Relationship between green space-related variables and traffic noise distribution in the urban scale, an overall approach

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ABSTRACT

The aim of this paper is to investigate the effect of green spaces as land use element of urban morphology on road traffic noise distribution. Two different scales of approach (macro, meso) were used for the analysis. In the macro-scale, six European cities were investigated for correlations between noise and green space parameters in order to explore whether greener cities can also be quieter. In the meso-scale, the analysis was focused on a sample area of 30km² in eight UK cities by incorporating features of green space ratio, pattern and road configurations. Results at this level proved that apart from the differences in the morphological features, traffic noise distribution can also be affected by the different settlement forms, such as linear and radial configurations. The scale of analysis was also proved to be a crucial factor in the extent of correlations.

Keywords: Green spaces, Cities, Road traffic noise

I-INCE Classification of Subjects Number: 52.3

1. INTRODUCTION

Noise annoyance problems have been rated as one of the most significant problems in urban areas as 25% of European citizens is regularly exposed to noise levels during the night that can cause serious damage on health (1). For this reason the Environmental Noise Directive 2002/49/EC (END) through strategic noise mapping can provide a representation of the noise levels and the population exposed over critical noise bands. In that way it is possible to set the base for developing community measures for noise reduction, emitted by major sources. One of the inherent elements of the cities’ urban morphology - coupled with the outdoor space, road infrastructure and buildings - is green spaces.

The relationship between traffic noise and green spaces has been investigated in multiple scales. The majority of these studies focuses on the small scale, where the absorption or scattering effects of branches and leaves are investigated (2,3) This kind of researches are extended from a single tree (4) to different plant types (5) or various tree belts (6). In the urban level previous works selectively emphasized on the quantitative assessment of parks concerning traffic noise reduction (7) or on noise levels prediction through land use regression models (8,9). Other studies have considered their effect either on the building level (10,11) or in large neighbourhoods (12, 13). Finally, traffic noise has also been investigated in the dwelling scale within the same or different cities (14) (15) (16). In a European level, apart from the European Green Capital Award, most benchmarking reports related to the characterization of cities based on their environmental performance or urban form; rarely do they include noise in their assessment parameters (17,18).

Finally from the morphological viewpoint, road infrastructure as a street pattern element can be used to describe the network of distinct units, such as cities and towns (19). For planning purposes at a city-scale level, “Lynch and Hack” (1962) proposed three simple systematic patterns/forms: radial, linear and grid, two of which are investigated in the current study. In radial patterns, a main ring road acts as the area constraint around built-up areas, while linear patterns refer to development, laid out along a transportation ‘spine’.

This paper has a dual aim according to the scale of analysis. For the macro-scale analysis the target is to
provide an evidence of whether greener cities can also be quieter through the analysis of noise mapping and land cover data. This research question is investigated for the entire area of six European cities. For the meso-scale analysis the aim is to investigate the influence of green spaces on traffic noise distribution in terms of ratio and pattern in eight average-sized UK cities.

2. METHODS

2.1 Macro-scale

Six cities with available noise and green space data online were selected, as presented in Figure 1, in order to perform a more detailed analysis between noise and green space indicators. The noise mapping areas in these cases were equal or smaller than the agglomeration areas, firstly because the main emphasis was in the core city zone and secondly because agglomerations are abide by specific population criteria. The population density apart from Brussels ranged between 2,340 and 3,715 people (M_density=3,425) per km². The noise data were extracted by calculating the percentage of pixels belonging to the different noise bands. As presented in Table 1, seven noise indices were formulated and tested to check which one could better describe the extent of noise pollution in the cities. Some of them were increasing proportionally to noise, while others were decreasing when noise levels were rising. The identification of the most suitable noise index was based on the highest correlation with green space indices. The values of p(x) in the “Equation” column of Table 1 represent the percentage of pixels in the corresponding noise band.

