Effects of Urban Morphology on Urban Sound Environment from the Perspective of Masking Effects

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ABSTRACT

This study explores how to improve soundscape quality in the context of urban morphology from the perspective of masking effects. Masking in this study is explained as a hearing phenomenon by which soundscape characteristics are altered by the presence of interfering sound event(s). The concept of this study is primarily based on two hypothesises: first, masking effects in soundscape can influence the perception and evaluation of sound environment; second, urban sound propagation has relationships with urban morphological parameters.

Diverse sounds from the common urban sound sources are characterised, using acoustic analysis and psychological evaluation, with a consideration of potential masking among them. The masking effects of traffic noise by birdsong are then investigated, showing the differences in the psychological evaluation on the traffic noise environment under different physical conditions, with maximum score differences of 3.9 in the Naturalness, 3.1 in the Annoyance, and 4.0 in the Pleasantness in a scale of 0-10. In view of the results in the psychological evaluation, two main research directions are confirmed, including urban noise attenuation (car traffic and flyover aircraft) and natural sound enhancement (birdsong loudness and the visibility of green areas). The relationships between spatial sound levels and quantitative urban morphological parameters are explored by noise mapping technique and a MATLAB program on spatial sound level matrix. For the traffic noise, it is possible to achieve noise level attenuation of more than 10 dB and reduction of 25% noisy area through the control of the parameters, e.g., the Building Plan Area Fraction, the Complete Aspect Ratio, the Building Frontal Area Index, and the Horizontal Distance of First-row Building to Road. For the flyover

aircraft noise, a decrease in the Horizontal Distance of First-row Building to Flight Path can result in more than 10 dB noise reduction. For the birdsong, with an increasing Green Area Perimeter, the sound levels in the areas further from the green areas can be increased by up to 11 dB; with an increasing Green Area Dispersion Index, the sound levels can increase by approximately 10 dB. Meanwhile, a site with a lower Building Plan Area Fraction has higher visibility of the green areas, with an increase of Mean Visibility of approximately 600.

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CONTENTS

LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
ANOVA	Analysis of variance
BFAI	Building Frontal Area Index
BPAF	Building Plan Area Fraction
BSAPAR	Building Surface Area to Plan Area Ratio
CAR	Complete Aspect Ratio
CPSP	Continuity Preserving Signal Processing
CRTN	Calculation of Road Traffic Noise
dB	Decibel (unweighted)
dBA	Decibel (A-weighted)
DFBGA	Distance of First-row Building to Green Area
DFBR	Distance of First-row Building to Road
END	Environmental Noise Directive
FBFLI	First-row Building Frontal Length Index
GADI	Green Area Dispersion Index
GAP	Green Area Perimeter
GIS	Geographic information system

HDFBFP	Horizontal Distance of First-row Building to Flight Path
HOSANNA	Holistic and sustainable abatement of noise by optimised combina tions of natural and artificial means
HWR	Height-to-Width Ratio
Hz	Hertz
ICC	intra-class correlation
IEC	International Electrotechnical Commission
ISO	International Standards Organization
ISO/TC 43/SC 1	Technical Committee ISO/TC 43, Acoustics, Subcommittee SC 1
kHz	kilohertz
LAeq	Equivalent Continuous Sound Level using A-weighting
PCA	Principal Component Analysis
RAF	Road Area Fraction
RGB	Red, green and blue
SNR	Signal-to-noise ratio
SPL	Sound pressure level
SRS	Simple Random Sample
UCL	University College London
VGA	Visibility Graph Analysis
WHO	World Health Organization

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CHAPATER 1

INTRODUCTION

1.1 Research background

“Acoustic environment as perceived or experienced and/or understood by people, in context” by ISO/TC 43/SC 1 has been widely accepted and emphasised as the definition of soundscape. In accordance with this, it is suggested that soundscape research, different from noise control engineering, is about the relationships between the ear, human beings, sound environments and society (Kang, 2007). Compared with the traditional noise research that concentrates on the impacts of certain unwanted sounds (Nilsson et al. 2009), the study of soundscape concerns multiple sound sources and has acted as an emerging intersection for the interdisciplinary studies, including physical measurements, perceptual assessment, identification and taxonomy of sound events, modelling, mapping and simulation, as well as soundscape design (Kang, 2007; Schulte-Fortkamp, 2010; De Coensel et al, 2010, Jeon et al, 2010; Krijnders et al, 2009; Guastavino, 2007; Dubois et al, 2006).

Masking, which is referred to a significant everyday-life phenomenon in hearing (Yost et al, 2008), has long attracted attention in the science of acoustics and psychoacoustics. In terms of human hearing, it is referred as masking when a perceiver’s performance is reduced by the presence of maskers (Durlach, 2006). In the early stage, the research results were mainly obtained through lab experiments on pure tones and noises (Licklider’s, 1951; Tanner, 1958; American Standard Association 1960,). Within the diverse definitions, explanations and categorizations of masking, ‘energetic masking’ and ‘informational masking’ seem to be the most frequently studied and referred to (Seeber, 2008; Shinn-Cunningham, 2008; Watson, 2005; Moore et al, 1997; Zwicker and Fastl, 1990). The “energetic masking” is traditionally considered as a peripheral process and is nowadays referred as “peripheral” masking, to distinguish it from “informational” or “central” which are related to higher level processing (Nilsson et al, 2009). Watson defined the interference among different sounds based only on the physical properties of the sounds as “energetic masking” and the masking or interference due to making the stimulus context variable and uncertain as “informational masking” (Watson, 2005). The models of energetic masking focus on sound frequency and primarily take the loudness and frequency response into account (Zwicker and Fastl, 1999; Havelock et al, 2008; Moore et al, 1997), while informational masking has been intensively studied in the current investigations of speech intelligibility and speech privacy (Hara and Miyoshi, 2009; Shimizu, 2009).

Recently, how does masking influence human auditory perception in real-life soundscape has contributed more and more methods to the perceptual assessment of soundscape and the design of sonic environments (Boubezari and Bento Coelho, 2005; Jeon et al, 2008; Boubezari and Bento Coelho, 2008; Boubezari et al, 2009; Hellström, 2009). However, in most of these studies, concepts of masking in the science of acoustics and psychoacoustics were directly used, e.g., “energetic masking” and “informational masking”, lack of attention to the psychological issues and the information of sound, which significantly attenuates the role of the individual or society as the positive perceiver in soundscape. Till now, there have been no studies on how to define particular masking effects in soundscape, how to explain the occurrence of masking in soundscape, or how to make good use of these masking effects in the design and planning of sonic and global environments. The definitions of masking effects in the previous studies cannot be directly used for the masking effects in soundscape.

Therefore, masking in this study is explained as a hearing phenomenon by which soundscape characteristics are altered by the presence of interfering sound event(s).

Urban morphology is at the root of urbanism and urban design, concerning not only space, but also social, cultural and historical issues (Kropf, 2005). A number of quantitative urban morphological parameters have been explored, developed and studied from the perspectives of environmental performance, landscape, land use, atmospheric and wind environment, and so on (Salat, 2007, Adolphe, 2001; Esbah and Deniz, 2007; Ng et al, 2011; Van de Voorde et al, 2011). Urban morphology can be employed to characterise contexts and compare site patterns in the soundscape studies from the perspectives of physical, cultural and social aspects (Kang, 2007; Memoli et al, 2008; Marry and Baulac, 2010). For example, a wide range of 14 case study sites that cover various urban form types were chosen for the soundscape study in urban open public spaces (Kang, 2007). Urban morphology has also been referred in the studies on sound propagation in terms of spatial structure (e.g. building layout, building geometry) (Kang, 2007; Raydan and Steemers, 2006) and urban morphological parameters (e.g. building density) (Salomons and Pont, 2012). In addition, urban morphology may play a promising role in the soundscape study when considering landscape as passive sound sources (Kang, 2007), e.g., water features and vegetation. Therefore, urban morphology can act as a bridge between the design practice and the soundscape research.

1.2 Aims and objectives

1.2.1 Research objectives

The aim of this research is to explore how to improve soundscape quality in the context of urban morphology from the perspective of masking effects. Figure 1.1 illustrates the general aim, objectives of each chapter and their correlations.

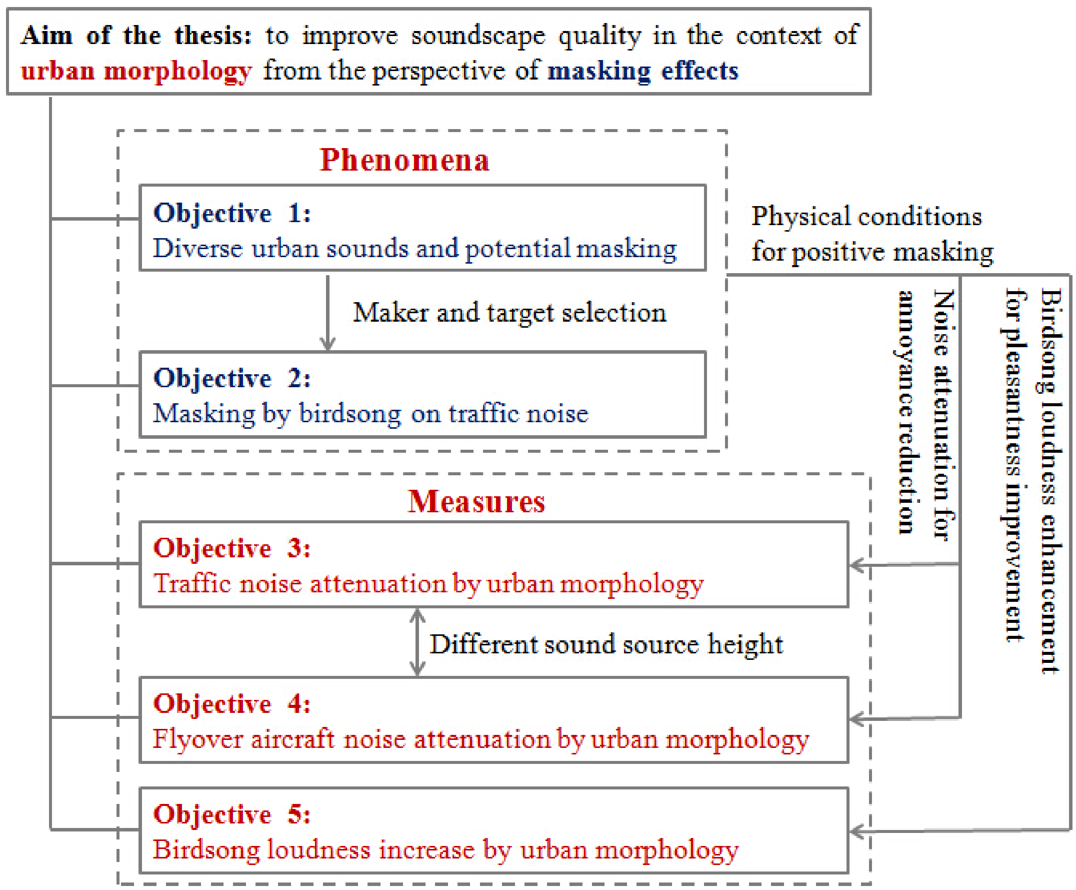


Figure. 1.1. Diagram showing overall research methodology of this study

The detailed objectives are:

(1) Objective 1: To initially reveal possible masking effects among the existing diverse urban sounds by conducting an acoustic analysis and psychological evaluations (Chapter 3). The characteristics of different urban sounds obtained will lead to the masking-related study interests in the following chapters, such as sound pressure level,

spectrum, height of sound sources.

(2) Objective 2: To explore the phenomenon of masking effects in soundscape and determine the physical factors influence the masking effects by psychological experiments, taking traffic noise and birdsong as an example (Chapter 4). How to achieve the physical conditions that can benefit the positive masking effects will be of interest in the following Chapter 5, 6 and 7.

(3) Objective 3: To figure out the characteristics of the traffic noise propagation in the urban area and reveal the relationships between spatial car traffic noise distribution and urban morphology by noise mapping techniques (Chapter 5). The traffic noise attenuation by urban morphology is the main objective of this chapter, based on the evidence provided in Chapter 4 that the decrease of noise level is essential for annoyance reduction.

(4) Objective 4: To figure out the characteristics of the flyover aircraft noise propagation in the urban area and reveal the relationships between spatial flyover aircraft noise attenuation and urban morphology by noise mapping techniques (Chapter 6). Compared with the traffic noise which is emitted approximately at the ground level, the reduction of the flyover aircraft noise, of which the sound source height is much higher, is more difficult; therefore, if flyover aircraft noise attenuation can be influenced by urban morphology is a representative case study.

(5) Objective 5: To figure out the characteristics of birdsong distribution in the urban area and reveal the relationships among birdsong distribution, the visibility of green areas and urban morphology by noise mapping techniques and space syntax theory

(Chapter 7). As demonstrated by the results of Chapter 4, noise reduction is not enough for the improvement of soundscape pleasantness; the increase of birdsong loudness is an effective measure to enhance pleasantness and naturalness of soundscape. Therefore, how to increase birdsong loudness is the primary objective in this chapter.

1.2.2 Research significances

(1) **Design**. In view of the significance of masking in auditory perception, this study first attempts to explore the masking effects in soundscape in the context of urban morphology to contribute knowledge on masking as a principle of practical urban design guidelines and techniques.

(2) **Sensorcity.** This study is also proposed to characterise and assess soundscape with a consideration of masking effects, of which the results can contribute to sound mapping and improvement of the sonic environment quality, in particular, for the Assen City Sensorcity Project, but also beyond.

1.3 Research methodology overview

The overall research methodology is illustrated in Figure 1.1. As shown in Figure 1.1, the study begins with physical measurements (i.e., in-situ sound recording and measurement) and perceptual assessment (i.e., psychological listening test) to analyse the physical conditions of urban soundscape and discover how people evaluate the soundscape under these different physical conditions in Chapter 3 and 4; then according to the results of the perceptual assessment, the positive physical conditions of soundscape are revealed as the research objectives in the following Chapter 5, 6 and 7. In the three chapters, the investigation on aural and visual conditions is conducted, using both noise mapping technique by Cadna/A software packages and Visibility Graph in Space Syntax by UCL Depth Map. The input data for the modelling, simulation and mapping is originally from a firstly established GIS database, which includes the 3D information of spatial structure, land use and population density, etc. To improve the accuracy and efficiency of transformation of the noise maps into quantitative data, a MATLAB programme on spatial sound level matrix is developed and employed. In the view of urban morphology as the context of study, the urban morphological parameters are defined, developed and calculated based on the research needs. The obtained data in Chapter 3-7 is primarily analysed by the SPSS software package. The results can be used for the suggestions on urban design guidelines and techniques. The detailed research methods will be further explained in each chapter.

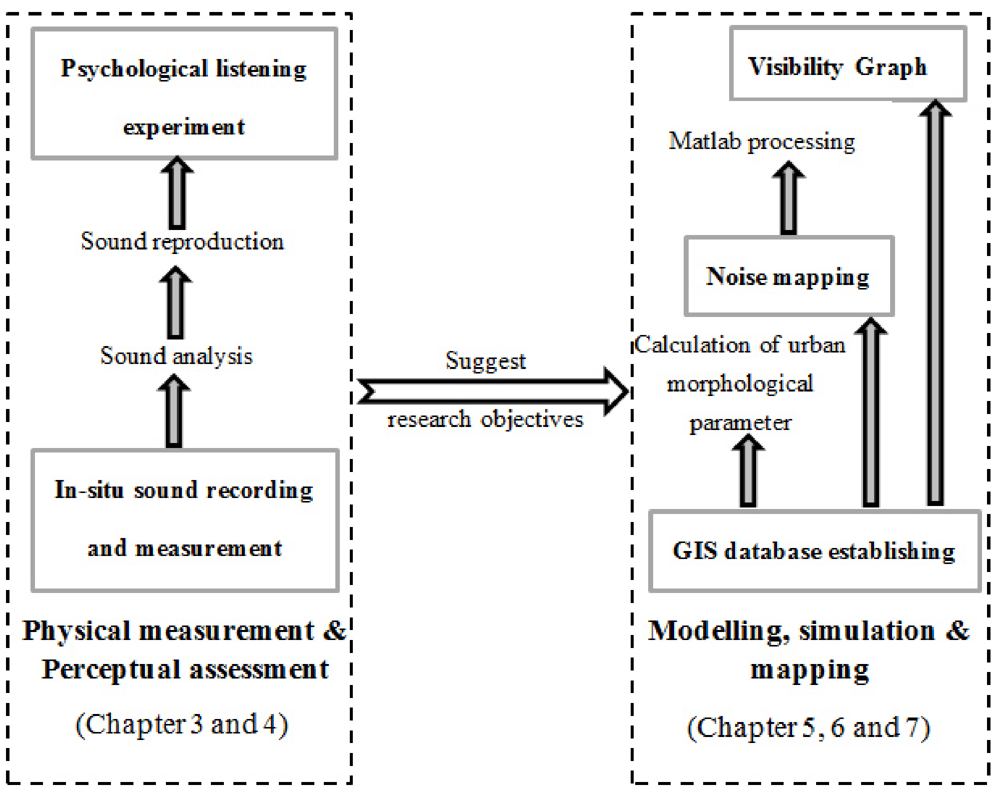


Figure. 1.2. Diagram showing overall research methodology of this study

1.4 Thesis structure

In summary, this thesis consists of 2 key parts of original research work: 1) Part A. Evaluation of urban sounds and their masking effects; 2) Part B. Exploration of the characteristics of different sound environments and their relationships with urban morphology. The methods to achieve the objectives for each chapter are described in the following:

Chapter 1, '*Introduction*', generally introduces the research backgrounds for soundscape, masking and urban morphology, as well as the potential for the study of masking effects in soundscape in the context of urban morphology, followed by the research aims and objectives, and the research significances. Finally, the overview of each chapter is listed.

Chapter 2, '*Literature Review*', extensively reviews the current literature on soundscape, masking and urban morphology that are pertinent to this research. Firstly, the studies on soundscape are covered by reviewing the publications on definitions and explanations of soundscape, evaluation of soundscape, and design and planning with the soundscape approaches. Secondly, the fundamental studies on masking are extensively reviewed in details, including auditory attention, concept of auditory masking and masking effects. Thirdly, the research on masking in soundscape is systematically reviewed by covering cognitive sound sources, masker and target, evaluation of masking effects, auditory visual interaction and design of masking in soundscape. Finally, the limited studies on urban morphology and soundscape are presented, including the definition of urban morphology, urban morphological parameters and urban morphology in soundscape studies.

Chapter 3, '*Urban Sound Sources*', presents the characteristics of the different urban sounds, including traffic noise, aircraft noise, water sounds and birdsong, using an acoustic analysis and psychological listening experiments. The influence of the visibility of sound sources is also a consideration in the soundscape quality evaluation.

Chapter 4, '*Masking Effects by Birdsong*', takes masking effects of birdsong on traffic noise as a case study to explore masking effects in soundscape and examine the impacts of the factors (i.e., spectra of traffic noise, loudness of birdsong, occurrence frequencies of birdsong and the visibility of sound sources) by psychological listening experiments. The results can contribute to not only the assessment of the traffic noise environment with masking by birdsong but also the optimum design of soundscape. The results in this chapter also indicate the importance of noise reduction and birdsong enhancement in the soundscape quality improvement.

Chapter 5, '*Resistance to Traffic noise in the Context of Urban Morphology*', explores how urban morphology influences the capability of a residential area on traffic noise level attenuation, with particular references to the low-density residential areas. Seven urban morphological parameters that are accessible and common in urban design and planning are selected. Noise mapping techniques are employed and a MATLAB program is developed to obtain the spatial noise level indices L_n. The relationships between the urban morphological parameters and the spatial noise level attenuation and the size of noisy areas have then been revealed.

Chapter 6, *'Resistance to Flyover Aircraft Noise in the Context of Urban Morphology'*, investigates the influence of urban morphology of the low-density built-up areas on spatial noise level attenuation of flyover aircrafts at a meso-scale. Six urban morphological parameters, including the Building Plan Area Fraction, the Complete Aspect Ratio, the Building Surface Area to Plan Area Ratio, the Building Frontal Area Index, the Height-to-Width Ratio, and the Horizontal Distance of First-row Building to Flight Path, are selected and developed. Effects of flight altitude and horizontal flight path distance to site on spatial aircraft noise attenuation are examined, concerning open areas and façades. Twenty sampled sites, each of 250 m x 250 m, are considered.

Chapter 7, *'Enhancement of Birdsong Loudness and Visibility of Green Areas'*, studies how to increase birdsong loudness and the visibility of green areas in the low-density residential areas by controlling urban morphological parameters. The spatial sound level distributions of birdsong of 12 sampled sites are simulated by the noise mapping techniques and calculated by a MATLAB program on spatial sound level matrix. The visibilities of green areas are analysed and calculated by Visibility Analysis Graph in Space Syntax. Correlation analyses are conducted between the obtained data on Spatial Sound Level Indices, Mean Visibility and the urban morphological parameters.

Chapter 8, *'Conclusions and future work'*, concludes the thesis, summarising the new findings from the original research, and introduce the future work.

CHAPATER 2

LITERATURE REVIEW

To explore the potentials for soundscape quality improvement with masking effects and the roles of urban morphology in soundscape, the chapter extensively reviews the current literature on soundscape, masking and urban morphology that are pertinent to this research. Firstly, in Section 2.1, the current studies on soundscape are covered by reviewing the publications on definition and explanation of soundscape, evaluation of soundscape, and design and planning with the soundscape approaches. Secondly, the fundamental studies on masking are reviewed in details in Section 2.2, including auditory attention, concept of auditory masking and masking effects. Thirdly, the research on masking, particularly in soundscape, is systematically reviewed in Section 2.3 by covering cognitive sound sources, masker and target, evaluation of masking effects, auditory visual interaction and design of masking in soundscape. Finally, the limited studies on urban morphology and soundscape are presented in Section 2.4, including the definition of urban morphology, urban morphological parameters and urban morphology in soundscape studies.

2.1 Soundscape

2.1.1 Definition and explanation

The concept of "soundscape" in "Handbook for Acoustic Ecology" is defined as "an environment of sound (or sonic environment) with emphasis on the way it is perceived and understood by the individual, or by a society" (Truax, 1978). "Acoustic environment as perceived or experienced and/or understood by people, in context" by

ISO/TC 43/SC 1 has been widely accepted and emphasised as the definition of soundscape. Human perception, cognition and understanding of the global sonic environment are very crucial in the soundscape research. In addition to the aspect of physical acoustics, soundscape was also characterized in the three other features: (1) strong psychological aspect; (2) meanings which add social and cultural factors; (3) aesthetic evaluation which displays in landscape architecture and town planning (Hiramatsu, 2004).

The soundscape study is constituted of the soundscape methods, including physical measurements, perceptual assessment, identification and taxonomy of sound events, modelling, mapping and simulation, and soundscape design (Kang, 2007; De Coensel et al, 2010, Jeon et al, 2010; Krijnders et al, 2009; Guastavino, 2007; Dubois et al, 2006). The study of soundscape has also acted as an emerging intersection for the interdisciplinary studies among these domains.

