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Research paper

Integrated effects of urban morphology on birdsong loudness and visibility of green areas

Yiying Hao[a,b], Jian Kang[a,*], Johannes D. Krijnders[b]

[a] School of Architecture, University of Sheffield, Western Bank, Sheffield S10 2TN, United Kingdom
[b] INCAS[3], Dr. Nassaulaan 9, 9401 HJ Assen, The Netherlands

HIGHLIGHTS

- Influence of urban morphology on birdsong loudness is demonstrated.
- Influence of urban morphology on visibility of green areas is revealed.
- There are varied relations between birdsong loudness and visibility of green area.

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ABSTRACT

The aim of this study is to determine how to increase birdsong loudness and the visibility of green areas in low-density residential areas by controlling urban morphological parameters. The spatial sound level distributions of birdsong at 12 sites sampled from a GIS database of Assen, the Netherlands, were simulated by noise mapping techniques and calculated using a MATLAB program on spatial sound level matrices. The visibilities of green areas are analysed and calculated by Visibility Analysis Graph in Space Syntax. Correlation analyses were conducted between the obtained data on spatial sound level indices, the mean visibility and urban morphological parameters. The results show that birdsong loudness has significant positive linear relationships with urban morphological parameters, including Building Plan Area Fraction ($R^2 = 0.491$), Green Area Perimeters ($R^2 = 0.491$) and Green Area Dispersion Index ($R^2 = 0.618$), while the visibility of green area has negative linear relationships with morphological parameters, including Building Plan Area Fraction ($R^2 = 0.431$) and Green Area Perimeters ($R^2 = 0.799$). It has also been found that in the proximity of green areas, the visibility of green areas has a positive relationship with birdsong loudness, whereas in most areas further from green areas, the visibility of green areas has a negative relationship with birdsong loudness. Either increasing birdsong loudness or enhancing visibility of the green areas by controlling urban morphological parameters is helpful for the optimisation of soundscape design with masking effects. Bird habitats and vegetation are important ecological issues to consider for the enhancement of the roles of urban morphology.

1. Introduction

Green areas are an important natural resource in urban areas and can fulfil a variety of human needs, such as natural view (Lange, Hehl-Lange, & Brewer, 2008), air quality (Currie & Bass, 2008), microclimate (Shashua-Bar and Hoffma, 2000) and noise reduction (Fang & Ling, 2003; Van Renterghem, Botteldooren, & Verheyen, 2012). Green areas therefore are significant for quality of life and have high social and economic values (Anderson & Cordell, 1988; De Hollander & Staatsen, 2003; Kirkpatrick, Davison, & Daniels, 2012). In terms of natural view, green areas have often been studied from the perspectives of visibility (Yang, Zhao, Mcbride, & Gong, 2009), aesthetics, recreation (Lange et al., 2008), safety and preference (Jorgensen, Hitchmough, & Calvert, 2002) in urban life.

Green areas are also an important supplier of birdsong due to their ecological function as habitats for birds and other animals (Hansson, 2000; Daniels & Kirkpatrick, 2006; Pellissier, Cohen, Boulay, & Clergeau, 2012). Birds are one of the best-known biological groups in cities (Pellissier et al., 2012); thus, birdsong is a frequent, distinct and frequency-adaptable natural sound source in the ambient noise of urbanised areas (Ryan & Brenowitz, 1985;

* Corresponding author. Tel.: +44 114 2220325; fax: +44 114 2220315.
E-mail addresses: y.hao@sheffield.ac.uk (Y. Hao), j.kang@sheffield.ac.uk (J. Kang), DirkjanKrijnders@incas3.eu (J.D. Krijnders).

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Halfwerk and Slabbekoorn, 2009; Cardoso & Atwell, 2011). Birdsong is ranked at the top of the desired natural urban sounds (Yang & Kang, 2005) and benefits people's rejuvenation and health through its pleasantness (Gidlöf-Gunnarsson and Öhrström, 2007). It also commonly interferes with traffic noise in urban areas (Best, Ozmeral, Gallun, Sen, & Shinn-Cunningham, 2005; Gidlöf-Gunnarsson, Öhrström, & Ögren, 2007; Kang, 2007; Gold, 2010).

Recently, with the emergence of the 'soundscape' concept (Zhang & Kang, 2007; Yu & Kang, 2009; Kang & Zhang, 2010; Brown, Kang, & Gjestland, 2011), research on the urban sound environment has been extended to perceptual assessment (Yang & Kang, 2005; Kang, 2007; Joynt & Kang, 2010), where "masking" has been employed to study the interference between natural sounds and urban noise (Nilsson, Alvarsson, & Rådsten-Ekman, 2009; De Coensel, Vanwetswinkel, & Botteldooren, 2011). Masking effects also have been considered as an important urban design technique (Siebein, Kwon, Smitthakorn, & Gold, 2007). Masking, which refers to a significant everyday-life phenomenon in hearing (Yost, 2008), has been widely identified and investigated in terms of two main categories:"energetic masking" and "informational masking" (Nilsson et al., 2009; Durlach et al., 2003; Watson, 2005). Watson (2005) defined the interference among different sounds based only on the physical properties of the sound as "energetic masking" and the masking or interference caused by making the stimulus context variable and uncertain as "informational masking". It has been demonstrated that as a result of "energetic masking" and "informational masking", either increasing birdsong loudness or enlarging the visibility of green areas can significantly improve the pleasantness and naturalness of the traffic noise environment (Hao, 2014). Therefore, the main motivation of this study is to determine how to enhance the positive effects of masking for soundscape optimisation from these two perspectives, i.e., increasing birdsong loudness and enlarging the visibility of green areas in urban design.