Table 1 – Noise and green space indicators tested in the macro-scale

<table>
<thead>
<tr>
<th>Noise indices</th>
<th>Comments</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δnoise 1</td>
<td>Proportional to noise levels (↑↑)</td>
<td>p70p/p55</td>
</tr>
<tr>
<td>Δnoise 2</td>
<td>Proportional to noise levels (↑↑)</td>
<td>p70p/p55 + 70p</td>
</tr>
<tr>
<td>Δnoise 3</td>
<td>Invers. proportional to noise levels (↑↓)</td>
<td>Sum (p55-p70)/p70p</td>
</tr>
<tr>
<td>Δnoise 4</td>
<td>Invers. proportional to noise levels (↑↓)</td>
<td>p55/[average (p60 - p70)]</td>
</tr>
<tr>
<td>Δnoise 5</td>
<td>Proportional to noise levels (↑↑)</td>
<td>p70p/[average (p55-p70)]</td>
</tr>
<tr>
<td>Δnoise 6</td>
<td>Invers. proportional to noise levels (↑↓)</td>
<td>[(p55/p70) * (1/sum(p60-p70))]</td>
</tr>
<tr>
<td>Δnoise 7</td>
<td>Invers. proportional to noise levels (↑↓)</td>
<td>[5<em>p55+4</em>p60+3<em>p65+2</em>p70+p70p]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Green space indices</th>
<th>Comments</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Space Ratio (Δgsr)</td>
<td>% total green spaces</td>
<td>Green space surface/Sum area</td>
</tr>
<tr>
<td>Porosity (Δporous)</td>
<td>% porous to non-porous surfaces</td>
<td>Δgsr/(BCOV + RCOV)</td>
</tr>
<tr>
<td>BCOV</td>
<td>Ratio of buildings</td>
<td>Area of buildings/Sum area</td>
</tr>
<tr>
<td>RCOV</td>
<td>Ratio of road area</td>
<td>Road area/Sum area</td>
</tr>
</tbody>
</table>

As regards the green space data, a first set of indicators was established referring to the green space coverage in the cities; firstly as a ratio compared to the whole area (Δgsr) and secondly as a percentage between porous and rigid areas (Δporous). In this case the ratio of buildings (BCOV) and roads (RCOV) was necessary to be calculated. Green space data were extracted from Mapzen, (21) which uses the latest Openstreetmap dataset.
2.2 Meso-scale

At this level the analysis was focused on eight UK cities within a sample area of 30km$^2$ around the broad city centre as presented in Figure 2a. The selection process of the cities was performed based on the availability of noise mapping data and the different urban settlements. In total four cities of a “radial” settlement were chosen (Coventry, Leicester, Nottingham, Sheffield) and four of a “linear” (Bournemouth, Blackpool, South End, Brighton). The first category refers to mainland cities, while the second to seaside cities. The sample size selection was based on a G-Power test for a multiple regression fixed model, which gave a minimum sample of 27 observations. Consequently, the final selection of 30 observations satisfied the above criteria.

Each city was divided in 30 smaller grids of 1km x 1km as presented in Figure 2b. The arrangement of the grid was such, so as to incorporate the main ring road for the radial cities and the highest
proportion of the primary roads for the linear cities. The basic data source for noise levels lies on the online noise maps for the first round agglomerations produced by the English Department for Environment Food and Rural Affairs (22). The noise bands for $L_{den}$ follow the dB(A) classification guidelines of the END arranged as follows: (0-54.9), (55-59.9), (60-64.9), (65-69.9), (70-74.9), (75+). Each noise map was reconstructed as a new raster file with the above classification and a Matlab code was used to convert the colours in noise levels (Figure 2b) calculated for each tile.

The green space parameters were extracted using the Digimap platform from Ordnance Survey, and the OS Mastermap Topography collection (23). Two main categories of variables were described according to their semantic content: “Green Space Ratio” and “Green Space Pattern” as presented in Table 2. The ANN index compares the observed and expected distances among the polygon centroids. Values greater than 1 suggest a trend towards dispersion, while values lower than 1 express a trend towards clustering. The whole analysis was performed in ArcGIS using Analysis and Pattern tools.

<table>
<thead>
<tr>
<th>Name</th>
<th>Green Space Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffer_100_road_A</td>
<td>Ratio of urban green within 100m from primary roads</td>
</tr>
<tr>
<td>Buffer_100_local_road</td>
<td>Ratio of urban green within 100m from local roads</td>
</tr>
<tr>
<td>Natural Urban Green ratio</td>
<td>Ratio of parks and urban woodland</td>
</tr>
<tr>
<td>Gardens ratio</td>
<td>Ratio of green surface in backyards and front yards</td>
</tr>
<tr>
<td><strong>Green Space Pattern</strong></td>
<td></td>
</tr>
<tr>
<td>ANN</td>
<td>Average Nearest Neighbour Index</td>
</tr>
</tbody>
</table>

### 3. RESULTS

#### 3.1 Macro-scale

The effect of green space indicators on noise indices was initially investigated in the macro-scale. A Pearson product-moment correlation coefficient was computed to assess the relationship between the seven noise indices and the four green space dependent variables. Results proved that there was a positive correlation between $\Delta noise(6)$ and the Porosity index ($r=.79, n=6, p=.035$), as well as between $\Delta noise(6)$ and Green Space Ratio ($r=.85, n=6, p=.016$). This fact suggests that lower noise levels - expressed with high values of $\Delta noise(6)$ - can potentially be achieved in cities with a higher ratio of green space coverage as shown in Figure 3a and higher levels of porous surfaces depicted in Figure 3b.