2.1.2 Evaluation of soundscape

A transdisciplinary and interactive concept, including contextual correlation, physical measures, psychological measures and cognitive evaluation, is being developed in the evaluation of both product sound quality and acoustic environments. The role of psychoacoustics in the evaluation of soundscape is emphasised by Fastle (2006). The results of physiological and psycho-acoustical experiments have shown that certain kinds of sound quality evaluation can be predicted without psychological measures (Furukawa et al, 2008; Yamaguchi et al, 2009). A six-factor structure, including pleasant, natural sound sources, time-variation, spatial impression, mechanical sound sources and time stability, involving psychoacoustic annoyance, loudness, fluctuation strength, impulsiveness, has been employed in the soundscape quality evaluation, using Principal Component Analysis (PCA) (Västfjäll et al, 2003). The cognitive approach developed by Dubois and Guastavino (2007) can be used to decrease the complexity in identifying relevant categories in the analysis of sound quality. Therefore, the research for an integrated evaluation of acoustic environments attracts attention in different domains, but standardised processes for soundscape quality evaluation still need to be further developed.

2.1.3 Design and planning with soundscape approaches

"Soundscape design attempts to discover principles and to develop techniques by which the social, psychological and aesthetic quality of the acoustic environment or soundscape may be improved" (Truax, 1978). The design-related study of soundscape is an interdisciplinary congregating the talents of scientists, social scientists and artists (Truax, 1978). The techniques of architectural design, landscape design and urban design/planning are being developed with the physical, sociological and psychological approaches to create and improve human living environments.

Besides the current control of noise parameters, soundscape is highly relevant to the landscape, architecture and planning which involve culture, policy, function and visual aesthetics. Currently, the soundscape design is primarily on the improvement of the existing noisy and unpleasant urban sound environments. Choy and Lui (2009) demonstrated that the research results of the acoustical parameters and human perception could be useful for the design of soundscape in recreational parks. A practical project was conducted to improve the traffic-noisy environment of the area near the Alcântara Bridge in Lisbon, using users' perceptual assessments and physical measurements on noise levels (Bouzebari et al, 2009). De Coensel et al (2010) stated how to use the soundscape approach in early stage of urban design in a case study in Antwerp, Belgium with acoustic measurement and questionnaire survey on living environments. Kang (2007) suggested design guidance with the four key components in soundscape: sounds, space, people and environment, which clearly illustrated the relationship between human and acoustic environment, and the relationship between acoustic and other physical environments. Moreover, soundscape transformations are highly related to the development of architectural design and planning in the historic sites (Balaÿ, 2007).

In addition to the current studies focusing on the measures and techniques familiar to acousticians, design guidelines and techniques should be more based on the results of design-related research questions, and deeply involved in the procedure of practical design by the architects and urban designers. Moudon (1992) states that to establish actual knowledge of urban design, it is significant to collect and assess all the research that can contribute to what the urban designer must be familiar with rather than searching for the right approach or theory. Therefore, besides the experiences from the practical projects of urban acoustic environments, various soundscape approaches (e.g., masking effects) should contribute more to the soundscape design/planning principles, standards and guidelines.

2.2 Masking

Masking, a significant psychoacoustic phenomenon, is important in everyday life (Zwicker and Fastl, 1999). How auditory masking influences the perception of the whole real-life acoustic environments is recently studied in different domains (Augoyard and Torgue, 2005; Balaÿ, 2007; Joen et al, 2008; Clark et al, 2009); masking is becoming a more and more important and powerful tool for soundscape evaluation and design (Boubezari and Bento Coelho, 2005; Bouzebari et al, 2009; Hellström, 2009; De Coensel et al, 2010).

Recently, there seems to be an increase in the studies of auditory masking. The definition and understanding of masking are diverse. According to Seeber's (2008) view, masking occurs when the components of a sound interact with those of another sound similar in frequency and time which induce them inaudible; partial masking occurs when the components are not inaudible but with their loudness reduction (Havelock et al, 2008). In terms of human hearing, it is referred as masking when a perceiver's performance is reduced by the presence of maskers (Durlach, 2006). Masking is often considered as one of the fundamental concepts of phenomena of hearing (Yost et al, 2008). Moore pointed out that frequency analysis abilities of auditory system were the most often demonstrated and quantified in the masking study (Moor, 1995).

2.2.1 Auditory attention

Unlike our eyes, our ears cannot be directed to avoid the unwanted sounds that we wish to ignore. Whatever sounds present, we have to be exposed to them; therefore, we attempt to select and pay attention to the information we need, which induces the evolutionary pressure for the hearing system. There are auditory attention debates on the sound and information processing. For example, Broadbent (1952, 1954) claimed that we could turn our listening attention to the desired sound demonstrated in a study of dichotic listening in lab experiments; location (sound sources from left and right ears) and voice pitch (male and female) were used as the cues for auditory attention during information processing. According to Broadbent's theory, after the first early stage of capturing all information in parallel, one will choose one stream and eliminate the rest, and the unattended message could only be shortly stored in echoic memory. However, in 1960, Treisman suggested that an attenuation process (i.e. reducing all signals' volume except for the attended signal) could be used to explain the ability to pick one's name out from elsewhere in a cocktail party even when one has already concentrated on one conversation. This phenomenon could not be explained by the process of all-or-nothing selection implied by Broadbent. Through the studies involved shadowing, Treisman (1960) also pointed out that once we were very sensitive to one signal (e.g. our names), we would process ample residual information for it and thereby pay our attention to it. Before long, it was suggested that all messages should receive the same processing, even when they were not attended (Deutsch and Deutsch, 1963); unattended messages' relevant semantic memories must be at least activated (Norman, 1968). Nowadays, there have been sufficient evidences for the parallel processing, while auditory attention indeed alters the early stage of analysis. Although the debates did not hold the identical views on the unattended information (eliminated, attenuated or shadowed), they all showed that it was possible to concentrate on one single sound of interest during the processing of auditory attention. In addition, based on the previous studies, for auditory attention, there are two opportunities for the attended information to be determined in term of information processing stages, i.e., first early stage for attended message selection and the stage when salient changes in sonic environment modify attended message selection.

These studies on auditory attention are primarily on the vocal message processing and conducted in lab experiments, concerning the psychological effects with an emphasis on the meaning of information. However, the masking effect usually induces a lack of attention to different sound sources (Augoyard and Torgue, 2005); especially in the real sonic world, auditory attention may be explored in the uncontrolled environment with diverse sensory stimuli (e.g. aural, visual and smell) and various categories of sounds. Therefore, for the study of masking in soundscape, laboratory condition asks for high ecological validity of sound reproduction.

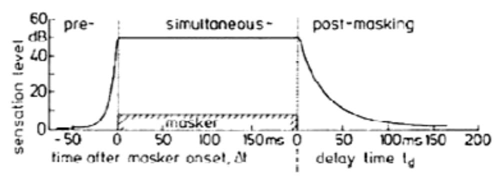
With certain degree of attention, people could listen to a message through loud ambient sounds; reconstitute missing portions of sentences if the topic discussed is familiar; and make up listening with sight via lip-reading.

2.2.2 Concepts of auditory masking

Table 2.1 shows the main categorisations of masking in auditory masking. Masking has long attracted attention in acoustic science. In the early masking studies, auditory masking was primarily defined with high relevance to the masking measurements and experiments. In Licklider's (1951) opinion, masking meant the disability of the auditory mechanisms that separated the tonal stimulation into components and distinguished the existence and absence of one of them, and the measuring of the thresholds of two components determined the degree to which one component of a sound was masked by another. Based on three masking experiments, Tanner (1958) firstly suggested that three distinct processes should be involved in the masking theories and definition, namely signal masking, distortion of the sound wave and listener distraction. In 1960, American Standard Association stated that masking was the process through which the threshold of audibility for a target sound was evaluated by the presence of another interfering sound (masker) in decibel (dB). The masking effects of a pure tone or noises were measured in psychoacoustic experiments, when maskers and targets simultaneously and not simultaneously occurred, named "premasking" and "postasking" (Zwicker and Fastl, 1999). Two main categories of masking, energetic masking and informational masking, have been recently frequently identified and investigated (Nilsson et al, 2009; Shinn-Cunningham, 2008; Durlach et al, 2003).

Table 2.1 Definitions and categorisations of auditory making.

Concept (Domain)	Definition
Auditory Masking (Acoustics, psychoacoustic, psychology)	1. The process through which the threshold of audibility for a target sound was evaluated by the presence of another interfering sound (masker) in decibel (dB). (American Standard Association, 1960) 2. Auditory masking occurs when the perception of one sound is affected by the presence of another sound (Gelfand, 2004).
On-frequency masking (Acoustics, psychoacoustics)	The greatest masking is when the masker and the signal are the same frequency and masking effect decreases as the signal frequency moves further away from the masker frequency. This phenomenon is called on-frequency masking and occurs because the masker and signal are within the same auditory filter (Gelfand, 2004).

Off-frequency masking (Acoustics, psychoacoustics)	The amount the masker increases the threshold of the signal is much less in off frequency masking, but it does have some masking effect because some of the masker overlaps into the auditory filter of the signal (Moore, 1998).
Energetic masking & Information masking (Psychoacoustics, physiology and psychology)	1. The interference among different sounds based only on the sound itself as “energetic masking” and the additional masking or interference due to making the stimulus context variable and uncertain as “informational masking” (Watson, 2005) 2. Most investigators use “energetic masking” to refer to masking that occurs due to “overlap between target and masker at the periphery” and “informational masking” to refer to non-energetic masking (Durlach, 2006).
Simultaneous masking (Psychoacoustics, physiology and psychology)	The situation where the masker is present throughout the presence of the signal (Moore, 2004).
Non-Simultaneous masking (Psychoacoustics)	Non-Simultaneous masking or temporal masking occurs when the signal and masker are not presented at the same time, including forward masking and backward masking (Moore, 1998).
Premasking (backward masking) & Postmasking (forward masking) (Psychoacoustics)	Premasking happens during the period of time before the masker is switched on. After the end of the masker, postmasking occurs. The  premasking measured lasts about 20 ms, while postmasking lasts more than 100 ms and ends after 200 ms delay (Zwicker and Fastl, 1999).

The “energetic” masking is traditionally considered as a peripheral process and is nowadays also referred as “peripheral” masking, to distinguish it from “informational” or “central” which are related to higher level processing (Nilsson et al, 2009). Watson defined the interference among different sounds based only on the physical properties of the sound as “energetic masking” and the masking or interference due to making the stimulus context variable and uncertain as “informational masking” (Watson, 2005). The models of energetic masking focused on sound frequency and primarily took the loudness and frequency response into account (Zwicker and Fastl, 1999; Havelock et al, 2008; Moore et al, 1997). Stimulus uncertainty, one factor of informational masking, concerned the changes in masking caused by the use of various targets or maskers in the same detection experiment (Nilsson et al, 2009). Target-masker similarity, the other main factor of informational masking, was also a significant real-life phenomenon that affected the masking in the acoustic environments (Bolin, 2009). While informational masking was intensively studied in the current investigations of speech intelligibility and speech privacy (Hara and Miyoshi, 2009), so there is a need to study masking in everyday-life soundscape.

2.2.3 Masking effects

In acoustics, the masking effect describes the existence of a sound (the masking sound) that, based on its intensity or frequency, partially or completely erases the perception of another sound (the masked sound) at a lower level (Augoyard and Torgue, 2005). The masking effects could be found very ubiquitously in diverse configurations in daily life.

It is difficult to accurately describe what acts as a mask unless distinct differences in levels exist. When the masking is induced by spectral distribution, the masking effect easily occurs, if the frequencies of the masking sound are close to those of the masked sound; the sound with a precise frequency (narrowband) is difficult to be masked by a complex sound that is consisted of a broad range of frequencies (broadband), because it is often noticeable enough to be perceived; a masking sound with a given frequency can mask sounds with higher frequencies. In acoustics, when there is 10 dB of sound pressure level difference between two sounds, the loudest sound is generally the sound only perceived, but the rule is not suitable for all sounds, for example, it may be more appropriate to analyse the difference in both sound levels and frequencies for the masking effects by the traffic noise. A broadband masking sound with 69 dB (A) or higher sound level could completely mask a sound with a frequency centred at 500 Hz at 60 dB, inducing it completely inaudible (Augoyard and Torgue, 2005).

2.2.3.1 Positive effects: reduce or eliminate unwanted sounds (noise)

In human communication and expression, sound masking is frequently used in open-plane office for private conversation (Shimizu and Fujiwara, 2009; Hao et al, 2010); 45dB (A) is an ideal ambient noise level for speech privacy and acceptable annoyance (Bradley and Gover, 2004); people who indicated a refusal of communication could use masking sounds (e.g. personal stereo) or get involved in a loud sound background; in movies, music could work as a mask to give audiences an amplified emotional representation and atmosphere.

In sociology and culture, background sounds (e.g. radio) could mask the "acoustic vacancy" which immersed solitary individuals in the silent atmosphere surrounds, and they might not perceive or understand the sounds; the sonic climate created by city festivities could temporarily make separation of functions and familiar classifications of spaces ambiguous by the masking effects; teenagers made very loud noises in motorcycles as masks to distinguish them by involving in an isolated sound world (Augoyard and Torgue, 2005; Jin et al, 2009).

In urban space, people need different auditory spaces that are recognised as private and public spaces, where the masking effect plays an important role. Constant background music can mask functional sound events by creating certain sound ambience in large department stores, waiting rooms, or work environments, compensating the lack of acoustic comfort due to the architectural weakness (Augoyard and Torgue, 2005; Jin et al, 2009). In the previous studies, urban drone was considered as unpleasant noise in urban open spaces; however, for indoor auditory space, the urban drone could mask sounds from neighbours in different apartments, acting as good sound insulation, which made it possible that the standards of architectural insulation of apartment buildings in an urban zone could be lower than those in a sub-urban region and a rural zone which were always quiet (Augoyard and Torgue, 2005).

2.2.3.2 Negative effects: prevent from the identification of a positive sound (e.g. soundmark)

Above a certain sound level, the masking sound can reach extremes to mask any other aural communication (e.g. noise of airplanes) (Augoyard and Torgue, 2005). The masking effect may influence people's perception in distinguishing sounds, localising sound sources and estimating their distance. When the background sounds of urban open spaces mask the remote emergent sounds and other important sounds (e.g., sound marks), people could only hear sounds close-by, not remote sounds; as a result, the scope of auditory space and the richness of sound environments might be reduced, and local citizens' consciousness of emergency and judgments of sound events might be significantly attenuated (Arras et al, 2003). Because of the masking effect of low frequency sounds from the activities in industrial buildings, it is very important to design the signals with the precise and audible frequency to guarantee the audibility of signals for dangers, such as signals for forklifts or swing bridges (Augoyard and Torgue, 2005).

In the different contexts, the same kind of sound can result in different subjective perceptions (Augoyard and Torgue, 2005). For the assessment of masking effect in soundscape, it is significant to take into account people's needs (e.g., acoustic comfort, speech privacy and intelligibility, auditory spatial awareness, and indicated information of signals), sociological and cultural backgrounds, as well as space.

2.3 Masking in soundscape

Masking is probably becoming a more and more important and powerful tool for the soundscape evaluation and planning (Boubezari and Bento Coelho, 2005; Jeon et al, 2008) under the condition that the recent masking research in soundscape is prone to take soundscape as the total real-life acoustic environment (Leroux et al, 2004; Watts et al, 2008; Nilsson et al. 2009) rather than the noise control (e.g. traffic noise).

2.3.1 Cognitive sound sources

The cognition of sound sources is important in the evaluation of soundscape. Although one study showed that the effect of the 'meaning' of the sounds seemed to contribute little in the assessment of loudness in sound quality evaluation by comparing the original sound and the meaning-neutralised sound (Ellermeier et al, 2004), in the urban environment, the complexity of the soundscape components makes the aural evaluation of soundscape different from the loudness evaluation of special products and inner spaces. It is because that the subjective attention was not automatically concentrated on the perceptual process for sounds with multiple components (Bodden and Heinrichs, 2001). Kang (2007) pointed out that the evaluation of the acoustic environment may be significantly influenced by the meaning of sounds. According with this, Genuit &

Fiebig (2006) mentioned that physical and psychoacoustic aspects which concerned the binaural signal processing and cognitive and psychological aspects (e.g., information content, acceptance of sound sources and the listener's attitude) had to be fully taken into account in soundscape approaches. Therefore, sound source perception and cognition should be an important consideration in the real soundscape of complex sound sources.

As mentioned above, the traditional evaluation of masking effects was primarily conducted on the pure tone and noise without meaning in energetic masking (Moore, 1975; Zwicker and Fastl, 1999; Moore, 1995). However, the research on sound source perception (Kidd et al, 2008) showed that masking effects had high relevance with sound source perception and cognition, especially energetic and informational masking. A set of experiments of improving the speech privacy by real masking sounds was conducted in the study of acoustic comfort in open-plan offices (Bradley and Gover, 2004; Andersson and Chigot, 2004; Hongisto et al, 2004; Helenius and Hongisto, 2004). Moreover, a cocktail party was a good example for the role of sound source cognition in object-based auditory attention, the failure of which could explain the informational masking well (Shinn-Cunningham, 2008). Therefore, the meaning and information contents of the sounds should be involved in the study of the masking effects in soundscape. The evaluation of masking effects of cognitive sound sources could be an effective and practical tool for the evaluation of the real soundscape.

Furthermore, cognitive approach and Semantic technique, which concern people's perception and cognition of the acoustic environment a lot, may be promising instruments for the study in auditory masking in soundscape. Because sound events could be described in terms of sources and action or movement of the noise source, the subjects' acoustic evaluation was closely correlated to their appraisal of the source itself and its semantic description (Guastavino et al, 2001). In Dubois's et al study (2006) study, the approach concentrating on meanings attributed to soundscape was employed to bridge the gap between individual perceptual categorisation and sociological representations; it required the cognitive evaluations that could be used to decrease the complexity in relevant category sound identification in the analysis of sound quality and auditory scene (Dubois and Guastavino, 2007). Moreover, the context, the exact situation and the perceivers' interpretation of sound events played a significant role in the sound classification; new affectively termed categories that allowed variations in the perception of sounds and context were created alongside the affective evaluation, using the semantic different scales (Payne, 2008). In the previous study of masking of real sounds, the sound events of soundscape were described by general sound sources (Leroux et al, 2004; Boubezari and Bento Coelho, 2005; Watts et al, 2008; Nilsson et al. 2009; Botteldooren and De Coensel, 2009), but there was still no systematic approach to classify the sound events, which were regarded as maskers and targets in auditory masking. Because subjective experiments play an important role in the evaluation of auditory masking effects, the general database of semantic description is proposed to be built for the further study. Pedersen and Zacharov (2008) created an onomasticon of sound describing words as the semantic space of sounds in connection with word elicitation for listening tests; it could be divided into 7 groups, namely direct sound descriptors, relating to other senses, reference to events and sources, changes or difference in perception, affective, connotative and onomatopoeia.

On the other hand, it is important to provide the objective data for sound source cognition by the sensor system, which can be used in physical cognition and analysis of the real soundscape. For example, CPSP (Continuity Preserving Signal Processing) which was a novel approach to the real-world sound recognition was designed as a signal processing framework to track the physical development of a sound source by the identification of signal components (Andringa and Niessen, 2006).

2.3.2 Maskers and targets

Narrowband and wideband sounds are used as both maskers and targets based on different experimental objectives. For example, traffic noise was masked by bird songs in De Coensel's et al (2011) experiment, but in Ishibashi's et al experiments (2004) the traffic noise and the air-conditioning system noise were separately assumed as the psychological maskers of the rock music and pump music; the results showed that the rock music could be masked by the stable air-conditioning system noise, but not be masked by the fluctuating traffic noise. Moreover, probably because of the harsh tonal components contained in the pump noise, the pump noise could not be masked by either of them.

Water sounds seem to be more often investigated as maskers than other sound sources. The auditory masking experiments by Nilsson et al. (2009) proved that the loudness of the (possibly unwanted) traffic noise could be reduced by the fountain sounds which were considered as one component of the city park soundscape. The masking effects of water sounds to the urban noise recorded in open public space in Sheffield were investigated, including road traffic, people's talking and construction; it was found that the water sound could mask when the SPLs of the water sound were similar to those of targets, while the masking effects were reduced when the overall SPL of the composed sounds was over 85 dBA (Jeon et al, 2008). Furthermore, it appeared that the higher frequency water sounds were more highly rated in the tranquillity improvement than the low frequency ones (Watts et al, 2008). It was showed that the sound of ocean waves and continuous large waterfalls were the top two efficient maskers among 12 masking sounds, including traffic under heavy rain, whispering leaves, frogs in a pond, heavy rain, tidal waves, small varying waterfalls, and so on (Leroux et al, 2004). However, in Watts' et al (2008) experiment, compared with the masking effect of the water sounds, the distracting effect of a pleasant water sound played a more dominating role in the perceived tranquillity improvements.

2.3.3 Evaluation of masking effects

One of the most important aims of auditory masking study is how to improve the overall soundscape quality by masking effects; therefore, in addition to the evaluation of masking effects, the quality evaluation of the acoustic environment influenced by masking should be paid attention. In some context, the masking effects of added maskers might decrease the quality of the soundscape because of the increase of the total loudness of soundscape (Nilsson et al, 2009).

In addition to the physical experiments and models, a set of recent evaluation of masking effects was conducted by subjective response (Ishibashi et al, 2004; Ise and

Sugimoto, 2004; Lee et al, 2009; Lam et al, 2008). In Jeon's (2008) research on the evaluation of soundscape in open public spaces, each of the typical individual sound and the combined sounds for masking effects were subjectively evaluated in laboratory conditions by varying the SPL of the stimuli. In the complex sound environments, it was still difficult to separate and evaluate the sound components of the soundscape and the masking effects physically, but Boubezari and Bento Coelho (2008) suggested a new method which could describe a soundscape by targeting one or more sounds from the background noise based on the masking experiments of "sound size", which was contrary to the traditional measurements. However, Bolin (2009) argued that the most results of auditory masking were from the listening experiments of artificial and speech sounds, which might not be effective for soundscape.

2.3.4 Auditory visual interaction

The interaction between aural and visual stimuli is the most important (Kang, 2007b) among the interactions between acoustics and other conditions. According to Southwoth's (1969) research, when aural and visual settings were joined, the conscious perception of sound could be reduced by the visual form; when the sounds were related to the scenes, people could obtain a more comfortable feeling by the interaction between aural and visual perception (Hatano et al, 2001; Hashimoto and Hatano, 2001; Yamaguchi et al, 2009). The consideration of in-situ views is emphasised in the recent studies of real soundscapes, especially in the sound recording and database of soundscapes (McGinley, 2005; Lemke, 2008; Brambilla et al, 2008). The investigation of low frequency perception in urban soundscape with the cognitive approach illustrated that the visual setting affected the subjective evaluation of low frequency sound (Guastavino et al, 2001). Therefore, the auditory and visual interaction should play an important role in the evaluation of an overall soundscape.

Although the experiments of auditory visual interaction for the evaluation of masking effects in soundscape are very limited and the role of auditory visual interaction in masking effects has not been fully demonstrated, it can be proved by the related studies. For example, Menzel (2008) suggested that psychoacoustic methods which required a spontaneous loudness judgment were more suitable for the investigation of the audio-visual interactions than those that needed a strong concentration on the auditory modality. Shinn-Cunningham (2008) argued that failures of object-based attention could be an explanation for the results of many studies of informational masking; it was proved that common neural mechanisms controlled attention across modalities by the similarities between auditory and visual perception in complex senses.

