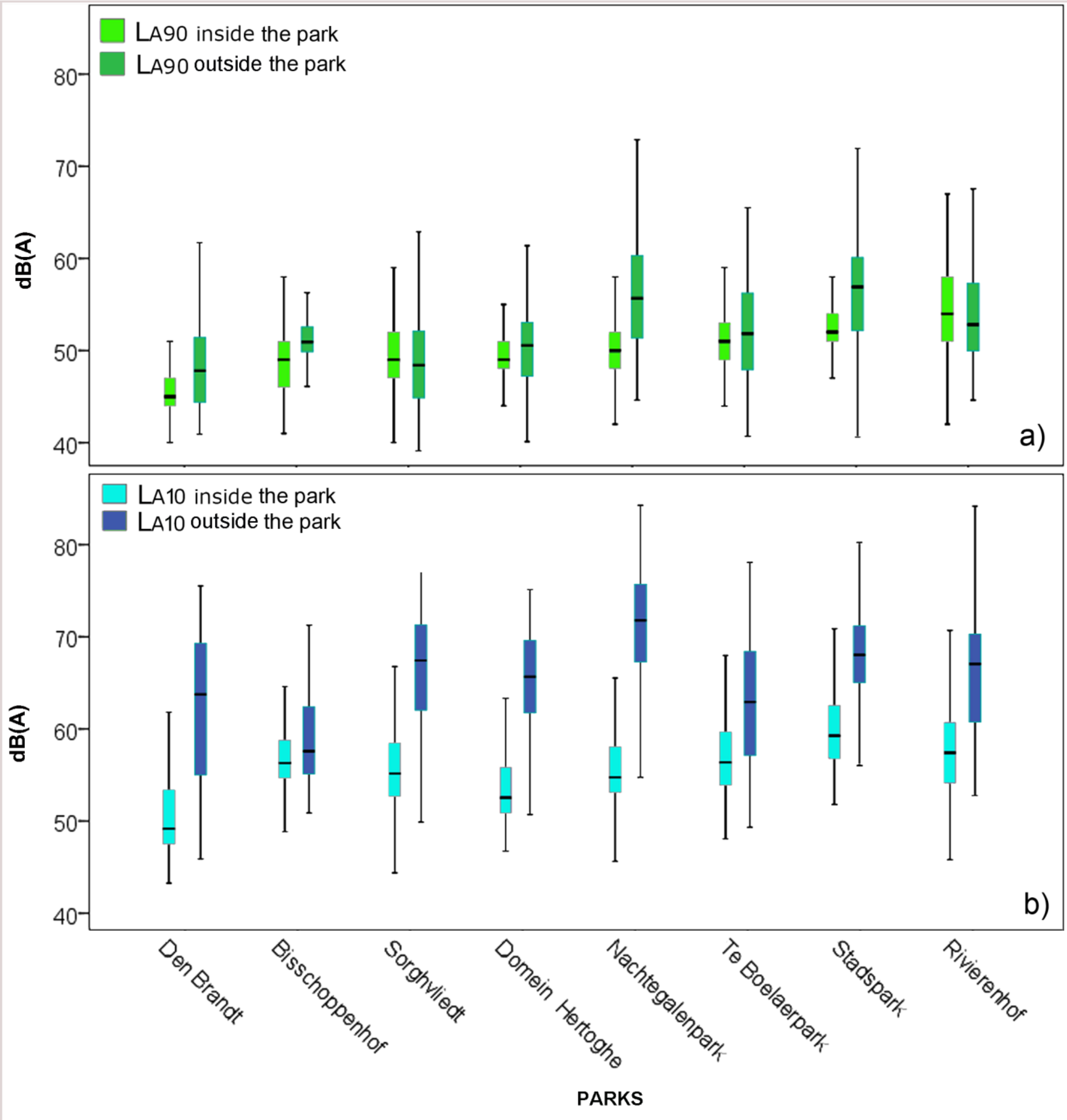

Fig.7. Box plots for(a) L_{A90} and (b) L_{A10} describing the sound environment inside and outside the eight parks. Results have been sorted in an ascending form for L_{A90} (inside).