![Figure 3 – Correlations of noise levels with: (a) the Green space coverage, (b) the Porosity index](image-url)
The classification process among the cities presented in Figure 4 showed that the less noise-polluted city at this level is Prague with Helsinki, Brussels, Amsterdam, Rotterdam and Antwerp to follow. The results reveal that the sequence of cities is not always the same depending on the classification parameter. Differences occur when the classification factor is the porosity index or the green space coverage. Practically this means that quieter cities can potentially be greener, however this does not always apply vice versa. For example Amsterdam appears quieter than Brussels; nevertheless Brussels has a higher ratio of green space coverage. In this case the porosity index seems more meaningful as a classification factor.

### 3.2 Meso-scale

This level refers to the analysis that was performed in eight UK cities, where the effect of green spaces on traffic noise distribution was investigated coupled with categories of settlement form. A Pearson product-moment correlation coefficient was used to assess the relationship between a group of green space-related variables and traffic noise levels. The results presented in Figure 5a proved that there was a negative correlation between the ANN index and traffic noise $r(8) = -.71$, $p < .05$ suggesting that an increase in the distance between the green space patches and their closest neighbouring patch can possibly infer a decrease in traffic noise.
The assessment of the relationship between the Natural Urban Green ratio and the two settlement forms was performed via an independent sample t-test. According to the scatter plot in Figure 6a, it was proved that there was a significant difference in the mean values of the green space ratio for radial (M=728, SD=39.6) and linear cities (M=622, SD=66.9); conditions, t=2.73, p=.034. Therefore, it is reasonable to deduce that radial cities are associated with a higher green space ratio and generalize this conclusion also in other urban areas with similar settlement form. A possible explanation is that linear sea-side cities tend to develop a denser urban structure with less natural green spaces available than mainland cities.

![Figure 6](image)

Figure 6 – Dot plots describing the relationship of the settlement forms with: (a) Natural Urban Green ratio, (b) ANN and (c) sound pressure level (SPL)

Especially for Sheffield and Brighton a further analysis was conducted. As far as Sheffield is concerned, the proportion of Gardens ratio as presented in Figure 5b had a significant negative correlation with L_{den}, r(30)=-.619 and r(30)=-.537 respectively. In Brighton there was also a negative effect of the Gardens ratio, r(30)=-.611. In a linear regression analysis conducted to test how effectively, green space variables can predict the average L_{den} in Sheffield and Brighton, it was found that the model in Sheffield explained 85.5% of the variance (R^2=.85, F(3,26)=51.2, p<.05) with a significant contribution from Gardens ratio (β=-.24). Accordingly, the regression model in Brighton accounted for 71.2% of the total variance (R^2=.71, F(3,29)=21.4, p<.05) with Gardens ratio to present also a high contribution (β=-.26).

4. CONCLUSIONS

The aim of this paper was to investigate the effect of green space-related factors on traffic noise in two different scales: macro and meso. On the macro-scale approach the target was to provide an evidence of whether greener cities can also be quieter, whereas on the meso-scale to quantitatively investigate the influence of green spaces on traffic noise distribution in terms of coverage and pattern. In this case two different settlement forms (radial, linear) were investigated in eight different cities.

In the macro-scale it was proved that quieter cities can potentially be greener, however this effect does not always work vice versa, as greener cities are not always quieter. On the top of that the analysis showed that lower noise levels can possibly be achieved in cities with a higher extent of porosity and green space coverage. Overall, it was shown that planners should emphasize more on the balance between green space surfaces and built-up surfaces, since this seems to be a more meaningful indicator compared to the green space coverage itself.

The meso-scale analysis showed that radial and linear cities are usually liable to a different Green Space Pattern. The distribution of Natural Urban Green spaces can be a possible reason affecting noise levels throughout the cities. In particular, a dispersed Green Space Pattern can possibly be a positive evidence of lower noise levels, in contrast with a clustered one. The radial cities in this investigation were associated with a significantly higher Natural Urban Green Ratio than linear cities, allowing for a generalization of this conclusion also to other average-sized cities with similar settlement forms in UK. Moreover, radial cities are more likely to be “quieter” than linear cities.

The analysis between Brighton and Sheffield proved that, green space parameters, such as the Gardens ratio were proved to have a negative effect on traffic noise levels. Also, the prediction model for traffic noise
in both cities managed to explain successfully more than 70% of the variance, proving that green spaces can have an effect on traffic noise distribution also from the land use viewpoint. These results can further be validated in other European cities, where the green space configuration is different than in UK cities.

ACKNOWLEDGEMENTS

This research received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013 under REA grant agreement n° 290110, SONORUS "Urban Sound Planner".

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