2.3.5 Design of masking in soundscape

Although the potential of auditory masking for soundscape design has not been fully verified, with the development of the soundscape research and auditory masking, the principle of auditory masking has been already implemented in the soundscape design to improve acoustic environments. The masking of unwanted sounds by wanted sounds was suggested as a method of soundscape quality improvement (Bolin, 2009). Boubezari and Bento Coelho (2005) developed a masking method for sound space representation regarding psychoacoustic and physical aspects in a synergetic protocol of measurements; the qualitative sound maps were proposed to be useful tools for the urban technicians and architects working on the urban noise. The natural soundscape and the artificial electro-acoustic system were used to mask unwanted sounds in projects (Bouzebari et al, 2009; Hellström, 2009).

Therefore, the design of masking effects may be considered as one “design technique” in the soundscape design to satisfy people’s need for pleasant acoustic environment. The maskers can be selected from sound database as design components, and the evaluation system of masking effects may help to predict the different makers’ effects and overall quality of soundscape. In addition, in the design of masking effects, besides the consideration of aural aspects, the spatial and visual aspects should be taken into account.

2.4 Urban morphology and soundscape

2.4.1 Definition of urban morphology

Urban morphology, which is sometimes referred to urban grain, urban fabric, and urban tissue, seeks to understand the spatial structure and character of a metropolitan area, city, town or village by examining the patterns of its component parts and the process of its development. Different levels of urban patterns, i.e., structure, cell, building, plot, plot series, street/block, and town, compose a complex network of spaces. It is at the root of urbanism and urban design (Kropf, 2005; Larkham, 2005).

Urban morphology has been widely studied for the different aspects of urban environment, e.g., solar potential and atmospheric environment. The factors of building density, building pattern, street layout and coverage, landscaping and land use have been extensively examined using a series of quantitative urban morphological parameters (Cheng et al, 2006; Xie et al, 2006).

2.4.2 Urban morphological parameters

A number of quantitative urban morphological parameters have been explored, developed and studied from the perspectives of environmental performance, landscape, land use, atmospheric and wind environment, and so on (Salat, 2007, Adolphe, 2001; Esbah, 2009; Ng, 2011; Van de Voorde et al, 2011). Table 2.2 lists a range of diverse urban morphological parameters used in the previous studies of the different urban environments. The parameters include 2D or 3D information of urban morphology and some of them are source-dependent, e.g., the Building Frontal Area Index in the study on ventilation (Hsie, 2008).

Table 2.2. Urban morphological parameters developed and used in the previous studies.

Aspect of urban environment	**Parameters**
Energy and bioclimatic (computer-based analysis) (Salat, 2007)	Mean and standard deviation of building height, Mean and standard deviation of vegetation height, Building height histograms, Area-weighted mean building height, Area-weighted mean vegetation height, Surface area of walls, Plan area fraction as a function of height above the ground surface, Frontal area index as a function of height above the ground surface, Height-to width ratio, Sky view factor, Roughness length, Displacement height, Surface fraction of vegetation, roads, and rooftops, and Mean orientation of streets.
Ventilation (climate map) (Hsie, 2008)	Mean Building Height, Standard Deviation of Building Height, Building Plan Area Density, Building Volume Ratio, Building Frontal Area Index (λ_f), Complete Aspect Ratio, Building Surface Area to Plan Area Ratio, and Height-to-Width Ratio.
Thermodynamic model (Long et al, 2003)	Building density, Vegetation density, Road density, Building height, Building perimeter, and Building volume

Environmental performance (Adolphe, 2001)	Density, Rugosity, Porosity, Sinuosity, Occlusivity, Compacity, Contiguity, Solar admittance, and Mineralization

2.4.3 Urban morphology in soundscape studies

The attributes of urban morphology can be employed to characterise the contexts and compare site patterns in the soundscape studies in terms of physical, cultural and social aspects. For example, urban morphology has been introduced in the site investigations of soundscape in terms of urban form types (De Oliveira Fonterrada and Filho, 2005; Memoli et al, 2008; Marry and Baulac, 2010). A wide range of 14 case study sites were chosen for the study in soundscape of the urban open public spaces in Europe, covering various climatic conditions and urban morphology types from summer 2001 to spring 2002 (Kang, 2007).

Urban morphology has also been referred in the studies on sound propagation in terms of spatial structure (e.g. building layout, building geometry) (Kang, 2007; Raydan and Steemers, 2006) and certain urban morphological parameters (e.g. building density) (Salomons and Pont, 2012). For example, Kang has compared the attenuation of broadband sound among different street patterns, with particular references to detached houses, semi-detached houses and terraced houses (Kang, 2007). Raydan and Steemers indicated that buildings could act as sound barriers to induce quiet side of residence in the traffic noise environment, but the research on traffic noise attenuation through various urban forms is rather limited (Raydan and Steemers, 2006). Salomons and Pont (2012) proved that in citywide, spatial traffic noise distribution is related to traffic volume, building density and general urban form, using the numerical calculation of

Amsterdam and Rotterdam and idealised urban fabrics. Urban morphology may play a promising role in the soundscape studies from the perspective of landscape as passive sound sources (Kang, 2007), e.g. water sounds from fountain and birdsong from green areas.

Urban morphology could also contribute to soundscape study in two scales: firstly, in a large scale, because the structure of urban fabric is generated during a social/cultural process and the structure at different levels response to distinct cultural customs (Kropf, 2005), urban form can be an important holistic social/cultural context concerning local habitants' memory and experience that influence their perception and evaluation of global environment, as well as soundscape; secondly, in a small scale, perception of sonic environment roots deeply in the detailed information and affordance of one space where perceivers are in a direct and timely way, which is related to the influence of other sensors on auditory and the role of auditory in a whole space perception. Modern culture always undervalues the significance of the soundscape as a means of sensory connection. The level of cell and structure in urban morphology can provide approaches to characterise and analyse spaces for the study of space perception.

The organisation of urbanscape is in terms of views and sound. However, it seems that the studies of urban morphology contribute more to the views of urbanscape than sound. As Schulte-Fortkamp (2010) suggested, compared with traditional noise control, the soundscape concept requires the evaluation and characterisation of urban acoustic environments to balance acoustic measurements, architectural planning and people's expertise. The study of the influence of urban morphology on soundscape may give the soundscape studies more evidences and suggestions to balance the three aspects.

2.5 Conclusions

Masking, which has been proved and studied in the traditional studies of masking mechanism and auditory perception, has been introduced to the soundscape studies. This review suggests that auditory masking would be one of the essential facets for the soundscape research and practice. The evidences on the effectiveness of masking in improving unpleasant acoustic environments have been shown in the literature review. The potential of masking to be developed as design techniques have been initially explored by reviewing the previous work. However, what factors of masking influence soundscape quality and what characteristics of soundscape do masking influence in the real world still needs further systematic investigation. This review also suggests that urban morphology, which is related to urban sound environment from the aspects of sound propagation, sound source and social and cultural issues, can be an important context for the studies of masking in soundscape.

CHAPATER 3

URBAN SOUND SOURCES

As discussed in Section 2.3.1 of Chapter 2, in actual soundscape, cognition of sound sources is an important context for "informational masking". This chapter presents the characteristics of the different urban sounds in terms of sound sources, including car traffic noise, aircraft noise, water sounds and birdsong, within the scope of soundscape using sound recording, measurement, acoustic analysis and psychological listening experiments It is a pilot study for the further study on masking effects in soundscape and urban spatial sound distribution in the following Chapter 4, 5, 6 and 7. This chapter first states how the soundscape database was established and how the acoustic analysis and psychological evaluation were conducted; and then shows the different characteristics of urban sound sources and masking related issues.

3.1 Introduction

Diverse sound sources exist in urban open space, resulting in complex and unique sound environments where human act as positive perceivers. The multiple sounds interact and compete in the global sound environment, and auditory masking occures as a very significant daily-life phenomenon (Zwicke and Fastl, 1999). The research on sound source perception demonstrates that sound source perception and cognition influence masking effects significantly (Yost et al, 2008). The cocktail party effect is a good example for the role of sound source cognition in object-based auditory attention, of which the failure could explain the informational masking well (Shinn-Cunningham, 2008). People have sound preferences related to sound sources. It has been demonstrated that, in general, natural sounds (e.g., birdsong and water sounds) are wanted and ranked at the top in sound preferences (Kang, 2007; Yu and Kang, 2010); and certain mechanical sounds (e.g., traffic and construction) are unwanted and unpleasant (Joen et al, 2008; Botteldooren et al, 2011). The masking effects by pleasant sounds on unpleasant sounds are believed to improvethe quality of total soundscape (Nilsson et al, 2010; Bolin et al, 2010; De Coensel et al, 2011). As mentioned in Section 2.3, masking in urban soundscape is strongly related to the acoustic characteristics of different sound sources. Therefore, it is crucial to study the sounds from various urban sound sources with meaning, involving human perception and evaluation from the perspective of soundscape.

In addition to the impacts of sound sources on soundscape quality, they also have cultural and social significance. For example, sound marks, which involve synecdoche effects in sound production and perception, make the community's sonic life unique. Once a sound mark has been identified, it is worth reserving (Schafer, 1977). Therefore, under vast modernist urban redevelopment and regeneration, it is meaningful to suggest conservation of historical urban texture, landscape and buildings from the viewpoint of sound mark and soundscape. For example, under the regeneration of the Sheffield City Centre, waterscapes and squares were embedded into the city for its vibrancy with the respect of the history of Sheffield. Along the Gold Route, diverse waterscapes have been developed (shown in Figure 3.1). Sheffield's first settlement was developed at the confluence of the Rivers Don and Sheaf, around the 12th century. With the role of market town at this time, Sheffield had continued to be shaped by the waterways. Sheffield's access to abundant natural resources made it an ideal centre for iron and steel industry, and the rivers contributed considerably to the production and industry of the city development. By the late 14th century, Sheffield was famous for its metal knives and its role in this industry. Along with the industrial development in the 18th century, a large number of water powered mills along river banks and dams were developed. In the 18th century, the Tinsley Canal was developed for connections for large steelworks. By the late 18th century, all available sites on the rivers were developed. In the 19th century, Sheffield became the principal location in Britain for the large steel works. In the 1980s of the last century, with the decline of the Sheffield steel industry, rivers lost their traditional function and became a forgotten part of the city. The urban landscape was also changed by leaving redundant industrial buildings and vacant sites. In the recent city centre regeneration, starting in the 1990s, great efforts have been made to ensure that the reconnection with the rivers continues to be fostered and their role in the history of the city to be celebrated (Kang and Hao, 2011; Sheffield City Council, 2011).

Figure. 3.1 The water features along the Gold Route of Sheffield. 1. Sheaf Square; 2. Howard Street and Hallam Garden; 3. Millennium Galleries and Winter Garden 4. Millennium Square; 5. Peace Gardens; 6. Town Hall Square and Surrey Street; 7. Barkers Pool.

The classifications on active sounds and passive sounds related to sound sources in urban open spaces (Kang, 2007) were employed to classify the soundscape database for the investigations in this chapter. Active sounds relate to sounds from the activities in the space, and passive sounds relate to the sounds from the landscape elements. For active sounds, two common kinds of sound sources were selected, i.e., car traffic and flyover aircraft, of which sounds are loud and widespread (Bell et al, 1996). For passive sounds, common landscape features in the urbanised areas were decided, i.e., water features and green area, which bring about water sounds and birdsong. The masking effects among the sounds are also an important consideration in the analysis of their acoustic and perceived characteristics in soundscape.

Additionally, aural–visual interactions have been long demonstrated to influence auditory perception intensively. According to Southwoth (1969), when aural and visual settings were joined, the conscious perception of sound could be reduced by the visual form; and when the sounds were related to the scenes, people could obtain a more comfortable feeling by the interaction between aural and visual perception (Hatano, et al, 2001; Hashimoto and Hatano, 2001; Yamaguchi et al, 2009). Recent studies on soundscape database recording and collecting took into account in-situ views (e.g. visual data collecting) (McGinley, 2005; Lemke, 2008; Brambilla et al, 2008). Therefore, view of sound sources is also concerned as soundscape stimuli.

3.2 Methods

3.2.1 Sound recording and collecting

As stated in Section 3.1, four kinds of typical and common urban sound sources are of interested, including car traffic, flyover aircraft, water features and birds.

3.2.1.1 Traffic noise

To record typical traffic noise of main roads in city, two locations in the city area, Crookes Valley Road (2×1 lane, 50 km/h) and A61-Sheaf Street (2×2 lane, 60 km/h) by Sheaf Square, Sheffield, UK, were selected, using Edirol R-44 Portable Recorder and BSWA TECH MP231 microphones. The microphone height was 1.6 m. The sound samples were recorded and stored as 16 bit, 44.1 kHz wave files. To record the traffic noise with different spectra during sound propagation, the multi-channel recordings were collected by the Crookes Valley Road at the distances of 1, 4, 9, 19 and 50 m from the road side during the rush hours (see Figure 3.2.)The single-channel sound recording was collected at a distance of 1 m from the Sheaf Street during rush hours, as a comparison. To record the scenes where the sound events occurred, the photos were taken from where the microphones were located, facing the road.

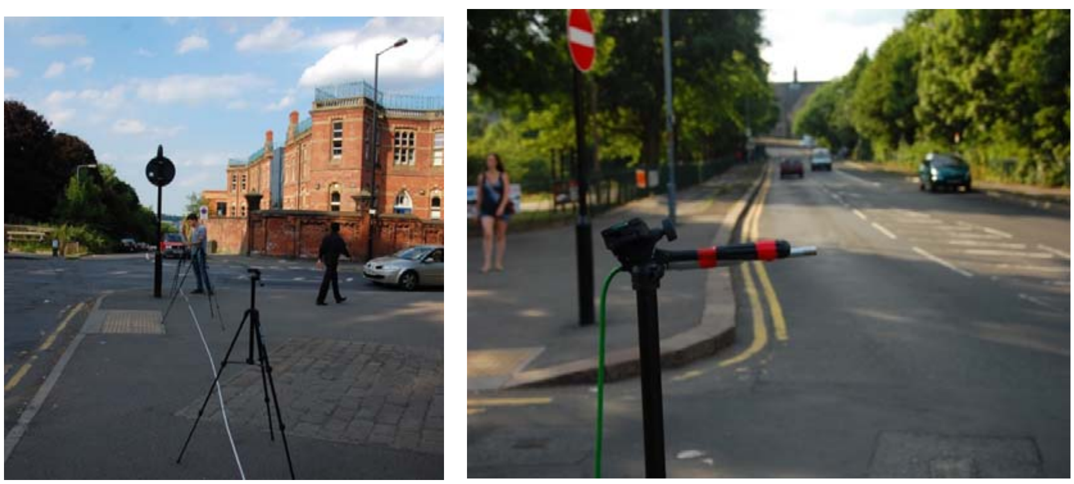


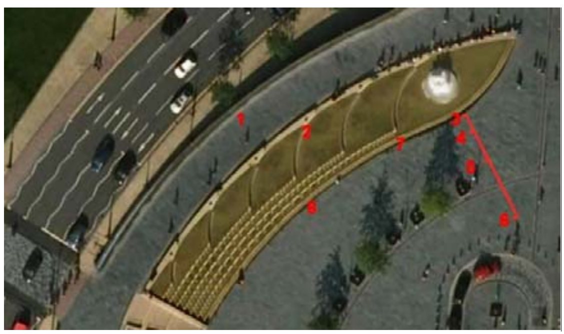
Figure. 3.2 The multiple-channel sound recording by the Crookes Valley Road.

3.2.1.2 Water sounds

As mentioned above, water features in Sheffield are rather diverse and have profound historical and cultural meaning. Therefore, a range of water features were recorded with Edirol R-44 Portable Recorder and BSWA TECH MP231 microphones along the Gold Route. The pictures of the water features were also taken as the visual data, in addition to the sound database. The microphone height was 1.6 m. The detailed information of the recording locations and water features will be shown below.

Sheaf Square

A number of water features exist in Sheaf Square, including big fountain, small cascades, medium cascades, waterfalls from the steel barrier, and so on. Figure 3.3-a illustrates the locations of the recording points. Figure 3.3-b, c, d and e show the views of the water features.



(a)

(b)

(c)

(d)

(e)

Figure. 3.3 A range of water features in the Sheaf Square (a) Location of the features [based on googlemap] and the recording points, 1, Steel barrier; 2, Medium cascade; 3-6, Big fountain (1, 4, 9 and 19 m); 7, Small cascade L1; 8, Small cascade L3; (b) View of the big fountain; (c) View of the small cascade; (d) View of medium cascade; (e) View of steel barrier.

Because of the large incidence of the big fountain, 4-channel recording was collected at the distance of 1, 4, 9 and 19 m from the fountain. For the other three water features, single-channel recording at a certain point was collected, considering the duplication of the elements of each feature (see Figure 3.3-c, d and e). The water of the big fountain falls on an iron base; the water of Sheaf Barrier slips to bite-size uneven stone pavements; the water of the other two features drops down on shallow water (Figure 3.3- b, c, d and e).

Peace Gardens

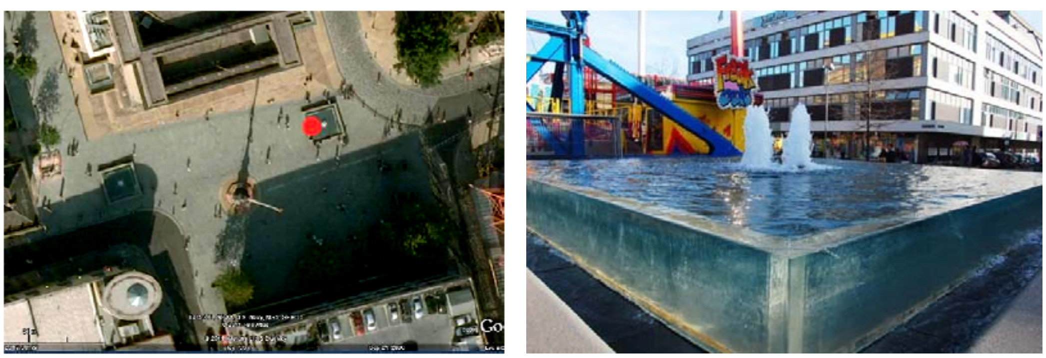
Figure 3.4-a illustrates the locations of recording points in the Peace Gardens. The 4-channel recording was collected at the distance of 1, 4, 9 and 19 m from the fountain. Figure 3.4-b shows the view of the fountain, which is consisted with dozens of multiple-height water streams. The water streams fall on even stone pavements. The fountain is accessible to people.

(a) (b)

Figure. 3.4 The water feature in the Peace Gardens. (a) Location of the water feature [Plan from googlemap] and the recording points (1, 4, 9 and 19 m); (b) View of the water feature in the Peace Gardens.

Bakers Pool

Figure 3.5 shows the fountain in the Bakers Pool Square, which is located in the front of the City Hall of Sheffield. The two water streams fall on a water surface of the pool and the water in the pool also slips onto a hard surface at a lower level, as shown in Figure 3.5-b.



(a) (b)

Figure. 3.5 The water feature in the Barkers Pool. (a) Location [Plan from googlemap] and the recording point (red dot). (b) View of the water feature in the Bakers Pool Square.

Howard Street

The water feature in Howard Street as shown in Figure 3.6 has one small water stream;

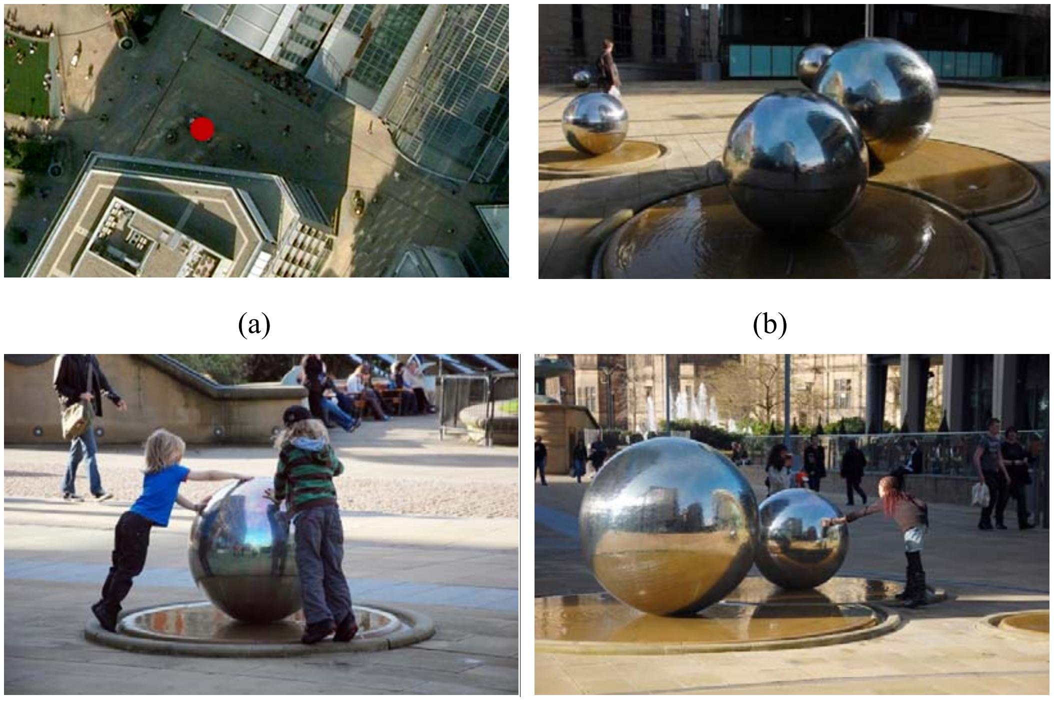
the water falls on a curved colourful and vivid mosaic tile pavement, which is different from the other water features in the Gold Route. The fallen water runs down along a narrow and shallow canal paved with the same mosaics (see Figure 3.6-b).

(a) (b)

Figure. 3.6 The water feature in the Howard Street. (a) Location [Plan from googlemap] and the recording point (red dot) (b) View of the water feature in the Howard Street.

Millennium Square

Silent water features in the Millennium Square is located between two buildings (shown in Figure 3.7-a). A small amount of water slips down from the top of the iron balls into the shallow pools with flat stone pavements, as shown in Figure 3.7-b. The iron balls can reflect the surrounding features, enriching their visual effects. Although the water sounds can be hardly heard, the appearance of the water features and their “Silence” and “approachability” also attract people’s attention (see Figure 3.7-c&d). Therefore, the masking effects of this kind of silent water features may be achieved by the failure of attention on the other sounds in the environment, which is related to the multimodal interaction (Shinn-Cunningham, 2008).