Urban morphology, which is at the root of urbanism and urban design (Kropt, 2005; Larkham, 2005), has direct and substantial impacts on both outdoor sound propagation (Raydan & Steemers, 2006; Kang, 2007) and space visibility (Yang et al., 2009; Sander & Manson, 2007). In previous studies on urban environments (e.g., solar potential, atmospheric environment and traffic noise), urban morphological factors, for example building density, building patterns, street layout and coverage and landscaping, have been represented and studied using a number of quantitative urban morphological parameters (Cheng, Steemers, Montavon, & Compagnon, 2006; Xie, Huang, & Wang, 2006; Salomons & Pont, 2012). However, there is a shortage of integrated research on green areas from the perspectives of both birdsong loudness and visibility of green areas in the context of urban morphology to suggest practical landscape and urban design guidelines.

Therefore, this study aims at exploring the integrated effects of urban morphological parameters that reflect the 3D nature of green areas and buildings on birdsong loudness and visibility of green areas. Correspondingly, this paper first will show how urban morphology influences these two aspects and then how the two aspects are related.

2. Methodology

2.1. Site sampling

The study sites were sampled in Assen, which is the capital city of the province of Drenthe. Assen can be regarded as a typical European town with diverse low-density urban morphologies and traffic characteristics (Hao & Kang, 2013). Using a GIS database with 763 grids (each 250 m × 250 m) of the built-up areas of Assen, approximately 51% of the grids have both the traffic arboreal green areas, which may result in masking effects between the two main sound sources at the sites (i.e., traffic noise and birdsong). In these areas, the daytime traffic noise is relatively constant; the sound levels are typically 50–60 dBA, and most of the energy is between 100 and 1600 Hz. The green ratio of Assen City, including gardens and forests, is approximate 36% according to official statistics released by the Assen Municipality (2011), therefore the grids that have this representative green ratio and main roads were randomly sampled. Fig. 1 shows figure-ground maps of the 12 sampled sites, with the buildings in black, roads in grey and green areas in light green.

2.2. Sound mapping of birdsong

To simulate the spatial distribution of birdsong sound levels, sound maps were calculated using a common noise-mapping package, Cadna/A (DataKustik GmbH, 2006; Szulecki, Zwerling, Anderson, & Turpin, 2010; McGowan, 2012). For noise mapping, the propagation of the frequency components of birdsong was calculated in the models. First, in the simulation, birdsong is emitted from green areas (250 m × 250 m) in eight idealised wild open spaces (see Section 2.2.1); this is a pilot study of birdsong loudness for the further study of birdsong in the actual urban morphology of the sampled sites (see Section 2.2.2).

The representative heights of major bird habitats in urban trees were used for the simulation sound source heights because in town centres birds nest more in trees than on the ground or in shrubbery, as is the case in the countryside. Approximately 70% of Passeriformes nest higher than 4 m in the centres of European towns (Clergeau, Croci, Jokimäki, Kaisanlahti-Jokimäki, & Dinetti, 2006). Tree nesters are considered to be better urban adaptors. The increased planting of trees may provide more suitable nesting habitats for the tree nesting guild, further increasing their abundance (Huhta, Jokimäki, & Rahko, 1999; Clergeau et al., 2006; Pellissier et al., 2012).

Patch size and its influence on avian habitats are also important issues to consider in the modelling because the green areas are composed of patches of different sizes in both idealised wide open spaces and the morphology of the study sites. Patch sizes in idealised open spaces vary from 0.28 to 2.25 ha, and the patch sizes in the actual urban morphology are 0.1 to 2.02 ha, except for one patch with an area of 0.06 ha. The effects of patch size on avian density and nesting are debated; it has been suggested that they are not clearly influenced by patch size but vary among regions, number of years of vegetation and species (Winter, Johnson, Sharffer, Donovan, & Svedarsky, 2006; Davis, 2004; Schmiegelow & Mönkkönen, 2002; Schieck, Lertzman, Nyberg, & Page, 1995; Andrén, 1994; Van Dorp & Opdam, 1987). However, Van Dorp and Opdam (1987) utilised 0.1 ha as a lower limit for the habitat of birds and proved that multiple bird species inhabited patches of 0.1 ha. Moreover, roads in the residential areas in Assen are primarily two-lane without a disturbed roadside, so they are not considered as patch barriers (Winter et al., 2006). Birds in the small patches can still use the resources of the neighbouring patches (Andrén, 1994). Therefore, although there is a risk that birds may not inhabit the small patches, for this study it was assumed that the fragmentation of the green areas has little influence on avian density in the same region and with similar vegetation and avian species. Given the same green area ratio, the number of birds in each site was set as a constant parameter to compare the effects of urban morphology.

2.2.1. Idealised wide open spaces

To initially examine the influence of geometric configurations of green areas and distributions of sound sources on birdsong loudness without sound obstacles (e.g., buildings), eight idealised wild open spaces were simulated. The open spaces have a consistent green ratio of 36%, which is a control parameter in the sound