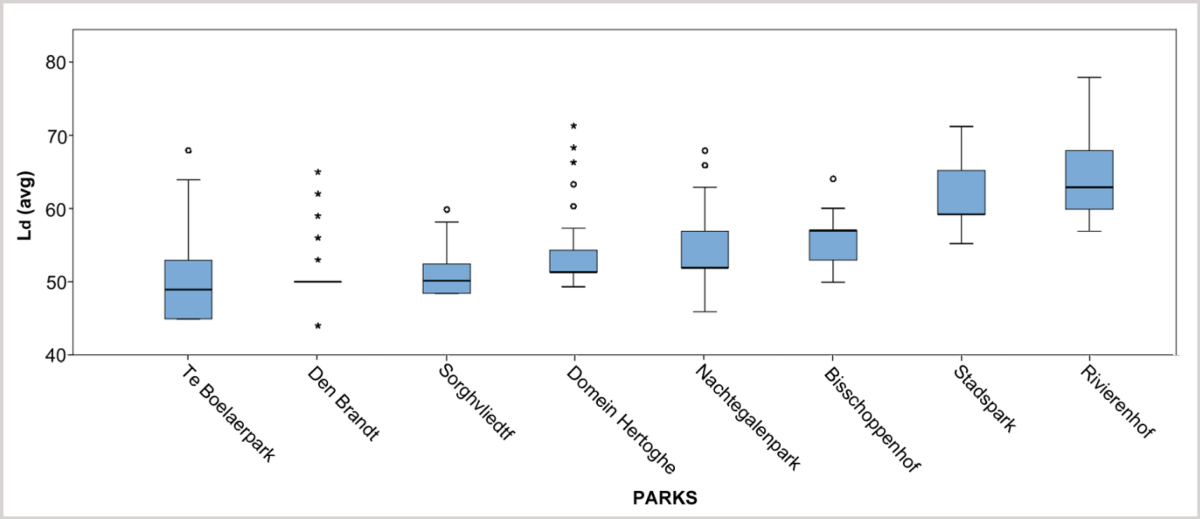

Fig.8. Box plots representing the simulated noise levels within the borders of the eight parks sorted in an ascending form for $L_{d(avg)}$.

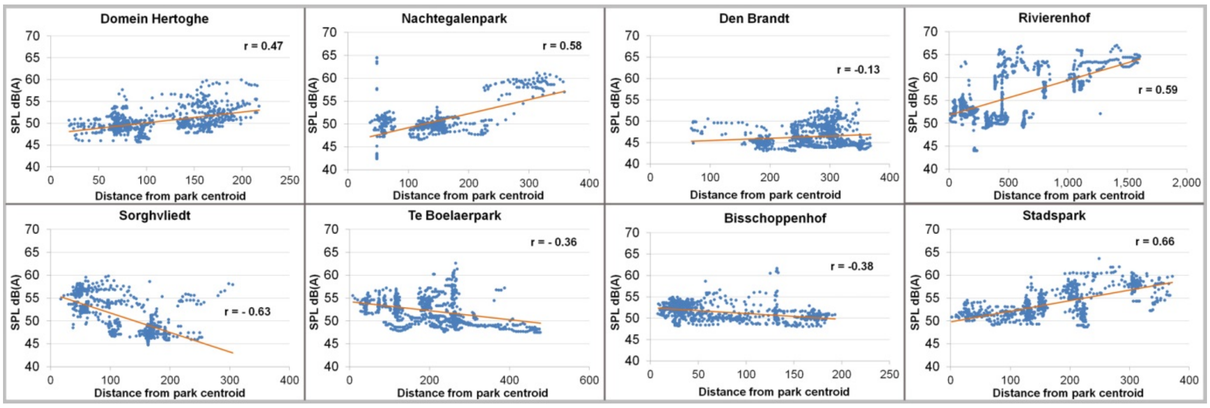

Fig.9. Relationship between the noise levels (L_{A90}) of the selected cluster points and the distance from each park centroid (p-value<0.001). The coefficient of determination (R^2) and Pearson correlation coefficient (r) for the two variables are reported in each graph.