(a) (b)

(c) (d)

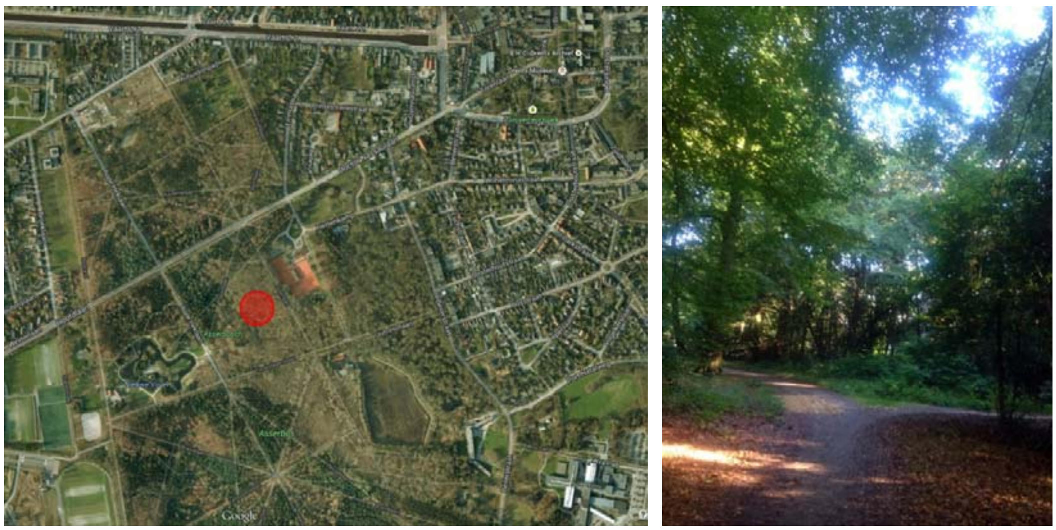
Figure. 3.7. Silent water features in the Millennium Square. (a) Location [Plan from googlemap] and the recording point (red dot) (b, c, d) Views of the water feature in the Millennium Square.

3.2.1.3 Aircraft noise

With the expansion of air transport and injection of airports and heli-pads into or close to city areas, aircraft noise has been an important cause for the degradation of soundscape, especially for the regions that have strong connections between noise annoyance and local outdoor life (Vogiatzis, 2012; Klaeboe, 2004). In Europe, the annoyance of the population caused by aircraft noise has been raised over recent years (Babisch et al, 2009). Assen, the capital of the province of Drenthe, is a quiet town in the north of Netherlands. It was selected as the location for flyover aircraft noise to avoid the mixture with various loud background urban noises.

The single-channel recordings were collected in the outskirt to the southwest of Assen, using Tascam DR-680 digital recorder and a BSWA TECH MP231 microphone. The microphone height is 1.6 m. The sound samples were recorded and stored as 16 bit, 44.1 kHz wave files. In addition, because it cannot be judged what types of aircraft engines the recorded flyover aircraft noise is belonged to, the audios of flyover jet, propeller and helicopter in the online open source of freeSFX (2013) were also analysed as references.

3.2.1.4 Birdsong



(a) (b)

Figure. 3.8. The forest embedded in the town of Assen. (a) Location [Plan from googlemap] and the recording point (red dot) (b) View of the forest.

Figure 3.8 shows the location of single-channel birdsong recording in the forest embedded in Assen in summer mornings. The microphone height is 1.6 m. The sound samples were recorded and stored as 16 bit, 44.1 kHz wave files. The overall sound level within the forest is under 40 dBA. Because of the large green area and biodiversity in Assen, diverse bird voices were recorded in the forest.

Meanwhile, more recordings of high-quality birdsongs of common species in Europe, including Common Black Bird, Great Tit, Eurasian Nuthatch and Sparrow were collected from the open source of Xeno-canto (2012) and added into the soundscape database.

3.2.2 Acoustic analysis

To compare the acoustic characteristics of the different sound sources, the audios in the database were analysed with the software package of 01dB to obtain the 1/3 octave spectrum (100 to 8000 Hz) and the time history of the sounds. The lengths of the acoustic stimuli of traffic noise, aircraft noise and water sounds are 30s because of their continuity; the length of the audios of bird songs is 3.5s, when a few times of bird songs continuously occurred. To illustrate the dynamic changes of spectrum of a sound source with distance, the spectra of the multiple-channel recordings were shown in one figure. To indicate the potential energetic masking among the different sounds, their spectra were also shown in the same figure in certain cases.

3.2.3 Psychological evaluations

To investigate the soundscape quality of different sound sources, fourteen 30 s acoustic stimuli were played back in the psychological evaluation, including 5 recorded acoustic stimuli of traffic noise (1, 4, 9, 19 and 50 m from the road at 50 km/h in Figure 3.9), 3 recorded acoustic stimuli of flyover aircraft noise (Recording aircraft noise 1,2&3 in Figure 3.16), 5 recorded water sounds (the big fountain in Sheaf Square, Peace Gardens, Bakers Pool and Howard Street in Figure 3.11, and the steel barrier in Sheaf Square in Figure 3.13), and one birdsong in the forest (Recorded multiple birdsong 1 in Figure 3.18). To investigate the impacts of visual information on soundscape, the acoustic stimuli of the 5 water features were presented with and without the pictures of their views. In total, nineteen acoustic stimuli were played. The acoustic stimuli were played to the participants in different sequences to decrease the order effects. The acoustic stimuli were presented through headphones (Sennheiser HD 558) and the pictures were shown by a projector (Hitachi ED–X33), respectively. The calibration was conducted by using a dummy head (Neumann KU100) before the experiment. The participants were seated in a chair comfortably in an anechoic chamber. The background noise level was approximately 25.0 dBA.

Thirty subjects participated in the experiment, including 12 women and 16 men, aged 18-35 years. The hearing threshold levels of all participants were tested using an audiometer to show the normal hearing for all frequencies (125, 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz). A 30 s audio clip, which includes traffic noise, birdsong, dog barking and human voice, was played back to the 30 participants to test the capability of sound sources recognition. All of the participants recognised and mentioned traffic noise and birdsong after listening. Two-way mixed intra-class correlation (ICC) with 95% confidence interval was employed to test the consistency of the answers of all of the 30 participants.

The participants were required to score the sounds in terms of four adjectives describing the soundscape characteristics, including “Loud”, “Natural”, “Annoying” and “Pleasant”, on a scale of 0–10, with 0 representing “Not at all” and 10 “extremely” (See the questionnaire in Appendix 1). The adjectives have been identified as the characteristics of soundscape quality in previous studies; one of the most important characteristics is pleasantness (Jeon et al, 2010; De Coensel et al, 2011; Rådsten-Ekman et al, 2013). For the perceptual assessment of traffic noise, perceived annoyance is a rather crucial and frequently examined characteristic (Kang, 2007; Jeon et al, 2010; Di et al, 2012; Dick et al, 2011). Considering the significant roles of perceived loudness in the masking study (Nilsson et al, 2010; Bolin et al, 2010; De Coensel et al, 2011) and naturalness in human relaxation (Ulrich et al, 1991; Kaplan, 1995; Gidlöf-Gunnarsson and Öhrström, 2007), the two characteristics were also included.

3.3 Results

3.3.1 Acoustic characteristics

3.3.1.1 Car traffic noise

It can be observed in Figure 3.9 that car traffic noise is wideband. More energy locates at the low frequencies from 100 to 250 Hz, and after 1600 Hz, the curve goes down significantly, for all the recording distances. The sound levels of the car traffic at 60 km/h (2×2 lane) in most of the frequencies are higher than those at 50 km/h (2×1 lane), with a maximum sound level difference of 5.2 dB at 400 and 1000 Hz. (see Figure 3.9). According to the study in HOSANNA project, the increase of sound level of traffic noise with speed is mainly caused by the sound source of car rolling rather than car engine (Defrance et al, 2012). The reduction of sound levels with distance is slightly larger at the high frequencies, such as 4.5 dB reduced at 8kHz and 2.4 at 200 Hz between 1m and 4 m, but generally the spectrum patterns are similar, excluding 50 m, where the sound level at 100 Hz is much higher than the other frequencies, as can be seen in Figure 3.9.

Therefore, in urban sound environment, car traffic noise can spread widely because of the high energy in low frequency components. It is difficult to be masked from the perspective of energetic masking because it is relatively loud and wideband (Zwicke and Fastl, 1999). When car traffic is distant, for example, 50 m, there is still a high risk of low frequency annoyance of population (Persson and Björkman, 1988; Leventhall, 2004).

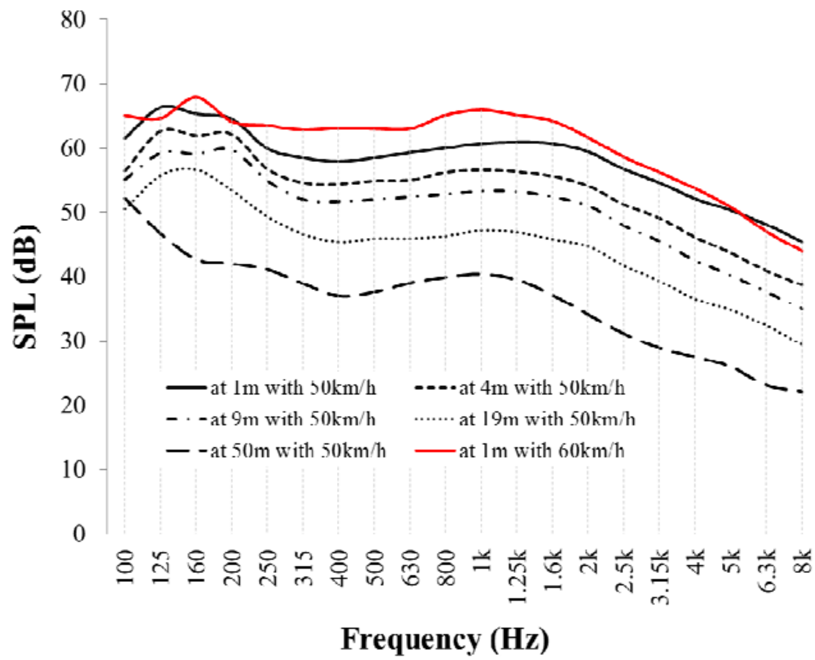


Figure. 3.9. Changes of spectrum of traffic noise with the recording distances of 1, 4, 9, 19 and 50 m from the Crookes Valley Road in Sheffield.

3.3.1.2 Water sounds

The water sounds of the water features in Sheffield vary considerably in terms of spectrum and dynamic process, as can be seen in Figures 3.10 and 3.11. The water sounds are all wideband as traffic noise, especially the water feature in Bakers Pool which has a similar spectrum with traffic noise, indicating its high efficiency of masking on traffic noise (see Figure 3.10). The high frequency components of the water feature in Bakers Pool have relatively lower energy (see Figure 3.10), because the falling of its small water steams on the water surface rather than hard surfaces. By contrast, the water sound of the Peace Gardens has higher energy at the high frequency components, with a peak value 54.2 at 3150 Hz (see Figure 3.10), probably because of its rapid falling of the large water streams on the hard stone surface. The water features in the Sheaf Square and the Howard Street both have relatively evenly-distributed sound levels at all the frequencies (Figure 3.10), but the water features in Howard Street (Figure 3.11-d) have lower sound levels and relatively large dynamic ranges.

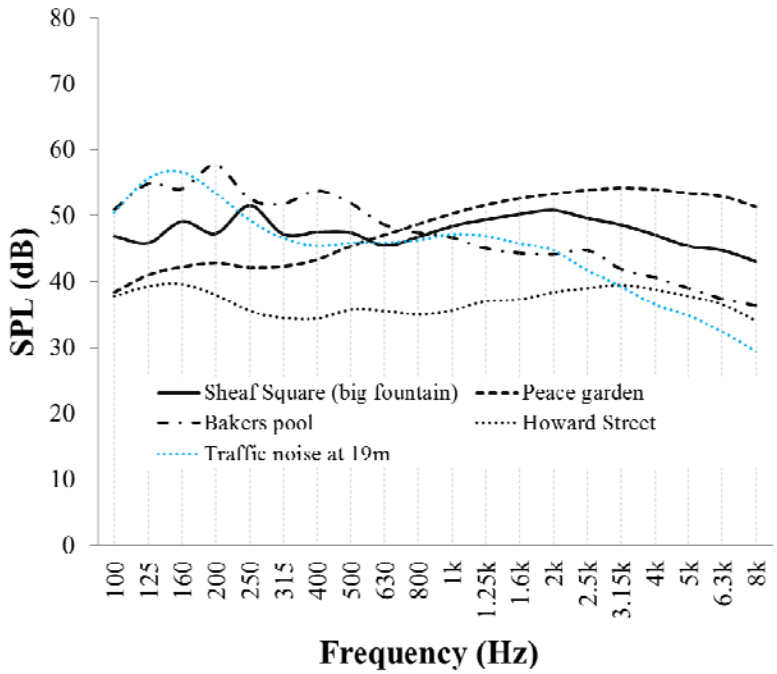


Figure. 3.10. The spectrum of the recorded water sounds of a range of fountains and traffic noise at 19 m distance.

The water features also have a big difference in loudness, up to 14.9 dBA. At the distance of 1 m, the water sound level is 59.9 dBA in the Sheaf Square, 63.9 dBA in the Peace Gardens, 57.9 dBA in the Bakers Pool and 49.0 dBA in the Howard Street. The water sounds are all constant in the 30 s (see Figure 3.11).

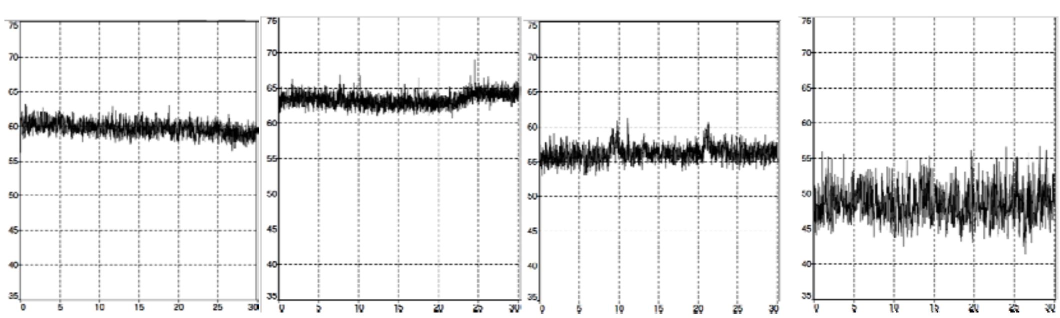


Figure. 3.11. The time history of the recorded water sounds of a range of fountains. (a) Sheaf Square (big fountain); (b) Peace Gardens; (c) Bakers Pool; (d) Howard Street.

Figure 3.12 shows the spectrum of the recorded water features in the Sheaf Square, indicating their high efficiency in masking effects on urban noise. It can be seen when the frequency is higher than 2000 Hz, the sound levels of the water features decrease constantly, while those of traffic noise decrease earlier, at 1000 Hz (see Figure 3.12). It is very interesting to note that the Sheaf steel barrier can reduce the noise not only by barrier effects but also masking effects. From the perspective of noise reduction, it is a successful soundscape element.

Because the water feature sounds were all on at the same time during recording, the similarity of the spectrum may have been enlarged, but their dynamic changes still varies significantly, as shown in Figure 3.13. Among them, Medium Cascade has the largest dynamic ranges, followed by the Sheaf Barrier (see Figure 3.13-b&d).

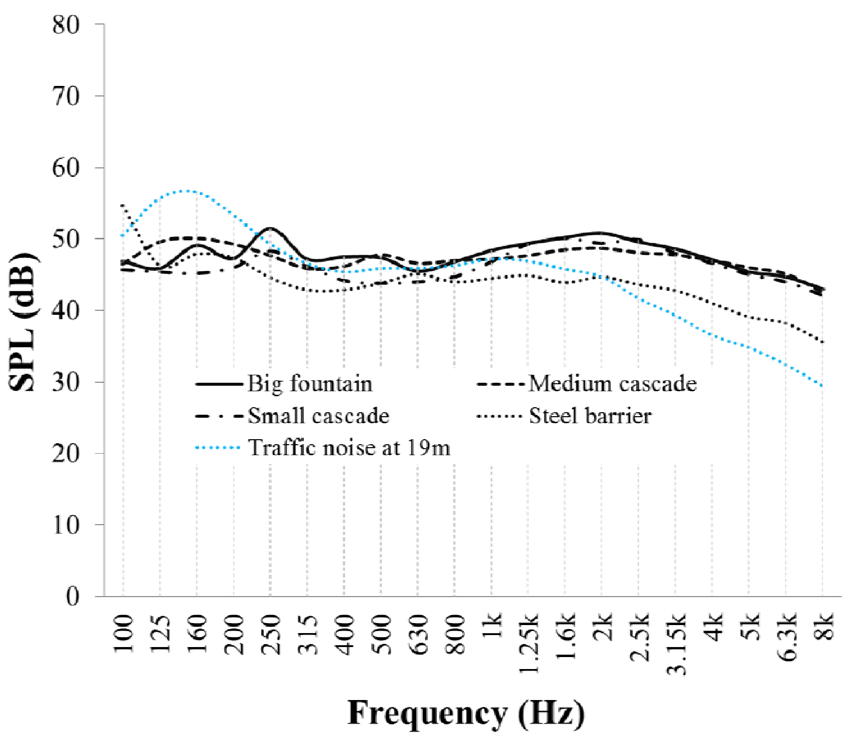
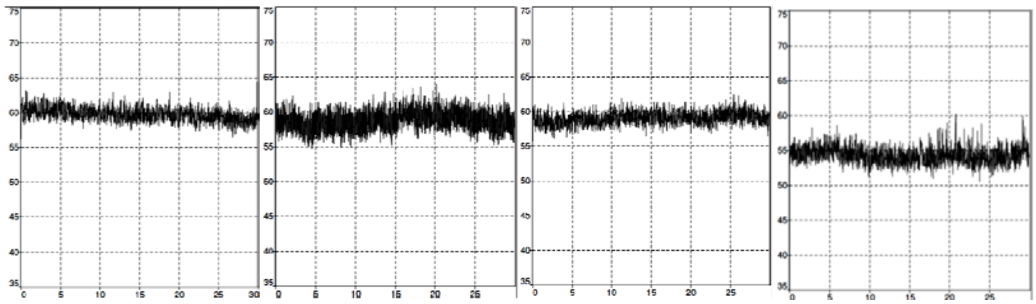


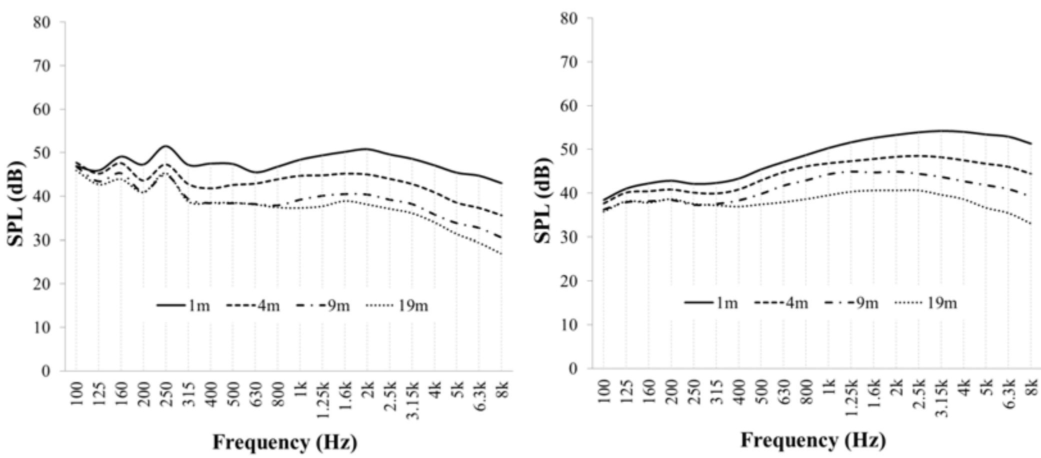
Figure. 3.12. The spectrum of the recorded water sounds of a range of water features in the Sheaf Square and traffic noise at 19m distance.



(a) (b) (c) (d)

Figure. 3.13. The time history of the recorded water sounds of a range of water features. (a) big fountain; (b) Medium Cascade; (c) Small Cascade; (d) Sheaf Barrier.

Figure 3.14 shows the changes of the spectrum of the two big water features with different recording distances of 1, 4, 9, and 19 m in the Sheaf Square and the Peace Gardens. With the increase of distances, the reduction of sound levels of high frequency components is larger than that of low frequency components. For example, in the Peace Gardens, when the distance changes from 1 to 4 m, the sound level reduction is 1.8 dB at 160 Hz, 6.9 dB at 8000 Hz. It is interesting to note that the water features can bring about richness of soundscape within a relatively short distance, giving a considering scope of soundscape design.



(a) (b)

Figure. 3.14. Changes of the spectrum of water sounds with the recording distances of 1, 4, 9, and 19 m from the sound sources. (a) Sheaf Square (big fountain); (b) Peace Gardens

Therefore, as demonstrated in the previous studies (Jeon's et al 2008; Nilsson et al 2010; De Coensel et al, 2011), water sounds can be an efficient urban noise masker. They are wideband and have rather diverse loudness and spectrum, providing a lot of possibilities to design tailor-made water features and sounds to mask certain noise.

3.3.1.3 Aircraft noise

Figure 3.15 shows the spectrum of the 4 flyover aircraft noise recorded in Assen. It can be seen in Figure 3.16 that the spectra and loudness of aircraft noise are very various. Excluding the Recorded aircraft noise 3, the sound levels of the others decrease generally after approximately 800 Hz (see Figure 3.15). Figure 3.16 further indicates more samples of the spectrum of flyover aircraft noise based on the different aircraft engines as sound source, including large commercial jet, private jet, medium propeller, propeller airplane and helicopter. Compared with the propeller noise, energy of the jet noise is more evenly distributed (see Figure 3.16). It can be observed in Figure 3.15&3.16 that the Recorded aircraft noise 1&2 in Assen are similar to the medium propeller noise, the Recorded aircraft noise 3 is similar to the private jet noise and the Recorded aircraft noise 4 is similar to the helicopter noise.

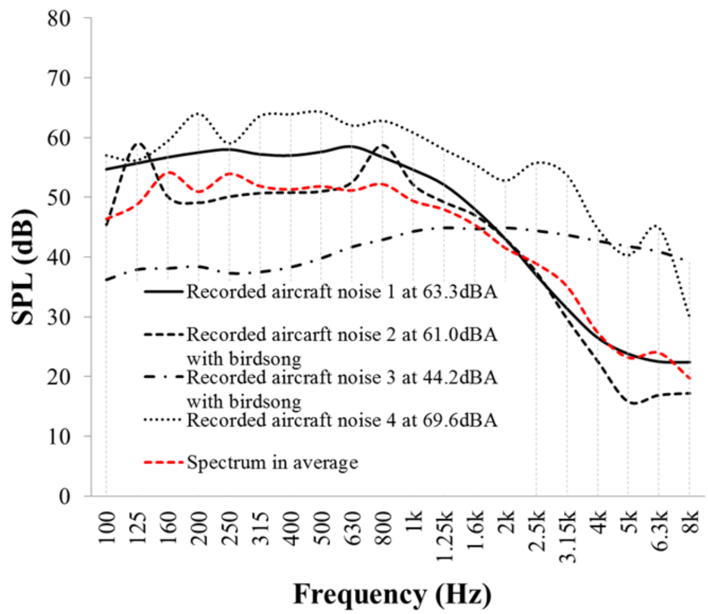


Figure. 3.15. The spectrum of the 4 recorded flyover aircraft noise.

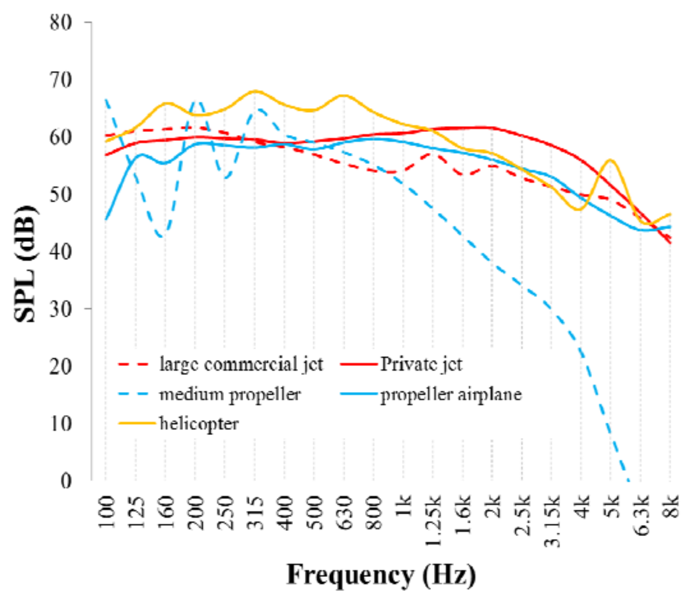


Figure. 3.16. The samples of spectrum of flyover aircraft noise in terms of different types of aircraft engines. (The audios are from the online database freeSFX, and the spectra are generated by the candidate)

Compared with car traffic noise, flyover aircraft noise is more widely spread because of the sound source height. The buildings in the urban areas may not attenuate the aircraft noise levels by the barrier effect, but increase its level caused by the reflection (Pande, 1972). Therefore, masking effects should play a more important role on the reduction of audible flyover aircraft noise.

3.3.1.4 Birdsong

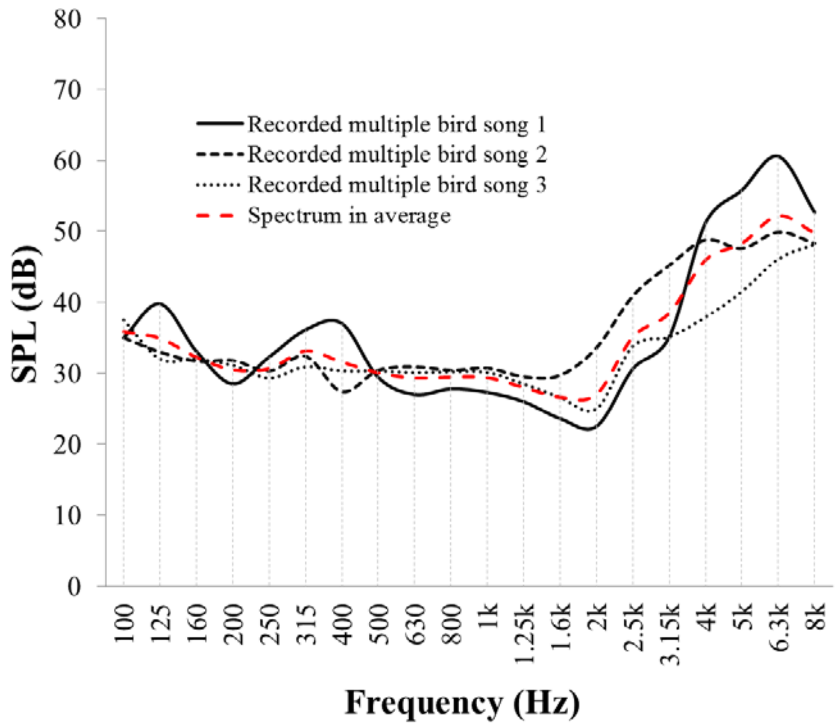


Figure. 3.17. The spectrum of recorded multiple bird songs.

The spectra of the 3 recordings of multiple birdsong and their spectrum in average are shown in Figure 3.17. The sounds are narrowband, and the energy primarily locates at the frequencies from 2000 to 8000 Hz (see Figure 3.17). The highest sound levels of the Recorded multiple bird song 1&2 are at 6300 Hz, and the highest sound level of the Recorded multiple bird song 3 is at 8000 Hz, as shown in Figure 3.17.

Figure 3.18 illustrates the spectra of 3 different bird voices of each species, including Common Black Bird, Great Tit, Eurasian Nuthatch and Sparrow. As shown in Figure 3.18, bird songs are mainly composed by high frequency components from 2000 Hz. The spectra of the four species of birds vary significantly. For example, most energy of

Eurasian Nuthatch locates between 2000 and 4000 Hz (Figure 3.18-c); Sparrow songs have high energy from 2000 to 8000 Hz (Figure 3.18-d). The spectra of the different voices of the same bird species are also rather various, e.g. Common Black Bird and Great Tit (see Figure 3.18-a&b).

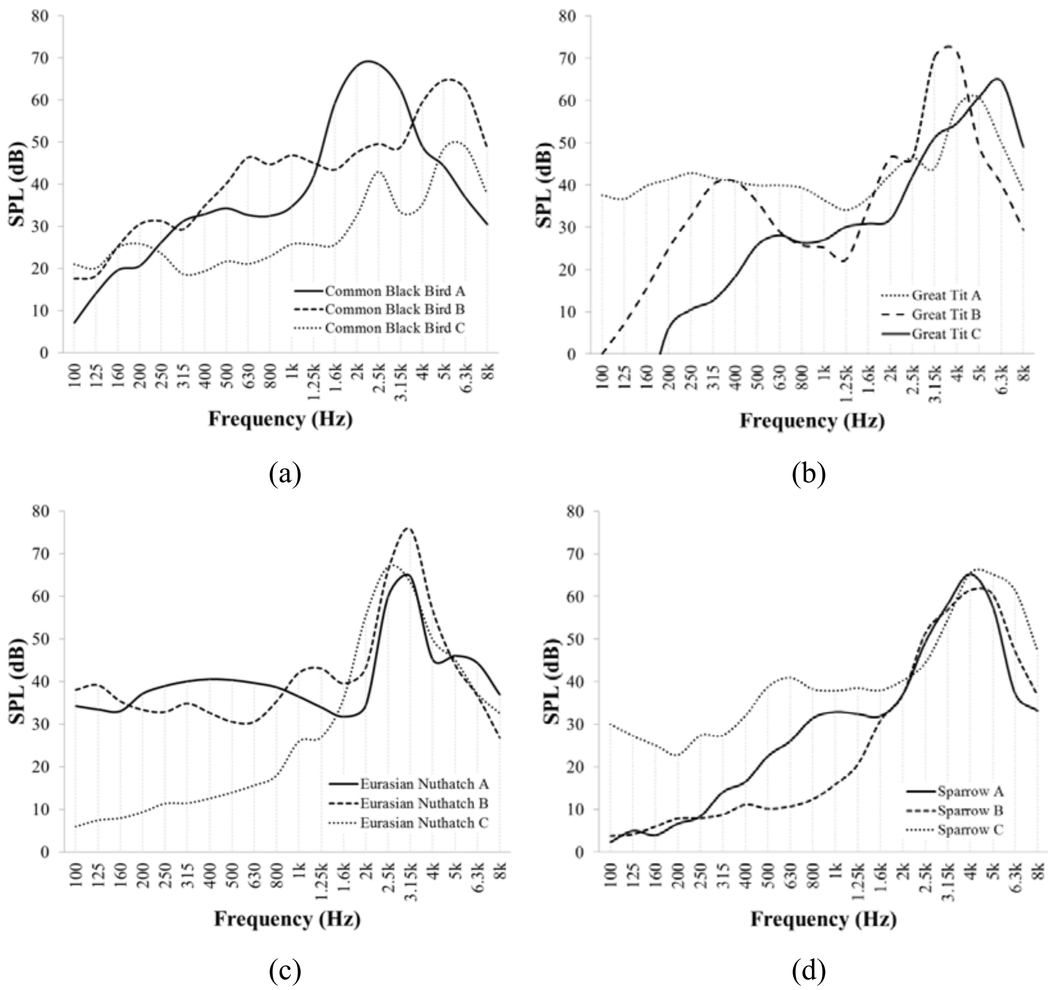
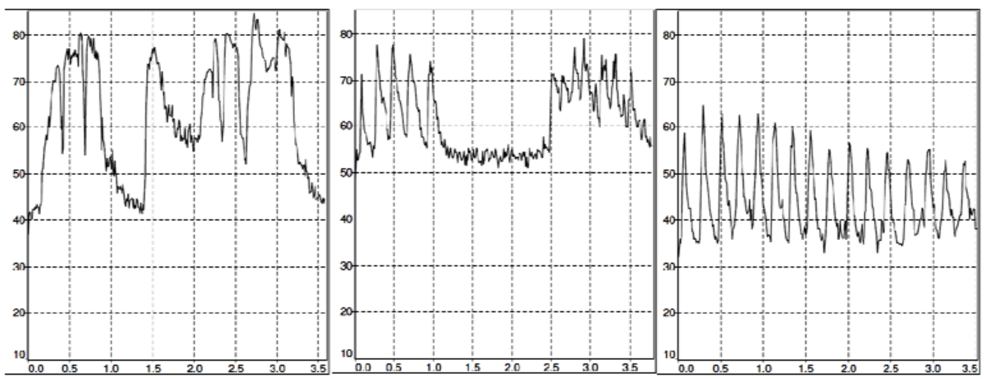


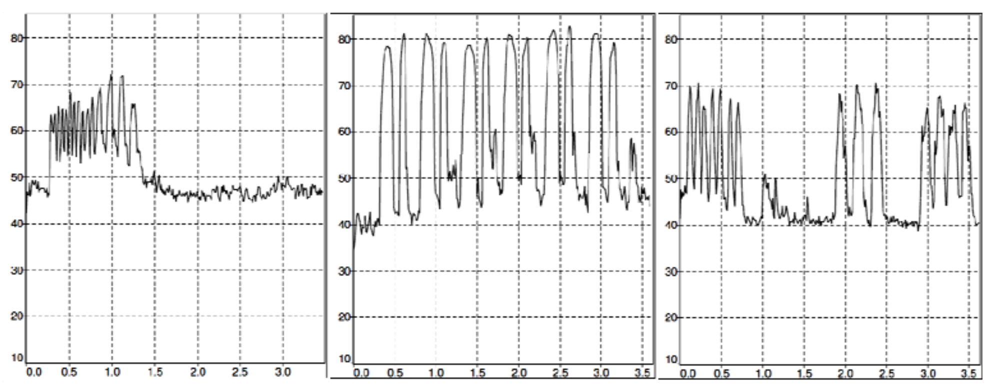
Figure. 3.18. The spectrum of birdsong of the different species of birds. (a) Common Black Bird; (b) Great Tit; (c) Eurasian Nuthatch; (d) Sparrow. (The audios are from the online database Xeno-canto, and the spectra are generated by the candidate)

In addition to spectrum, the bird songs are also diverse in the dynamic process (see Figures 3.19 - 3.22). Figures 3.19 - 3.22 show the dynamic ranges of sound levels of the voices of Common Black Bird, Great Tit, Eurasian Nuthatch, and Sparrow. Although birdsong cannot mask traffic noise and aircraft noise significantly in terms of energetic masking because of the lack of low frequency components, it has been still suggested that birdsong can reduce the perceived loudness of traffic noise and improve pleasantness of soundscape effectively (De Coensel et al, 2011). Therefore, it is interesting to study what factors of birdsong play an important role on its masking effects on traffic noise.



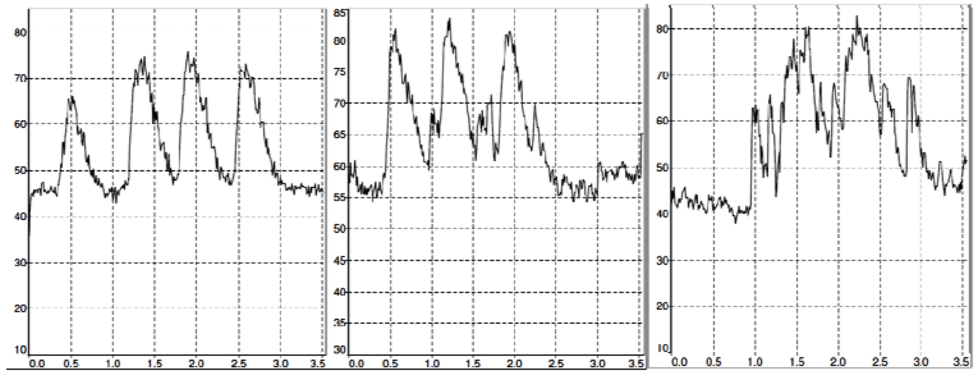
(a) (b) (c)

Figure. 3.19. The time history of the voices of Common Black Bird. (a) Common Black Bird A; (a) Common Black Bird B; (C) Common Black Bird C.



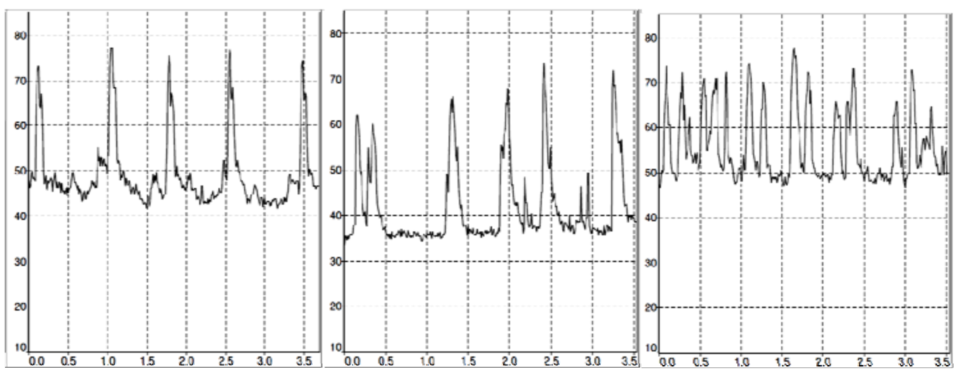
(a) (b) (c)

Figure. 3.20. The time history of the voices of Great Tit. (a) Great Tit A; (a) Great Tit B; (C) Great Tit C.



(a) (b) (c)

Figure. 3.21. The time history of the voices of Eurasian Nuthatch. (a) Eurasian Nuthatch A; (a) Eurasian Nuthatch B; (C) Eurasian Nuthatch C.



(a) (b) (c)

Figure. 3.22. The time history of the voices of Sparrow. (a) Sparrow A; (a) Sparrow B; (C) Sparrow C.

3.3.2 Evaluation of soundscape

The results of two-way mixed intra-class correlation (ICC) with 95% confidence interval show that the average intra-class correlation coefficients of Perceived Loudness, Naturalness, Annoyance and Pleasantness were 0.983, 0.985, 0.980 and 0.980, which indicates that the subjects research high consent in the judgements of the four characteristics. Compared with the average intra-class correlation coefficients of Perceived loudness and Naturalness, those of Annoyance and Pleasantness are lower, indicating that the subjects have a higher degree of consistency on objective measurements than subjective feelings.

Normalisation of the responses was conducted prior to the data analysis in order to decrease the impacts of the differences in the ranges of the score used by the participants in the evaluation. The response variance of each participant was normalised according the equation employed in the previous study (Hong and Jeon, 2013). A one-way analysis of variance (ANOVA) was conducted to examine the statistically significant mean difference in terms of the scores of the four characteristics, and *post hoc* comparison was further used to examine the differences between each pair of the acoustic stimuli.

3.3.2.1 Car traffic noise

Table 3.1 The mean values of the four characteristics of the five acoustic stimuli of traffic noise obtained by the multiple-channel recording at the distances of 1, 4, 9, 19 and 50 m from the road.

	Mean value			
Characteristics / **Traffic noise**	**Perceived Loudness**	**Naturalness**	**Annoyance**	**Pleasantness**
at 1m	9.1	0.3	8.4	0.4
at 4m	7.7	0.3	7.3	0.7
at 9m	6.8	0.5	6.9	1.1
at 19m	5.6	0.9	5.4	1.2
at 50m	3.6	2.4	4.1	1.9

Table 3.1 shows the mean values of the four characteristics of the five acoustic stimuli collected with the multiple-channel recording at the distances of 1, 4, 9, 19 and 50 m from the road. It can be observed in Table 3.1 that, when the distance increases, the Perceived Loudness and Annoyance decreases constantly, while the Pleasantness keeps on increasing. The ANOVA indicates that the mean differences of Perceived Loudness

among the 5 acoustic stimuli are significant, with F (4, 145) = 78.08, $p < 0.00$. Excluding the difference between traffic noise at 4 and 9 m ($p > 0.05$), the Perceived Loudness of the other pairs of traffic noise is all significantly different from each other ($p < 0.05$). Figure 3.23 shows the changes of Loudness, Perceived Loudness and Annoyance of the five acoustic stimuli of traffic noise with distance. To compare the changes of Loudness and Perceived Loudness, Loudness is represented by the score from 0-10, calculated with A-weighting sound pressure levels (dBA) based on the loudness of the five audios (69.8, 65.3, 62.3, 56.0 and 47.0dBA). The score of 9.1 for Perceived Loudness in Table 3.1 was set to represent initial Loudness of 69.8dBA. Accordingly, the other scores of Loudness were calculated. It can be seen in Figure 3.23 that the decrease of Perceived Loudness is significantly faster than that of Loudness that is related to the physiological hearing. This interesting phenomenon reveals that, the changes of spectrum of traffic noise, which give human the indication on distance of traffic, influence their judgement on loudness in psychoacoustics. Therefore, it is important to note that Perceived Loudness is decreased by the sense of distance. It can be an evidence for the role of top-down process in auditory perception and "informational masking". The influence of the sense of distance can be also seen in the responses of Q1 in the interview after the experiment (see Appendix 2).

Because car traffic noise is dominant without other obvious sounds, the naturalness is all lower than 1 in the scale of 0-10, except for the traffic noise recorded at 50 m from the road (47.0 dBA), with naturalness of 2.4, as shown in Table 3.1. The ANOVA shows that the mean difference of Naturalness is significant, with F (4, 145) = 19.5, $p < 0.00$, but the significant differences only exist between the traffic noise at 50 m and the other four ($p < 0.00$) in *post hoc* comparison. The reason might be that the quietness and uneventfulness increase the perceived naturalness of the sound environment.

The changes of Annoyance of the traffic noise are highly accordant with those of Perceived Loudness, as shown in Figure 3.23. The ANOVA shows that the mean difference of Annoyance is significant [F (4, 145) = 24.60, p <0.00]. Therefore, it is essential to reduce the Loudness of the traffic noise environment to achieve low Annoyance, which can be also seen in the responses of Q1&3 in Appendix 2.

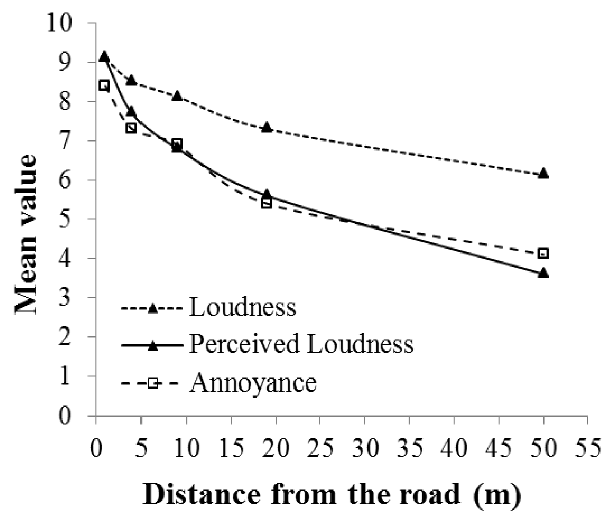


Figure. 3.23. The changes of Loudness, Perceived Loudness and Annoyance of the five acoustic stimuli of traffic noise obtained by the multiple-channel recording at the distances of 1, 4, 9, 19 and 50 m from the road.

Although the Pleasantness increases with the increase of the distances from the road, the highest score is still lower than 2 (see Table 3.1), which suggests that although attenuating traffic noise can decrease the Annoyance of sound environment, it is not enough for the increase of the Pleasantness.

3.3.2.2 Water sounds

In general, the soundscape characteristics of the five water features in Sheffield are diverse, as shown in Table 3.2. The ANOVA further shows that the mean differences of the Pleasantness among the five water sounds are significant [F (4, 145) = 15.03, p <0.00]. The Naturalness of the five water sounds is not high, from 1.9 to 6.0 (4.7 in average) (see Table 3.2), and the standard deviation is 1.37. A two-tailored bivariate correlation analysis and linear regressions were conducted to reveal the relationships between each pair of the four characteristics. The results show that the Perceived Loudness is not correlated to any of the other three characteristics, while the Naturalness has a significant positive relation with the Pleasantness (p = 0.004, R^2 = 0.945) and a negative relation with the Annoyance (p = 0.014, R^2 =0.960), which suggests the importance of naturalness in evaluation of soundscape quality of water sound environment rather than the Perceived Loudness.

The water feature in the Howard Street which has the largest dynamic range (see Figure 3.11-d) was perceived as most natural, 6.0 (see Table 3.2), followed by the water feature in the Peace Gardens (5.7) (see Table 3.2), of which the sound energy locates relatively more at the high frequency components (see Figure 3.10). The Pleasantness of these two water features is also ranked at the top, 5.5 and 5.0, as shown in Table 3.2. The water features in the Sheaf Square Bakers Pool, which have more low-frequency sounds (see Figure 3.10), have the highest Annoyance of 3.5and 2.0, and the lowest Pleasantness, 1.7 and 3.9. In accordance with this, Watts et al (2008) has demonstrated that the higher frequency water sounds are more highly rated in tranquillity improvement than the low frequency ones.

As shown in Table 3.2, for the water sounds, the visibility of the sound sources has little influence on Perceived Loudness, with a maximum difference of 0.3, whereas it can increase the Pleasantness of water sounds. For example, the Pleasantness of Peace Gardens is 1.6 higher with view than without view, with p <0.05 in *post hoc* comparison.

Among the five water features, only the visibility of the Steel Barrier decreases the soundscape quality of its water sound, e.g., the increase of 1.2 in the Annoyance and the decrease of 0.3 in the Pleasantness (see Table 3.2). It might because that the appearance of steel is not favourable or natural (4.1) for the participants. The big fountain in the Sheaf Square has the most significant improvement of Naturalness with view (from 1.9 to 4.3), as shown in Table 3.2, which indicates the important role of additional visual information in auditory perception. In conclusion, the visibility of water sound sources as a context of acoustic stimuli influences the Perceived Loudness little, but it increases the Pleasantness significantly. Therefore, to create positive masking in soundscape by water sounds, the visibility of water features should be taken into account.

Table 3.2 The mean values of the four characteristics of the five acoustic stimuli of water sounds obtained by the single-channel recording at the distance of 1 m from the water features. *N means audio only, and Y means both audio and view.

	Mean value							
Characteristics / Water features	Perceived Loudness		Naturalness		Annoyance		Pleasantness	
	N	Y	N	Y	N	Y	N	Y
Sheaf Square (big fountain)	4.2	4.3	1.9	4.3	3.5	3.5	1.7	3.2
Peace Gardens	4.1	4.1	5.7	6.0	1.9	1.6	5.0	6.6
Bakers Pool	3.1	3.3	4.9	4.8	2.0	2.0	3.9	4.7
Howard Street	2.8	3.0	6.0	5.9	1.3	1.5	5.5	6.5
Steel Barrier	4.5	4.2	5.2	4.1	1.7	2.9	4.1	3.8

3.3.2.3 Aircraft noise

To examine the influence of loudness of aircraft noise on soundscape quality evaluation and the masking effects of birdsong on aircraft noise, the mean values of four characteristics of the three aircraft noise recordings were calculated, as shown in Table 3.3. The ANOVA shows that the mean differences of the four characteristics among the three recordings were all significant (p <0.00).