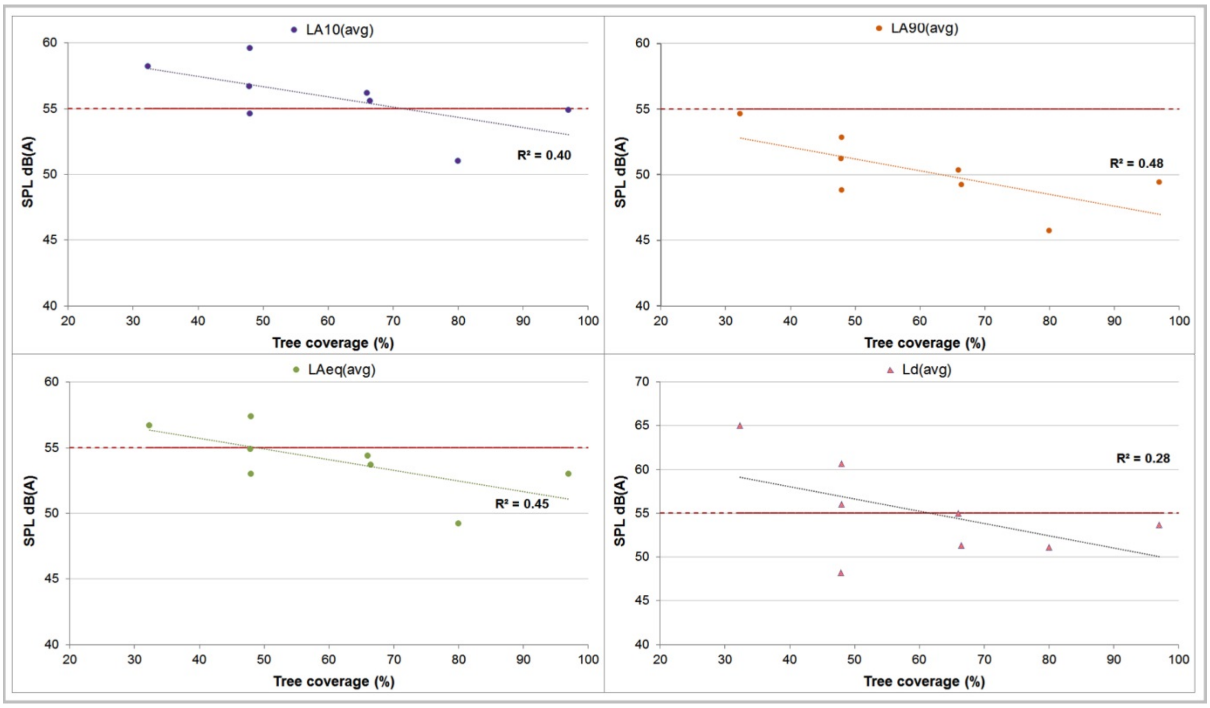

Fig.10. Correlations between tree coverage and $L_{A10,}$ L_{A90} L_{Aeq} and L_d with the respective R^2 values. A cut-off line has been added at 55 dB(A) in order to facilitate the comparison among the noise indicators. $L_{d(avg)}$ refers to simulated noise levels, while the other acoustic indicators refer to measured values in the parks.