Table 3.3 The mean values of the four characteristics of the three recorded aircraft noise.

Characteristics / Aircraft noise	Mean value			
	Perceived Loudness	**Naturalness**	**Annoyance**	**Pleasantness**
63.3 dBA	6.0	2.0	5.2	1.5
63.0 dBA + birdsong	4.7	3.0	4.0	1.6
44.2 dBA + birdsong	3.3	5.5	1.8	3.7

In *post hoc* comparison, the difference of "63.3 dBA" and "63.0 dBA + birdsong" is only significant in the Perceived Loudness. It can be seen that the aircraft noise with birdsong has much lower Perceived Loudness (4.7) than the one without birdsong (6.0), as shown in Table 3.3. However, the differences in the other three characteristics are not significant (Table 3.3). It is interesting to note that the traffic noise at 62.3 dBA at a distance of 9 m from the road in Section 3.3.2.1 has higher Annoyance (6.9) than that of aircraft noise at 63.3 dBA (5.2), which indicates the impacts of the information of sound source on the soundscape evaluation.

The acoustic stimuli of "63.0 dBA + birdsong" and "44.2dBA + birdsong" are significantly different in the Naturalness, Annoyance and Pleasantness (p <0.00). A sound pressure level decrease of 16.8dBA results in an increase of 2.5 in the Naturalness, an increase of 2.1 in the Pleasantness and a decrease of 2.2 in Annoyance (see Table 3.3). Therefore, it seems that attenuating the sound pressure level of aircraft noise is essential for the soundscape quality improvement.

3.3.2.4 Birdsong

Because of the acoustic similarity of the multiple bird songs recorded in forest (see Figure 3.17), only "Recorded multiple bird song 1" in Figure 3.17 was examined by the psychological listening experiment. The A-weighting sound pressure level of the audio is 28.7 dBA. The Perceived Loudness, Naturalness, Annoyance and Pleasantness are 1.8, 9.4, 1.1 and 7.7. Compared with water sounds in Table 3.2, bird songs have much higher Naturalness and Pleasantness, and lower Annoyance. Because of its high score in the Naturalness, it can be considered as a sound mark of nature (evidence also shown in the responses of Q2 in Appendix 2). Although the bird song is narrowband, its big potential for masking on the traffic noise may be still achieved through attention abstraction. In the study by De Coensel et al (2011), birdsong has been proved to be a preferred masker in the traffic noise environment.

3.4 Conclusions

This chapter examined the acoustic and soundscape characteristics of the urban sounds from different urban sound sources with a consideration of masking effects. Sound recording and measurement, sound analysis and psychological listening experiments were employed. The dynamic ranges and spectrum of the sounds were presented; the results on psychological evaluation of the sounds were shown in terms of the Perceived Loudness, Naturalness, Annoyance and Pleasantness.

In the urban sound environment, car traffic noise is difficult to be masked from the perspective of energetic masking, because it is relatively loud and rather wideband. When car traffic is distant, e.g., 50 m, there is still a high risk of low frequency annoyance of population (see also the responses of Q3 in Appendix 2). The decrease of the Perceived Loudness is significantly faster than that of the Loudness that is related to physiological hearing, probably because the sense of distance perceived through the changes of spectrum decreases the Perceived Loudness. It can be an evidence for the role of top-down process in auditory perception and “informational masking. The high correlations between annoyance and loudness indicate the importance of traffic noise level reduction to achieve low annoyance. Although the Pleasantness increases with an increase of distances from the road, the highest score is still lower than 2 in a scale of 0-10, which suggests that although attenuating traffic noise decreases the Annoyance of sound environment, it is not enough for the increase of the Pleasantness.

The sounds of the water features are all wideband as the traffic noise and vary in terms of spectrum and dynamic process considerably, providing a lot of possibilities to design tailor-made water features and sounds to mask certain noise. They can also bring about richness of soundscape within a relatively short distance, giving a considering scope of soundscape design. The water features have big differences in loudness (up to 14.9 dBA) and pleasantness. The Naturalness of the five water sounds is not high and has a significant positive relationship with the Pleasantness and a negative relationship with the Annoyance, which suggests the importance of naturalness in the soundscape quality evaluation of the water sound environment. The water features thathave larger dynamic ranges and more high-frequency components are perceived as more natural and pleasant. The visibility of the water sound sources has little influence on the Perceived Loudness, with a maximum difference of 0.3, but it can increase pleasantness significantly (see also the responses of Q1 in Appendix 2), therefore, to create positive masking in soundscape by water sounds, the visibility of water features should be taken into account.

For aircraft noise, the spectra and loudness of the noise are rather various in urban areas. Compared with the car traffic noise, the flyover aircraft noise is more widely spread because of the sound source height. However, when sound pressure levels are similar, the Annoyance of the traffic noise is higher than that of the aircraft noise. When adding birdsong, only the Perceived Loudness of the aircraft noise is reduced significantly, but when sound pressure levels decrease, e.g., by 16.8 dBA, the Naturalness and Pleasantness can be effectively increased by 2.5 and 2.1, and the Annoyance can be largely decreased by 2.2. Therefore, attenuating aircraft noise level is essential for soundscape quality improvement.

The urban bird songs are primarily composed by the high frequency components from 2000 Hz, so birdsong cannot mask the traffic noise and the aircraft noise significantly in terms of energetic masking because of the lack of the low frequency components. But the bird songs are diverse in both spectrum dynamic and process, and highly scored in the Naturalness (9.4) and the Pleasantness (7.7), higher than water sounds. It can be considered as a sound mark of nature. It has a big potential to mask the traffic noise through attention abstraction to improve soundscape quality in terms of the Naturalness and Pleasantness.

CHAPATER 4

MASKING EFFECTS BY BIRDSONG

Regarding the high score of birdsong in naturalness and pleasantness proved in Chapter 3, birdsong is studied in this chapter as a potential masker in terms of the soundscape characteristics, including the Perceived Loudness, the Naturalness, the Annoyance and the Pleasantness. Three factors that may influence the masking effects by birdsong, including acoustic features (i.e. spectra of noise and loudness of masker), occurrence frequencies of masker, and visibility of sound sources, were examined by psychological listening experiments. The study aims at the assessment of the traffic noise environment with masking by birdsong, and also optimum of soundscape design in the context of landscape with roads and woods. This chapter firstly presents how traffic noise and birdsong were recorded and what the physical conditions of the soundscape were, then explains how the acoustic stimuli were designed, and finally shows the impacts of the different physical conditions on the masking effects.

4.1 Introduction

As indicated in Section 2.1 of Chapter 2, with the emergence of the soundscape concept, which is defined and explained as an "acoustic environment as perceived or experienced and/or understood by people, in context" by ISO/TC 43/SC 1, the research interests on urban sound environment have been extended from traditional noise control to multi-disciplinary research. Because of the crucial role of visual-aural interaction of human perception on sound environment assessments, integrated studies of soundscape and landscape have also been conducted recently (Pheasant et al, 2008; Hong and Jeon, 2013; Maffei et al, 2013; Liu et al, 2013). For example, Pheasant et al (2008) proposed to evaluate perceived tranquillity of a location by linear expressions composed by L_{Amax},

L_{Aeq} and the percentage of presented view of natural features. Beyond total sound level of a sound environment, the significance of sound meaning has been also emphasised. The identification and taxonomy of multiple sound events in the daily-life soundscape have become essential in soundscape studies (Dubois et al, 2006; Guastavino, 2006). Natural sounds, such as birdsong and water sounds, which may benefit people's relaxation in urbanised area (Gidlöf-Gunnarsson and Öhrström, 2007), have been studied frequently, with particular considerations for their interaction with common urban noise, e.g., car traffic noise (Best et al, 2005; Halfwerk and Slabbekoorn, 2009; Cardoso and Atwell, 2011; Rådsten-Ekman et al, 2013). As a result, the concept of 'masking' has re-emerged within the scope of soundscape becausemasking effects have been demonstrated to have considerable impacts on the quality of soundscape (Brown and Muhar, 2004; De Coensel et al, 2011; Axelsson et al, 2014).

Great attention has long been paid to the research on auditory masking, but the scope of masking is mainly limited in the domain of acoustics and psychoacoustics, as indicated in Section 2.2 of Chapter 2. Among the two main categories of masking, namely "energetic masking" and "informational masking", have been widely accepted and investigated (Durlach et al, 2003; Watson, 2005; Brungart et al, 2001; Arbogast et al, 2002).

However, in the real-life soundscape, the role of sound source perception and cognition have high relevance with the masking effects (Yost, 2008), therefore, the results within the scope of acoustics and psychoacoustics cannot not be directly applied in the soundscape studies. For example, it has been found that the masking capability of natural sounds is lower than the prediction by Moore et al.'s model of energetic masking

(Nilsson et al, 2009; Bolin et al, 2010). Therefore, informational masking that concerns contexts should be an important consideration in soundscape studies, in addition to energetic masking. Masking here is explained as a hearing phenomenon by which soundscape characteristics are altered by the presence of interfering sound event(s).However, how the factors of sound events induced by landscape may influence masking effects in daily-life soundscape, and how much the masking effects of natural sounds can contribute to the improvement of total soundscape have not been systematically studied.

Two rather common sounds, car traffic noise and birdsong, which have considerable interactions in urbanised areas (Yang and Kang, 2005) are selected as the target and masker. Birdsong has been also demonstrated as the most preferred natural sound in the traffic noise environment (Hong and Jeon, 2013; De Coensel et al, 2011). Three factors may influence the masking of traffic noise by birdsong are motivated from landscape: variant sound pressure levels and frequencies of sound events caused by distances between perceivers and the landscape features; occurrence frequencies of birdsong caused by daytime and vegetation characteristics (McNamara,1987; Ambuel and Temple, 1983; Mills et al, 1991), with particular references to that the number of sound event can cause significant difference in perceived activity disturbance (Lavandier et al, 2011); visibility of sound sources decided by the existence of view block in landscape.

4.2 Methods

Based on the analysis of the recordings of typical real sound environments dominated by road traffic noise and birdsong, listening tests were designed, using a series of reproduced acoustic stimuli.

4.2.1 Sound recording

To reproduce acoustic stimuli and investigate the characteristics of the urban road traffic noise environment, sound recordings were collected along two main roads, namely Crookes Valley Road (2×1 lane, 50km/h), Sheffield, UK and Hoofdlaan (2×1 lane, 50km/h), Assen, Netherlands, which both lead to the city centres with woods flanking the roads. An Edirol R-44 Portable Recorder and Tascam DR-680 digital recorder were used for sound recording. The microphones height is 1.6 m. The sound samples were recorded and stored as 16 bit, 44.1 kHz wave files. To record the spatial road traffic noise distribution, simultaneous multi-channel recordings were collected at the distances of 1m, 4m, 9m, 19m and 50m from the road side of Crookes Valley Road during summer 2013 rush hours (see Figure 4.1-a).. Meanwhile, the photos were taken from where the microphones were located, facing the road, to record the scenes where the sound events happened. To record the temporal changes of both road traffic noise and birdsong, single-channel sound recordings were conducted on a path way at a distance of 2 m from the road side of Hoofdlaan during sunny and windless weekdays in September 2013 (see Figure 4.1-b). The recordings started at sunrise around (approximately 07.30) and ended at sunset (approximately 19.30) (Dateandtime.info, 2013), considering the influence of daytime on bird chirping behaviour (McNamara, 1987). There are six 5min sound recordings in each hour during the total 12 hours of daytime.

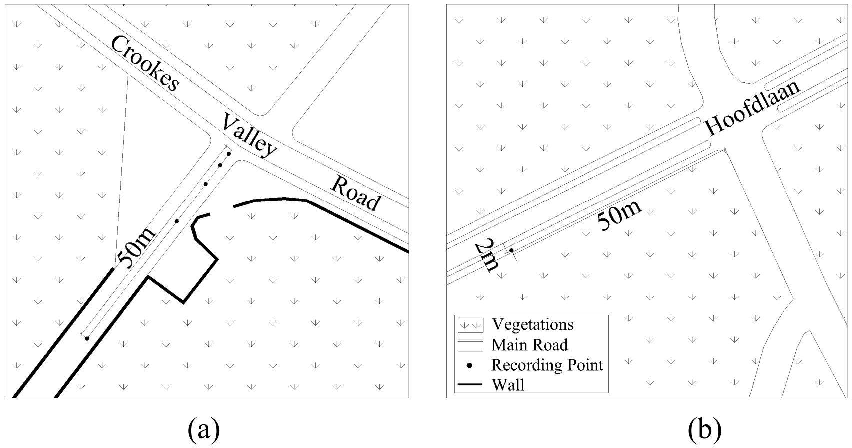


Figure. 4.1. Maps of the recording points. (a) Crookes Valley Road, Sheffield, UK; (b) Hoofdlaan, Assen, Netherlands.

4.2.2 Sound analysis

To obtain the representative sound pressure levels and occurrence frequencies for acoustic stimuli reproduction, a pilot study of sound analysis was carried out with thirty-six 5 min sound recordings (three recordings for every 12 hours) at Hoofdlaan. The recordings were analysed by the software package 01dB to obtain the time histories of each recording with LAeq values, and further physically represented by means of Time-component Matrix Chart proposed by Matsui et al (2009), which is a tool for sound annotation and calculation of percentage time of the sound level range and percentage time of the sound event audible.

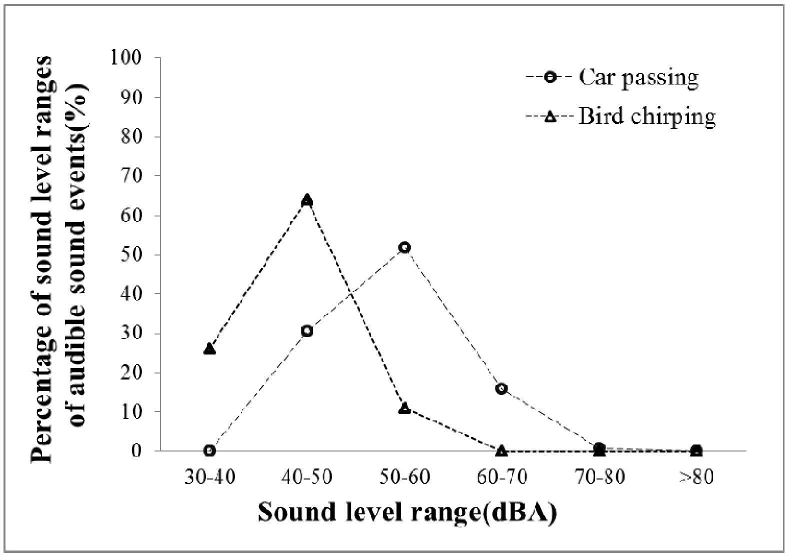


Figure. 4.2. The percentage time of each sound level range of car passing and bird chirping in their total time history.

The sound pressure levels obtained by calculation of LAeq value are classified into 6 ranges, including 30-40, 40-50, 50-60, 60-70, 70-80 and >80 dBA. Figure 4.2 shows the percentages of each sound level range of car passing and bird chirping in the total time history. For car passing, the sound levels between 50- 60 dB occupied the highest percentage, at 51.8%, while only a few sound levels are beyond 70 dBA, at 0.9%. The ranges of 60-70 dBA (15.9%) and 40-50 dBA (30.7%) represented the high and low sound level ranges. For bird chirping, most sound levels (64.0%) were in the 40 -50dB range, followed by the ranges of 30-40d BA (26.0%) and 50-60 dBA (11%). It can be observed in Figure 4.2 that, in general, the distribution of sound levels of bird chirping is 10 dBA lower than that of car passing. The mean sound pressure level of backgrounds (excluding car passing and bird chirping) was calculated at approximately 36.2 dBA.

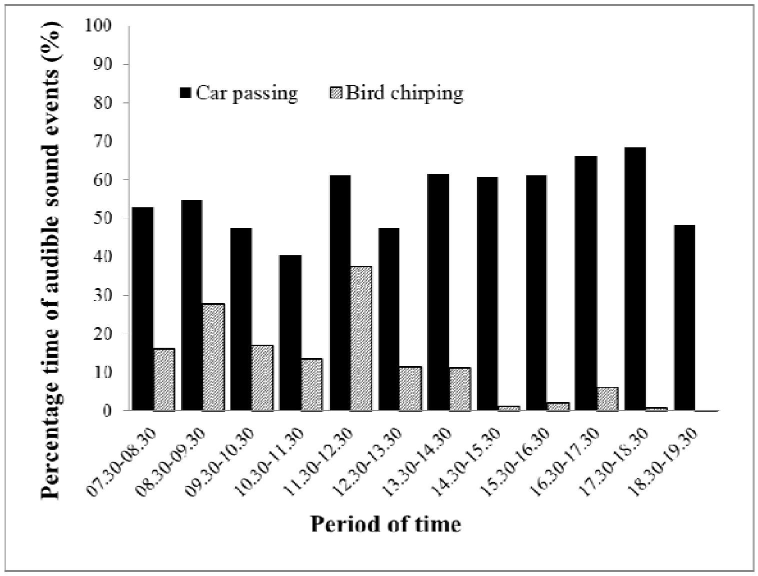


Figure. 4.3. The percentage time of both car passing and bird chirping in different time periods of daytime.

Figure 4.3 shows the percentage time of audible car passing and bird chirping over the 12 daytime hours. Table 4.1 shows the event frequencies of car passing and bird chirping. The percentages in Figure 4.3 and the numbers in Table 4.1 are the mean values of three recordings in each of 12 hour periods, to avoid the influence of rare individual noises. The mean percentage time of audible car passing in Figure 4.3 is 55.9%, which is used as a constant percentage for the time length of car passing in the following acoustic stimulus reproductions. The mean occurrence frequency of car passing in the 12 hours in Table 4.1 is 18 in five minutes, which is used as a typical occurrence frequency of car passing in this study, so the numbers of car passing is set as 2 in 30s. Meanwhile, the variant percentage time (11.3% - 37.7%) and currency frequencies of audible bird chirping during 07.30 to 14.30 (when bird chirping mainly occurred) will be the factor examined in the experiment.

Table 4.1. The numbers of the sound events of car passing and bird chirping during 5 minutes.

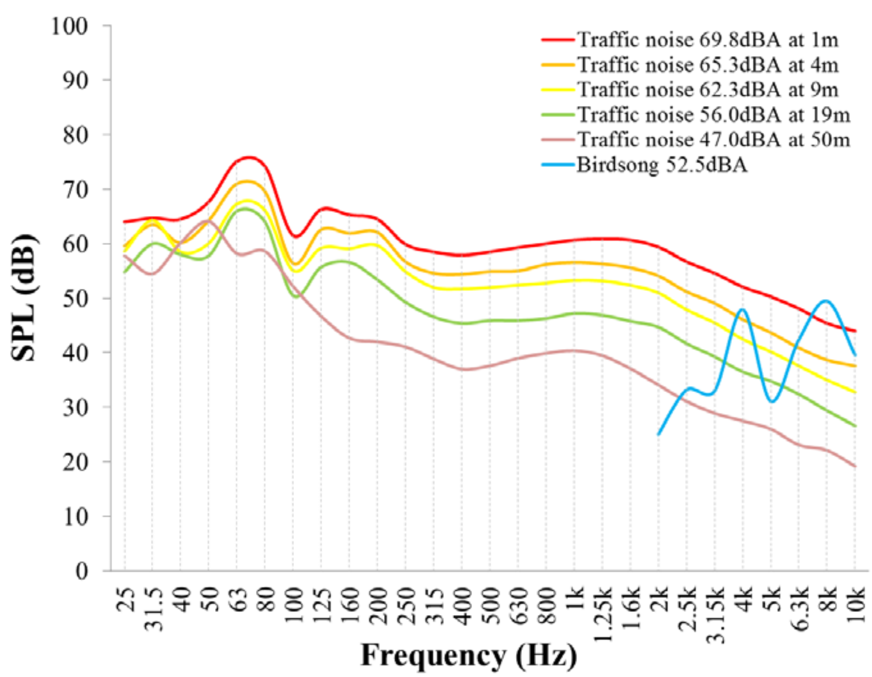
Sound event	Period of time											
	07.30 - 08.30	08.30 - 09.30	09.30 - 10.30	10.30 - 11.30	11.30 - 12.30	12.30 - 13.30	13.30 - 14.30	14.30 - 15.30	15.30 - 16.30	16.30 - 17.30	17.30 - 18.30	18.30 - 19.30
Car passing	14	18	13	8	18	13	16	18	20	22	24	16
Bird chirping	23	25	30	19	29	25	25	4	6	7	1	1

4.2.3 Acoustic stimuli

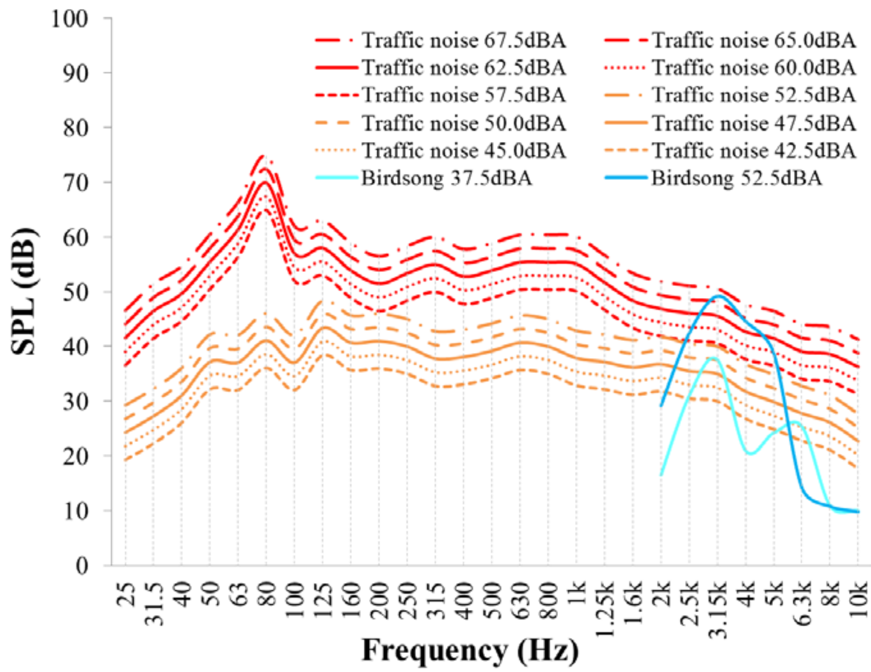
The acoustic stimuli were constructed based on the audios recorded, using Adobe Audition CS6. Diverse lengths have been used in the previous listening experiments on masking and soundscape (De Coensel et al, 2011; Pheasant et al, 2008; Hong and Jeon, 2013). Considering the aims at the total quality of soundscape, 30s was confirmed according to the study results by Pheasant et al on the time scales for participants' constant assessments.

According to the factors of spectra of traffic noise, loudness of birdsong and occurrence frequencies of birdsong, three groups of acoustic stimuli were reproduced, of which the spectra are illustrated in Figure 4.4. Figure 4.4 shows ⅓ octave band level relative to the A-weighted level of bird chirping and car passing. The patterns of bird chirping used in the three groups were cut directly from the single-channel sound recordings by Hoofdlaan when backgrounds were quite, lower than 36.2 dBA. To avoid unreality of the acoustic stimuli, multiple pattern of bird chirping of passerine bird species were included. They are rather common urban bird communities in Europe (Clergeau et al, 1998; Clergeau et al, 2006), such as Great Tit (Parus major), Common Blackbird

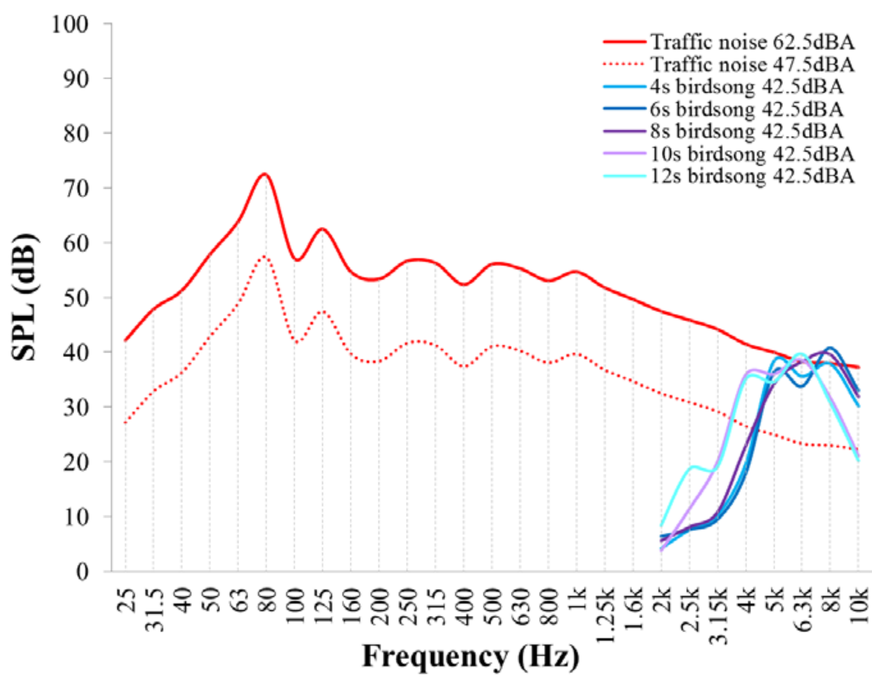
(Turdus merula) and Sparrow (Passer). The frequencies of bird chirping mainly locate at 2000-10,000 Hz (see Figure 4.4). The patterns of car passing used in Group B and C were cut directly from the single-channel sound recordings by Hoofdlaan, and those used in Group A were cut directly from the multi-channel sound recordings by Crookes Valley Road. Spectrum of car passing is the parameter investigated in Group A composed by ten acoustic stimuli, of which the spectra can be seen in Figure 4.4-b. As shown in Figure 4.5-a, five acoustic stimuli in the Subgroup I are original recordings at the distances of 1, 4, 9, 19 and 50 m. The other five acoustic stimuli in Subgroup II in Figure 4.5-b were reproduced by adding the same bird chirpings at 52.5dBA each. The bird chirpings were designed to be audible for 8 s in each stimulus.



(a) Group A&D

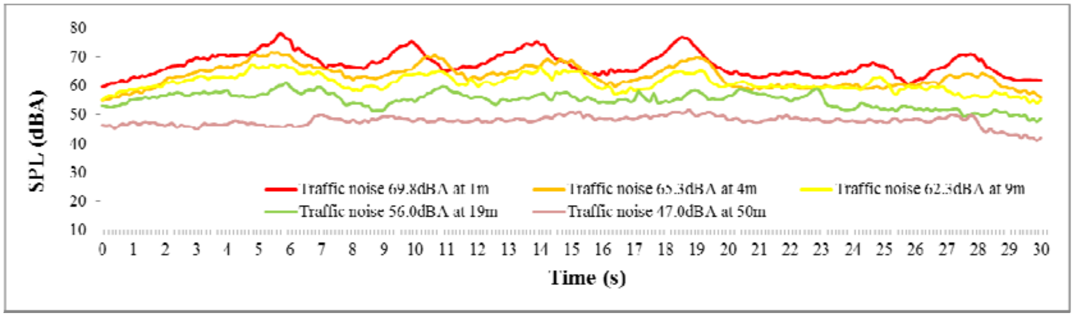


(b) Group B

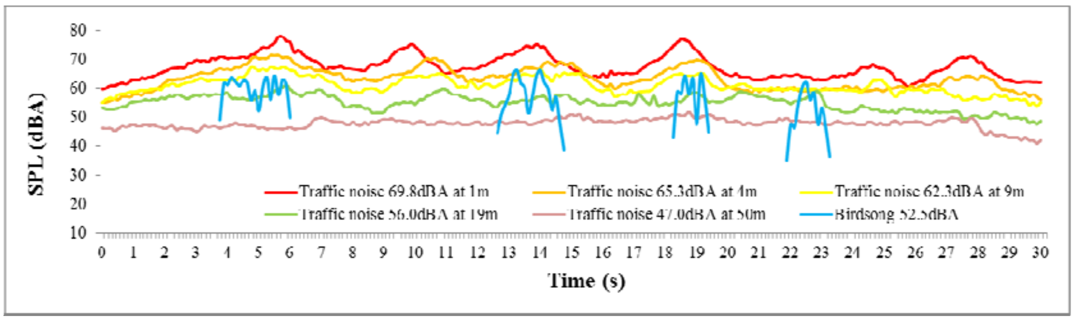


(c) Group BC

Figure. 4.4. The ⅓ octave band spectra of the car passing and bird chirping used in the reproduced acoustic stimuli. (a) Spectra of the acoustic stimuli used in Group A&D; (b) Spectra of the acoustic stimuli used in Group B; (c) Spectra of the acoustic stimuli used in Group C.



(a)



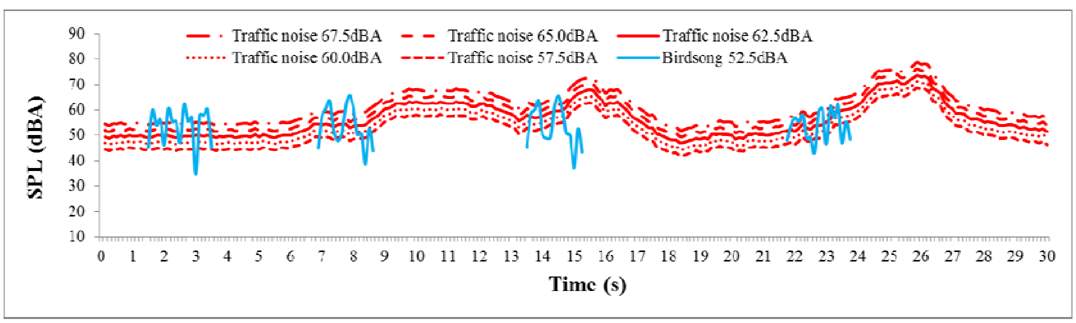
(b)

Figure. 4.5. The time histories of the acoustic stimuli in Group A. (a) Subgroup I includes five acoustic stimuli of merely car passing originally recorded at the distances of 1, 4, 9, 19 and 50m; (b) Subgroup II includes five acoustic stimuli composed by the same birdsong at 52.5dBA and the five sounds of car passing, respectively.

The aim of Group B that included 20 acoustic stimuli is to investigate how the loudness of masker influences the masking effects, of which the spectra are shown in Figure 4.4-b. Based on the pilot study of sound analysis, two sounds of bird chirping (8 s, 4 events) at 52.5 dBA (high) and 37.5 dBA (low) are combined with ten sounds of car passing at different sound pressure levels of 57.5, 60, 62.5, 65, and 67.5 dBA (loud traffic noise) and 42.5, 45, 47.5, 50, and 52.5 dBA (quiet traffic noise), respectively, as illustrated in Figure 4.6. Because 0-4.5 dBA at L_{Aeq} was suggested as the steps of sound pressure levels of traffic noise (Jeon, et al 2010; De Coensel et al, 2011), 2.5 dBA was used to represent the changes of masking effects within a sound level range of 10 dBA. However, unlike the precious studies, the sounds of car passing at lower sound levels were first included. The spectrum pattern of car passing as control parameter in this group are remained the same for each sound level range (see Figure 4.6). The bird chirping was designed to be audible for 8s in each stimulus.

Group C aims to elucidate the influence of occurrence frequency of birds chirping on the masking effects, as shown in Figure 4.7. Five audio clips of different occurrence frequencies of birds chirping (audible for 2 s each time), i.e., 2, 3, 4, 5 and 6 times, were combined with two audio clips of car passing at 62.5 (high) and 47.5 dBA (low) with the same spectrum pattern (see Figure 4.7). The occurrence frequency of cars passing was set as a constant value of 2. Ten acoustic stimuli are reproduced in total.

In Group D, the five acoustic stimuli used in the subgroup II of Group A (Figure 4.5-b) were played back with the pictures of the scenes taken at the points of sound recording, facing the road. Finally, forty-five 30 s acoustic stimuli dominated by the sound events of cars passing and birds chirping were reproduced.



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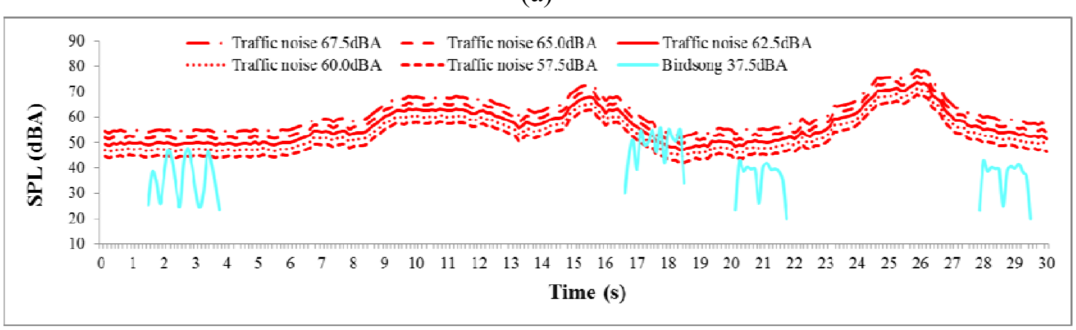

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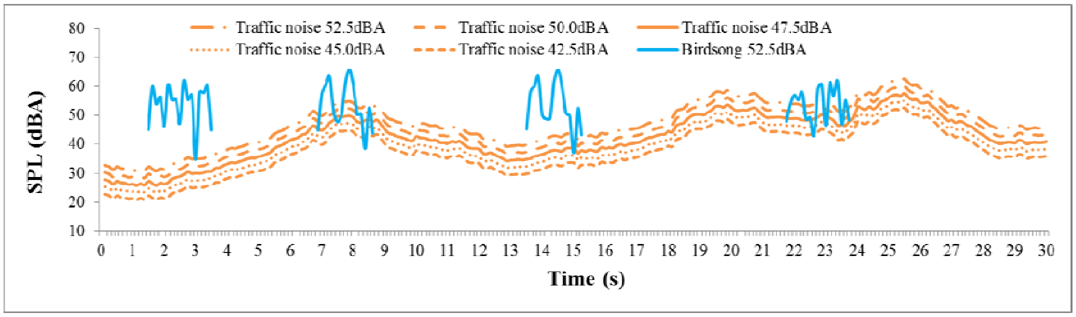

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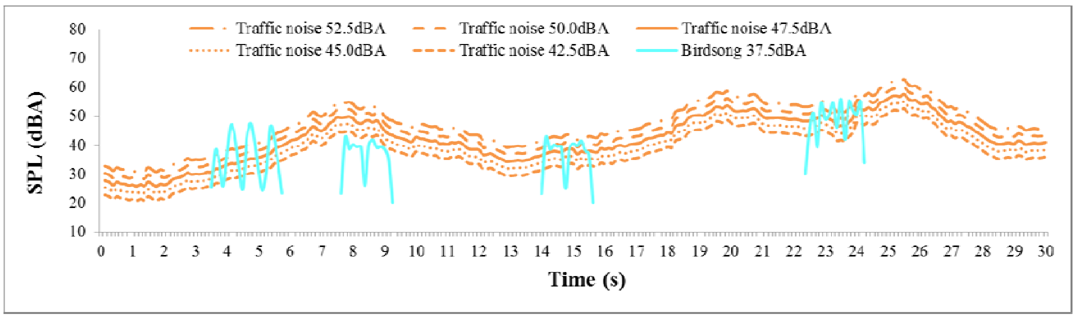
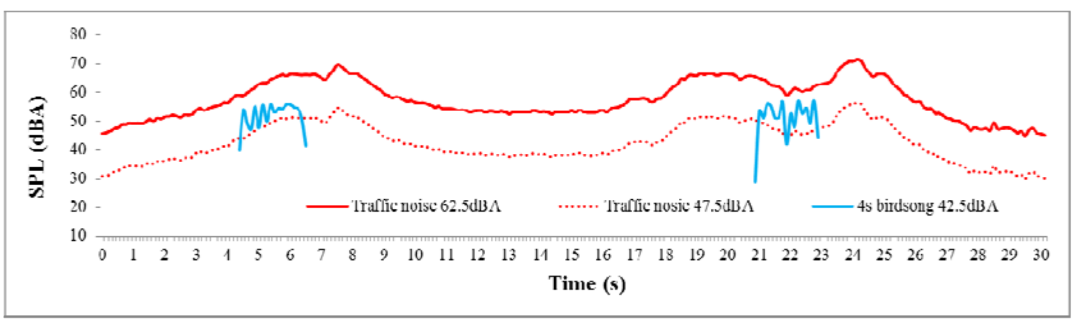


(d)

Figure. 4.6. Time histories of the acoustic stimuli used in Group B. Each subgroup includes five acoustic stimuli composed by the same birdsong and five different levels of car passing, respectively: (a) birdsong at 52.5 dBA and loud traffic; (b) birdsong at 37.5 dBA and loud traffic; (c) birdsong at 52.5 dBA and quiet traffic; (d) birdsong at 37.5 dBA and quiet traffic.



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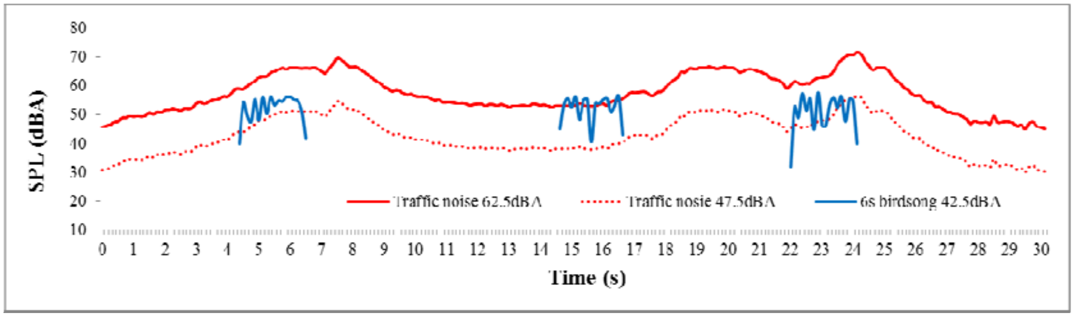

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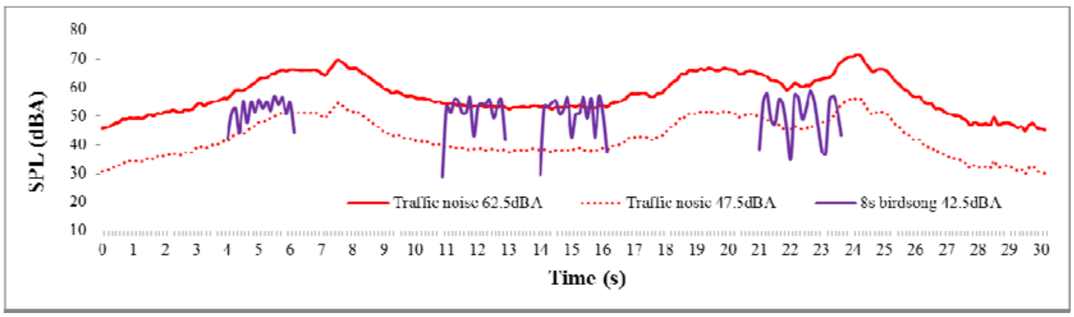

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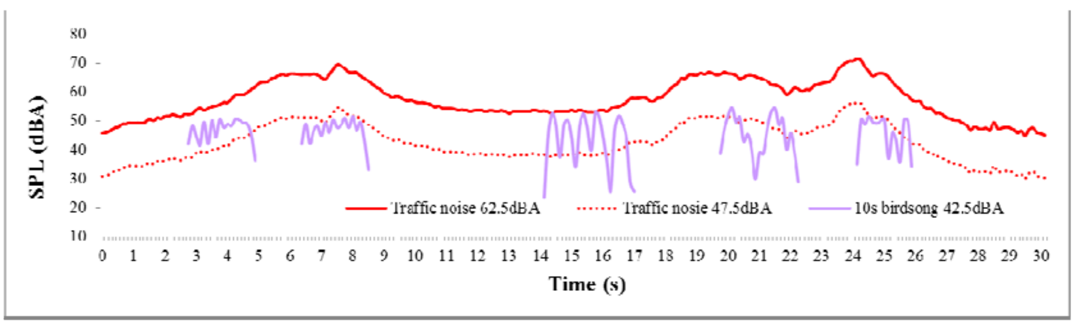

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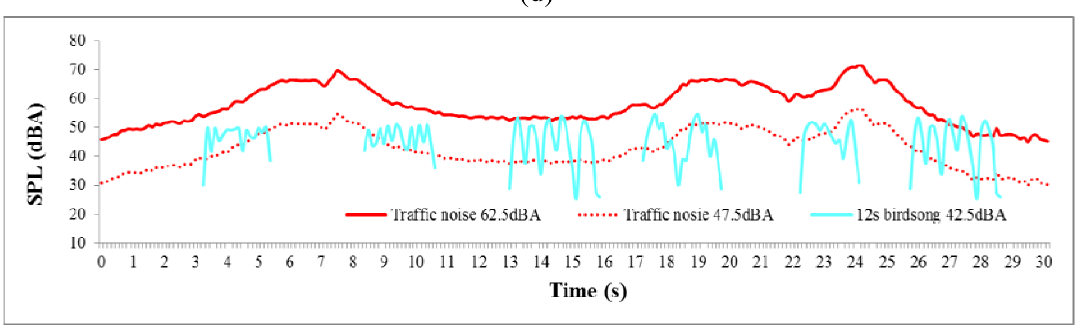


(e)

Figure. 4.7. The time histories of the acoustic stimuli in Group C. Each of the five occurrence frequencies of birdsong are combined with the two sounds of car passing at 62.5 and 47.5 dBA. (a) 2 times; (b) 3 times; (c) 4 times; (d) 5 times; (e) 6 times.

Additionally, twenty 30 s acoustic stimuli of daily-life urban sounds, including construction, aircraft, human voice, steps, winds through leaves, fountain, are used in the experiment to weaken the subjects' consciousness in the particular purpose of the experiment on traffic noise and birdsong. One acoustic stimulus was duplicated and added to the acoustic stimuli to test how much the order effect impacts the results.

4.2.4 Participants and evaluation procedure

Thirty subjects participated in the experiment, including 12 women and 16 men, aged18-35 years. The procedure is similar with that of the experiment in Chapter 3. The hearing threshold levels of all participants were tested using an audiometer for all frequencies (125, 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz). A 30 s audio was played to the 30 participants to test the capability of sound sources recognition. All the participants recognised and mentioned traffic noise and birdsong after listening. The audio clip includes traffic noise, birdsong, dog barking and human voice. Two-way mixed intra-class correlation (ICC) with 95% confidence interval was employed to test the consistency of the answers of all of the 30 participants.

The 66 acoustic stimuli were arranged in a random order and divided into 3 groups to provide breaks to avoid listener fatigue. The acoustic stimuli were played back in different sequences for the participants to decrease the order effects. The acoustic stimuli and the pictures were presented through headphones (Sennheiser HD 558) and a projector (Hitachi ED–X33), respectively. The calibration was carried out using a dummy head (Neumann KU100) before the experiment. The participants were seated in a chair comfortably in an anechoic chamber (See Figure 4.8). The background noise level was approximately 25.0 dBA.

Figure. 4.8. The anechoic chamber where the experiment were conducted.

The participants were required to score the sounds in terms of four adjectives describing the soundscape characteristics, including “Loud”, “Natural”, “Annoying” and “Pleasant”, on a scale of 0–10, with 0 representing “Not at all” and 10 “Extremely” (See the questionnaire in Appendix 1). The adjectives have been identified as the characteristics of soundscape quality in previous studies, and one of the most important characteristics is pleasantness (Jeon et al, 2010; De Coensel et al, 2011; Rådsten-Ekman et al, 2013). For the perceptual assessment of traffic noise, perceived annoyance is a rather crucial and frequently examined characteristic (Kang, 2007; Jeon et al, 2010; Di et al, 2012; Dick et al, 2011). Considering the significant roles of perceived loudness in the masking study (Nilsson et al, 2010; Bolin et al, 2010; De Coensel et al, 2011) and naturalness in human restoration (Ulrich et al, 1991; Kaplan, 1995; Gidlöf-Gunnarsson and Öhrström, 2007), the two characteristics were also included.

4.2.5 Data analysis

Normalisation of the responses was conducted prior to the data analysis to decrease the impacts of the differences in the ranges of the score used by the participants in the evaluation. The response variance of each participant was normalised according the equation employed in the previous study (Hong and Jeon, 2013). To test the consent of the subjects on the evaluation of soundscape, the analysis of two-way mixed intra-class correlation (ICC) with 95% confidence interval was employed. The average intra-class correlation coefficients of Perceived Loudness, Naturalness, Annoyance and Pleasantness were 0.969, 0.946, 0.962 and 0.872, which indicates high agreement in the judgements of the four characteristics. The average intra-class correlation coefficients of Pleasantness are lower than that of the other three characteristics, indicating that the participants have a lower degree of consistency on Pleasantness.

A one-way analysis of variance (ANOVA) was conducted to examine the statistically significant mean difference in terms of the scores of the four characteristics among the audios. A *post hoc* comparison was further used to examine the differences between each two of the acoustic stimuli. The result of the *post hoc* comparison shows no significant differences when the one acoustic stimuli played in different orders, which indicates the order effect has little influence on the evaluation in this study.