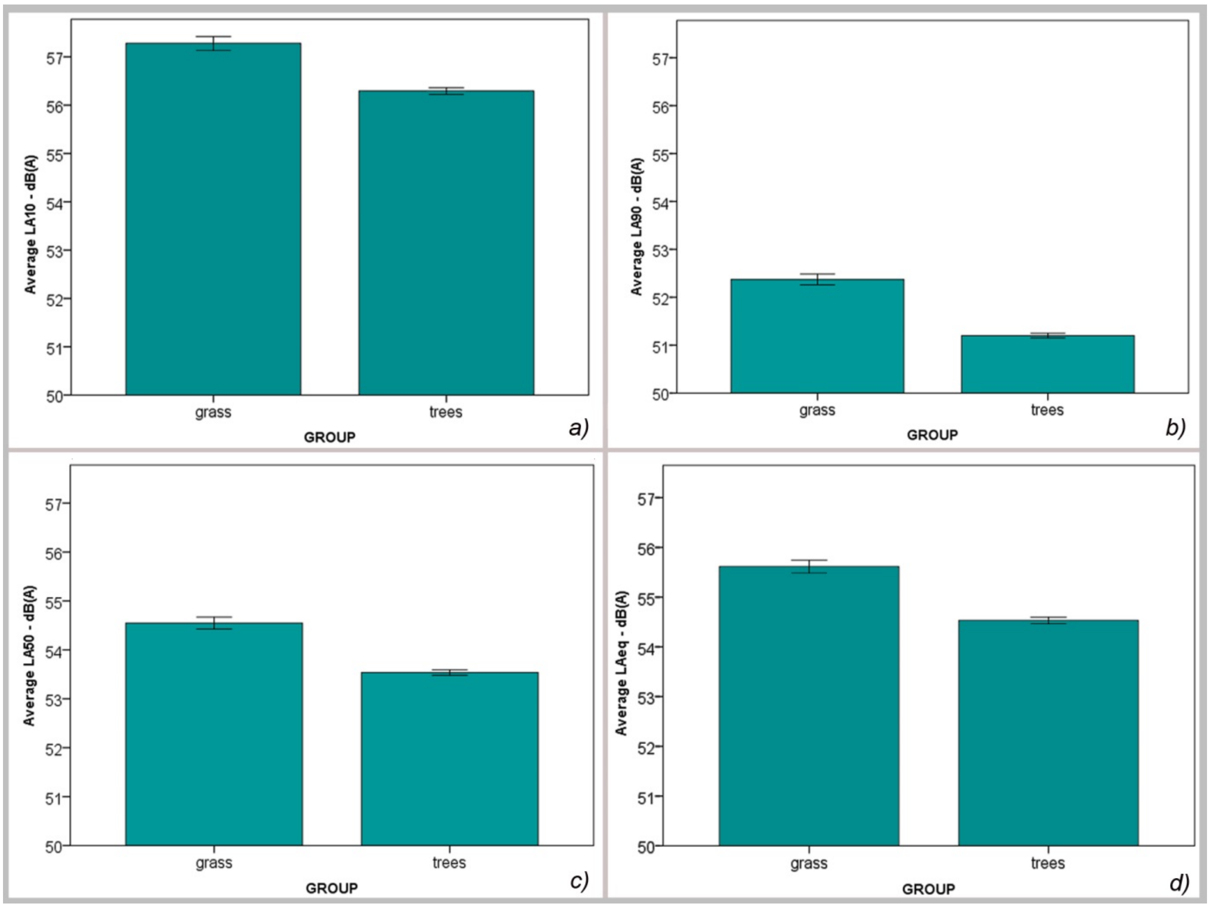

Fig.11. Average noise levels per index for the measurement points classified in tree or grass areas using error bars (95% confidence interval).

List of tables

Table 1. Parks size and distance from the roads

A/A	Park	Size (ha)	Distance from the ring/national road (m)
1	Bischoppenhof	3	128
2	Domein Hertoghe	4	10
3	Stadspark	11	13
4	Te Boelaerpark	14	500
5	Sorghvliedt	16	637
6	Nachtegalenpark	19	12
7	Den Brandt	21	370
8	Rivierenhof	129	6

Table 2. Vegetation and morphological indicators measured inside and around the parks.

Variable	Symbol	Comment
	Vegetation-related indicators	
Park size	*CA*	Total area in hectares.
Tree coverage	*Tree_COV*	Ratio of tree coverage.
Grass coverage	*Grass_COV*	Ratio of grass coverage.
	Morphological indicators	
Road coverage (100m)	*RCOV_100*	Road coverage (m^2) measured in a buffer zone of 100m around the park borders.
Building coverage (100m)	*BCOV_100*	Building coverage (m^2) measured in a buffer zone of 100m around the park borders.
Mean distance from major roads	*Mean_dist_major*	The average Euclidian distance from all sides of the park to the closest major road.
Maximum traffic volume	*Max_veh*	The maximum simulated traffic volume (veh/h) in all the streets adjacent to the park.

Table 3. Description of all the noise indicators applied in the analysis.

Variable	Category	Comment
		Simulation-based indicators
L_d	min, max, avg	Day noise levels based on traffic flows calculated in CadnaA and Matlab.
		Measurement-based indicators
L_{A10}	min, max, avg	A-weighted sound pressure level exceeded 10% of the measurement period.
L_{A50}	min, max, avg	A-weighted sound pressure level exceeded 50% of the measurement period.
L_{A90}	min, max, avg	A-weighted sound pressure level exceeded 90% of the measurement period (background noise).
L_{Aeq}	min, max, avg	A-weighted equivalent sound pressure level.

Table 4. Average simulated and measured noise levels in the eight parks sorted in an ascending form for $L_{d(avg)}$. Standard deviation values are presented in parenthesis in each case. Measured values have been calculated by averaging the point levels inside the parks over the entire measurement period (11:00am - 19:00pm).

Parks	**Simulated**	**Measured**		
	$L_{d(avg)}$	$L_{A10(avg)}$	$L_{A90(avg)}$	$L_{Aeq(avg)}$
Te Boelaerpark	48.2 (±5.4)	56.7 (±4.8)	51.2 (±2.9)	54.92 (±4.6)
Den Brandt	51.1 (±2.8)	51.0 (±5.3)	45.7 (±2.3)	49.21 (±4.6)
Sorghvliedt	51.3 (±4.6)	55.6 (±5.2)	49.2 (±3.5)	53.67 (±5.2)
Domein Hertoghe	53.7 (±4.3)	54.9 (±5.4)	49.4 (±2.7)	53.02 (±5.0)
Nachtegalenpark	55.0 (±4.0)	56.2 (±5.2)	50.3 (±3.4)	54.37 (±5.2)
Bisschoppenhof	56.0 (±2.8)	54.6 (±5.0)	48.8 (±3.6)	53.04 (±5.4)
Stadspark	60.7 (±4.2)	59.6 (±4.6)	52.8 (±2.9)	57.44 (±4.4)
Rivierenhof	65.0 (±5.0)	58.2 (±6.0)	54.6 (±5.2)	56.73 (±5.7)

Table 5. The effect of each predictor (R^2) in the respective noise indices."D_centr" denotes the distance from the park centroid and "Cover" stands for the binary variable of grass and tree coverage per point.

A/A	**Parks**	L_{Aeq}		L_{A10}		L_{A50}		L_{A90}	
		D_centr	**Cover**	**D_centr**	**Cover**	**D_centr**	**Cover**	**D_centr**	**Cover**
		R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2
1	Stadspark	*0.21*	0.01	*0.22*	0.01	*0.32*	0.02	*0.26*	0.01
2	Rivierenhof	*0.20*	0.03	0.17	0.03	*0.20*	0.03	*0.29*	0.03
3	Te Boelaerpark	0.00	0.05	0.00	0.04	0.00	0.03	0.03	0.02
4	Nachtegalenpark	0.08	0.07	0.11	0.02	0.08	0.00	0.09	0.02
5	Bisschoppenhof	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01
6	Sorghvliedt	0.00	0.04	0.03	0.03	0.05	0.01	0.13	0.01
7	Domein Hertoghe	0.04	0.01	0.04	0.01	0.12	0.01	0.11	0.00
8	Den Brandt	0.04	0.07	0.05	0.07	0.03	0.03	0.01	0.01