4.3 Results

4.3.1 Effects of traffic noise spectrum on masking

Five acoustic stimuli of traffic noise at the distances of 1, 4, 9, 19 and 50 m from the road (at 69.8, 65.3, 62.3, 56.0 and 47.0 dBA) without and with birdsong at 52.5 dBA (see Figure 4.5) were investigated to determine how the spectrum of noise influenced the masking effects (see Figure 4.9). The ANOVA shows the statistically significant mean differences among the ten acoustic stimuli in Perceived Loudness [F (9, 290) = 95.19, p = 0.000], Naturalness [F (9, 290) = 69.75, p = 0.000], Annoyance [F (9, 290) = 51.59, p = 0.000] and Pleasantness [F (9, 290) = 42.68, p =0.000]. It has been demonstrated that adding birdsong can indeed alter the soundscape characteristics of the road traffic noise environment. Figure 4.9 illustrates the mean values of the four characteristics of traffic noise environment at the five distances from the road without birdsong and with birdsong at 52.5 dBA. The results of the *post hoc* comparisons reveal that none of the five stimuli has significant differences ($p < 0.05$) in Perceived Loudness when adding birdsong, but all have significant differences in Naturalness. As shown in Figure 4.9-a, Perceived Loudness of the traffic noise environment is similar with and without birdsong, with a maximum mean value difference of 1.2 at 50 m. However, Naturalness is largely increased when birdsong is added, especially when the traffic noise fluctuates less and becomes quieter at 19 and 50 m (see Figure 4.5). For example, with birdsong, Naturalness increases by 3.2 at 19 m and 3.9 at 50 m (see Figure 4.9-b). Therefore, birdsong can be considered an important sound mark of naturalness in the urban sound environment. For Annoyance and Pleasantness, the significant differences between with and without birdsong happen only at the distances of 19m and 50m. With birdsong, Annoyance of the traffic noise environment decreases by 1 at 19 m and 2.3 at 50 m, as shown in Figure 4.9-c. It can be also seen that adding birdsong is not useful for reduction of Annoyance when the perceivers are rather close to the traffic, e.g., at 1 m and 4 m (Figure 4.9-c). Similar to Annoyance, Pleasantness can be significantly increased by adding birdsong when the distance is further than 19m (Figure 4.9-d). At a distance of 50 m, Pleasantness of the traffic noise environment is only 1.9, while it increases to 5.5 when birdsong is mixed (Figure 4.9-d).

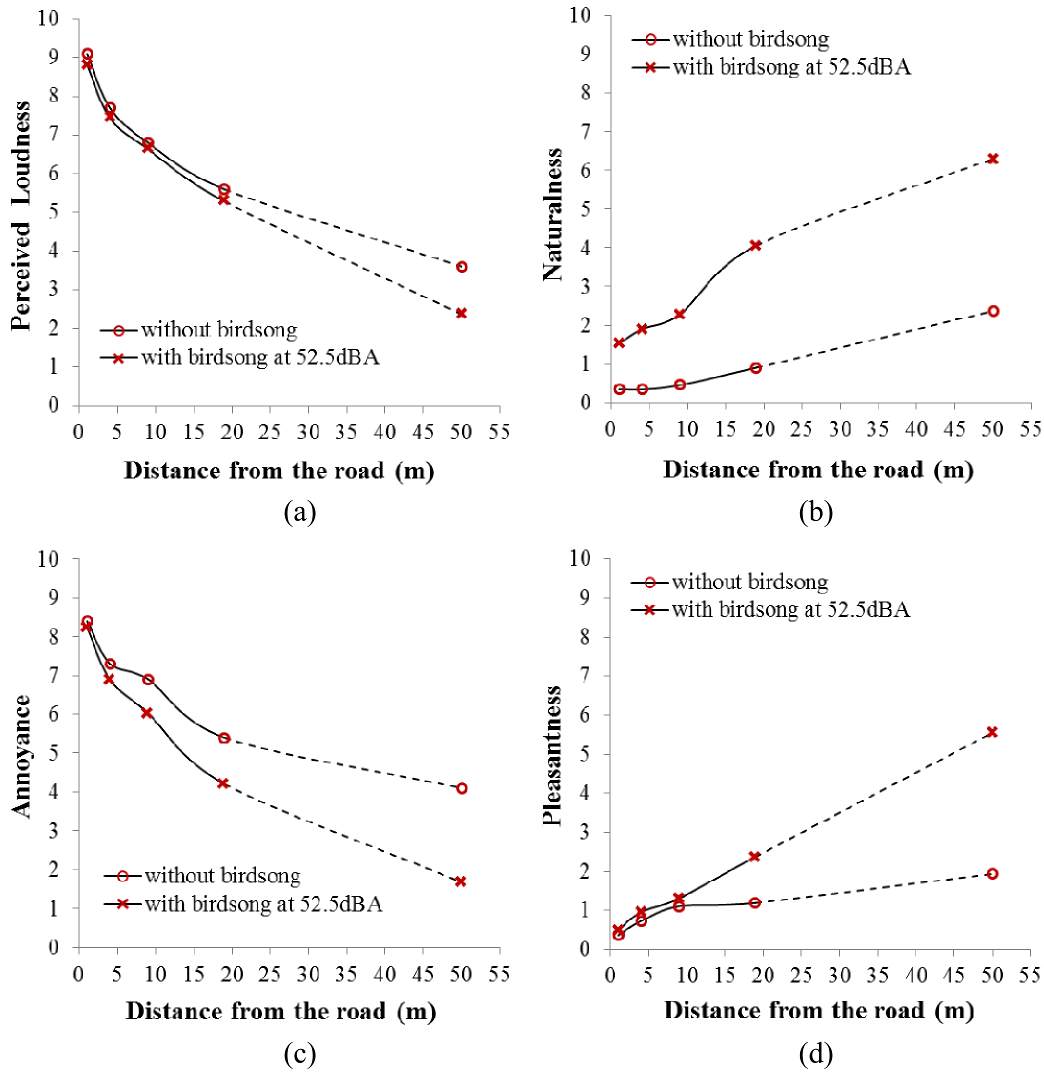
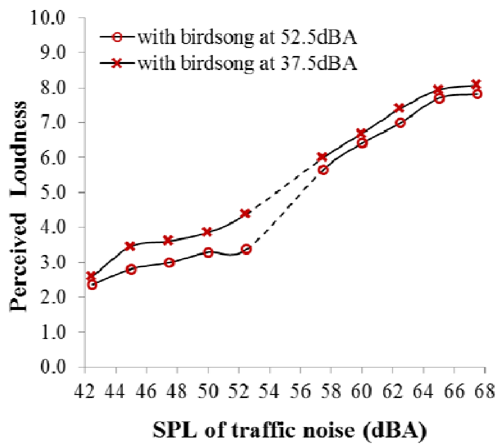


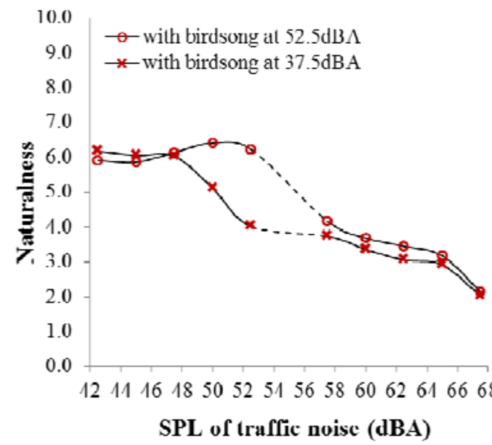
Figure. 4.9. The mean values of the psychological evaluation on the four characteristics of the traffic noise environments at distances of 1, 4, 9, 19 and 50 m from the road without birdsong and with birdsong at 52.5 dBA. (a) Perceived Loudness; (b) Naturalness; (c) Annoyance; (d) Pleasantness.

4.3.2 Effects of birdsong loudness on masking

Figure 4.10 shows the mean scores of the psychological evaluation on the four soundscape characteristics of traffic noise environments with birdsong at 52.5 and 37.5 dBA. In each of the four graphs, the results of the relatively quiet traffic noise environment (i.e., 42.5-52.5 dBA) are presented on the left and those of relatively loud traffic noise environment (i.e. 57.5-67.5 dBA) on the right. It can be seen in Figure 4.10 that, in general, under the two conditions of birdsong at 52.5 and 37.5 dBA, the differences of the scores become larger with the increase of the loudness of traffic noise from 42.5 dBA, and then become smaller with the increase of the loudness after it reaches 52.5 dBA.



(a)



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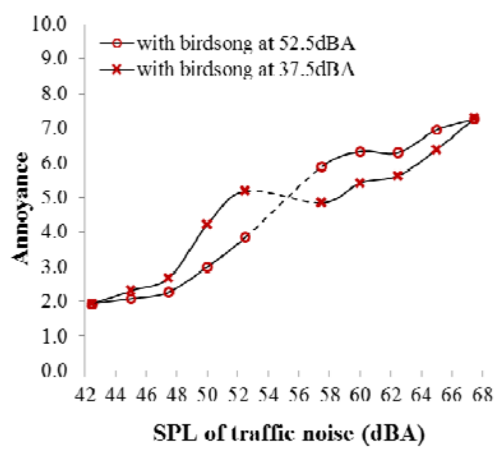

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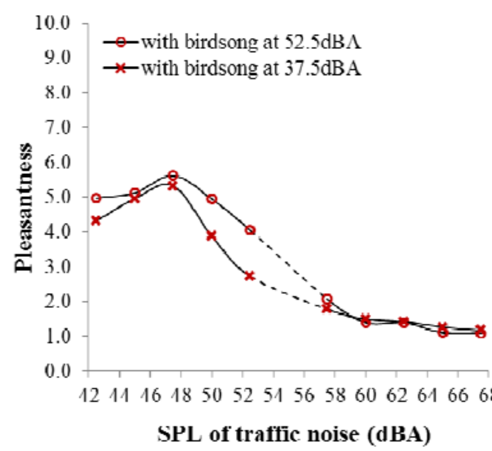


(d)

Figure. 4.10. The mean values of the psychological evaluation on the four characteristics of the traffic noise environments with birdsong at 52.5 and 37.5 dBA. (a) Perceived Loudness; (b) Naturalness; (c) Annoyance; (d) Pleasantness.

It appears that compared with the quiet traffic noise environment, the birdsong loudness has little influence on the evaluation of the four characteristics in the loud traffic environment. The detailed analysis results on the effects of birdsong loudness in the both quiet and loud traffic noise environments will be further separately discussed below in the Sections of 4.3.2.1 and 4.3.2.2.

4.3.2.1 Quiet traffic noise environment

To further explore the effects of masker loudness on masking when the noise is relatively *quiet*, five acoustic stimuli of *quiet* traffic noise (42.5, 45.0, 47.5, 50.0 and 52.5 dBA) were combined with birdsong at 52.5 and 37.5 dBA in Group B (see Figure 4.6-a&b). The signal-to-noise ratios (SNR) with the 52.5 dBA birdsong are 10, 7.5, 5, 2.5 and 0 dBA. The SNRs with the 37.5 dBA birdsong are -5, -7.5, -10, -12.5 and -15 dBA. The ANOVA shows the significant mean differences among the ten acoustic stimuli in Perceived Loudness [$F(9, 290) = 4.51$, $p = 0.000$], Naturalness [$F(9, 290) = 5.88$, $p = 0.000$], Annoyance [$F(9, 290) = 5.37$, $p = 0.000$] and Pleasantness [$F(9, 290) = 10.48$, $p = 0.000$].

Figure 4.10 illustrate the mean values of the four characteristics of traffic noise environment with birdsong at different loudness. To find out whether significant differences in the masking effects exist between 52.5 dBA birdsong and 37.5 dBA birdsong, *post hoc* comparisons were conducted, of which the results reveal that the five acoustic stimuli of quiet traffic noise are not significantly different in Perceived Loudness ($p > 0.05$), which indicates that when the traffic noise is relatively quiet, less than 52.5 dBA, louder birdsong cannot enhance the masking effects in Perceived Loudness. However, in the *post hoc* comparisons, the five acoustic stimuli are significantly different in Naturalness, Annoyance and Pleasantness when the sound pressure levels of traffic are 50.0 and 52.5 dBA, which indicates that when the traffic noise become louder, loudness of birdsong have more significant influence on Naturalness, Annoyance and Pleasantness

As shown in Figure 4.10-b, with 52.5 dBA birdsong, Naturalness hardly changes when the traffic noise becomes louder, but with 37.5 dBA birdsong, Naturalness decreases sharply when the traffic noise is louder than 47.5 dBA. Annoyance of the traffic noise is significantly higher with 37.5 dBA birdsong than with 52.5 dBA birdsong when the traffic noise is louder than 50 dBA. For example, Annoyance is 5.2 with 37.5 dBA birdsong and 3.9 with 37.5 dBA birdsong when the traffic noise is 52.5dBA (see Figure 4.10-c). Pleasantness increases slightly and then decreases significantly after 47.5 dBA, with either 37.5 or 52.5 dBA birdsong, and it is always higher when birdsong is louder (see Figure 4.10-d). The increase of Pleasantness before 47.5 dBA might be caused by the failure in sound source recognition when the traffic noise is too low.

In conclusion, the masking effects of louder birdsong are more effective when the traffic noise environment is relatively quiet. It is also important to note that no matter how loud the masker is, Annoyance of the traffic noise environment increases sharply and Pleasantness decreases sharply when the traffic noise is louder than 47.5 dBA (see Figure 4.10-c-d). Therefore, attenuation of the traffic noise level is essential for the improvement of soundscape quality.

4.3.2.2 Loud traffic noise environment

To further explore the effects of masker loudness on masking when noise is *loud*, five acoustic stimuli of *quiet* traffic noise (57.5, 60.0, 62.5, 65.0 and 67.5 dBA) were combined with birdsong at 52.5 and 37.5dBA in Group B (see Figure 4.6-c&d). The SNRs with 52.5dBA birdsong are -5, -7.5, -10, -12.5 and -15. The SNR with 37.5dBA birdsong are -20, -22.5, -25, -27.5 and -30. The ANOVA shows the significant mean differences among the ten acoustic stimuli in Perceived Loudness [$F(9, 290) = 14.50$, $p = 0.000$], Naturalness [$F(9, 290) = 8.57$, $p = 0.000$], Annoyance [$F(9, 290) = 14.65$, $p = 0.000$] and Pleasantness [$F(9, 290) = 2.369$, $p = 0.013$].

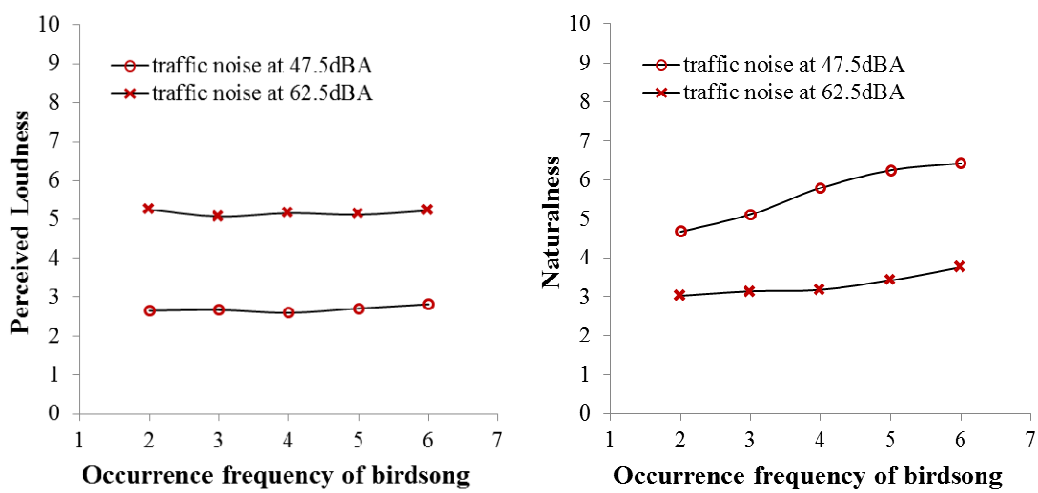
For all the four characteristics, the five acoustic stimuli have no significant differences between with 52.5 and 37.5 dBA birdsong in the *post hoc* comparisons, and as shown in Figure 4.10, the mean values are rather similar between the two sound pressure levels of birdsong, which indicates birdsong loudness hardly influence the masking effects when the traffic noise is loud (louder than 57.5 dBA). It is interesting to note that the mean values of traffic noise are higher with birdsong at 52.5 dBA than at 37.5 dBA in Annoyance when the traffic noise is loud.

Moreover, to find out the relationships among the four characteristics, a two-tailed Bivariate Analysis and linear regressions between each pair of characteristics were conducted with the mean values in Figure 4.10. The results show that Annoyance has a significant positive relationship with Perceived Loudness ($p<0.01$, $R^2 = 0.904$) and a negative relationship with Naturalness ($p<0.01$, $R^2 = 0.883$), while Pleasantness has a significant negative relationship with Perceived Loudness ($p<0.01$, $R^2 = 0.905$) and a positive relationship with Naturalness ($p<0.01$, $R^2 = 0.905$), which indicates for the traffic noise environment, in general, either decreasing Perceived Loudness or increasing Naturalness can reduce Annoyance and increase Pleasantness.

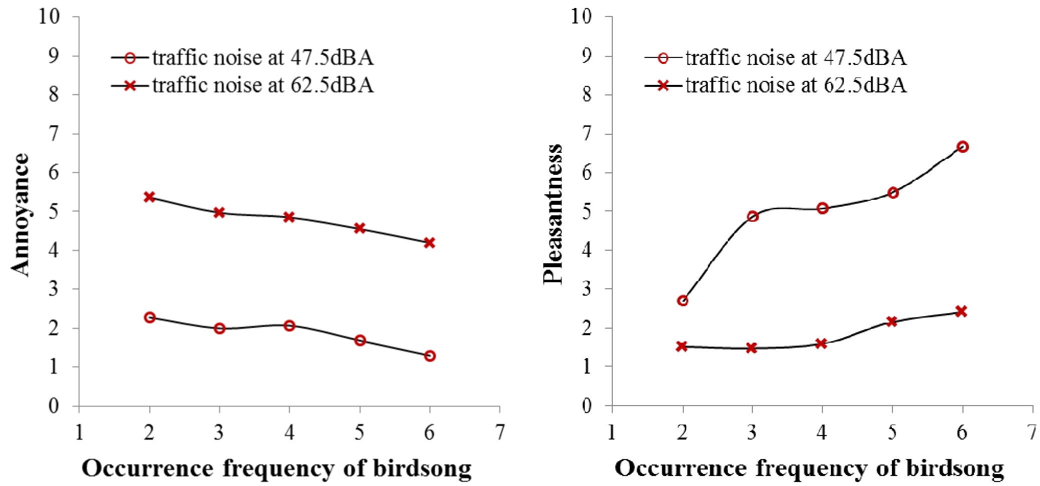
4.3.3 Effects of occurrence frequencies of birdsong on masking

Figure 4.11 shows the mean scores of the psychological evaluation on the four soundscape characteristics of traffic noise environments with a set of occurrence frequencies of birdsong. In each of the four graphs, the results of the relatively quiet traffic noise environment (i.e., 47.5 dBA) and loud traffic noise environment (i.e., 62.5 dBA) are presented. It can be seen in Figure 4.11 that, generally, compared with the quiet traffic noise environment, the occurrence frequencies of birdsong seem to have less influence on the masking effects.

The detailed analysis results on the effects of occurrence frequencies of birdsong in both the quiet and loud traffic noise environments will be further separately discussed separately below in the Sections of 4.3.3.1 and 4.3.3.2.



(a) (b)



(c) (d)

Figure. 4.11. The mean values of the psychological evaluation on the four characteristics of the traffic noise environments with a set of occurrence frequencies of birdsong (2, 3, 4, 5 and 6 times). (a) Perceived Loudness; (b) Naturalness; (c) Annoyance; (d) Pleasantness.

4.3.3.1 Quiet traffic noise environment

To further study the effects of occurrence frequencies of masker on masking when the noise is relatively *quiet*, five acoustic stimuli of birdsong (2, 3, 4, 5 and 6 times) at 42.5 dBA combined with traffic noise at 47.5 dBA in Group C (see Figure 4.7) were examined. The ANOVA shows significant differences in the masking effects among the five acoustic stimuli in Naturalness [F (4, 145) = 7.17, p = 0.000], Annoyance [F (4, 145) = 2.52, p = 0.044] and Pleasantness [F (4, 145) = 23.36, p =0.000], but not for Perceived Loudness (p = 0.587), which indicates that the occurrence frequency of birdsong indeed influences the masking effects in terms of the soundscape characteristics, excluding Perceived Loudness. Figure 4.11 shows mean values of the four characteristics of traffic noise environment with a set of occurrence frequencies of birdsong, i.e. 2, 3, 4, 5 and 6 times. It can be seen in Figure 4.11 that when the occurrence frequency increases from 2 to 6 times, Naturalness increases constantly from 4.7 to 6.4 (Figure 4.11-b), Annoyance slightly decreases from 2.3 to 1.3 (Figure 4.11-c), and Pleasantness significantly increases from 2.7 to 6.7 (Figure 4.11-d). Compared with Naturalness and Annoyance, the occurrence frequency of birdsong plays a more important role on Pleasantness. It is interesting to note that when the occurrence frequency increase from 2 to 3, Pleasantness increases sharply from 2.7 to 4.9 (see Figure 4.11-d), of which the reason might be that 3 times the amount of birdsong is necessary to make the birdsong much more noticeable.

4.3.3.2 Loud traffic noise environment

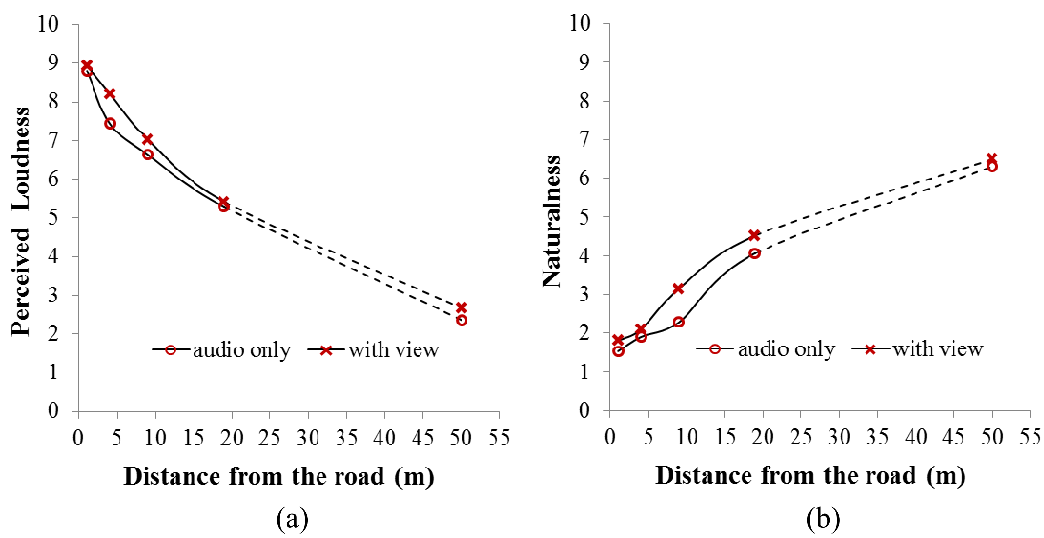
Five acoustic stimuli of birdsong (2, 3, 4, 5 and 6 times) combined with *loud* traffic noise at 62.5dBA in Group C (see Figure 4.7) were also examined. The ANOVA only shows the significant mean differences among the five acoustic stimuli in Pleasantness [F (4, 145) = 2.91, p =0.024], but the differences between the occurrence frequencies are small, with a maximum value of 0.9 between 2 and 6 times (see Figure 4.11-d). Therefore, when the traffic noise is loud, the masking effects are little influenced by the occurrence frequency of birdsong.

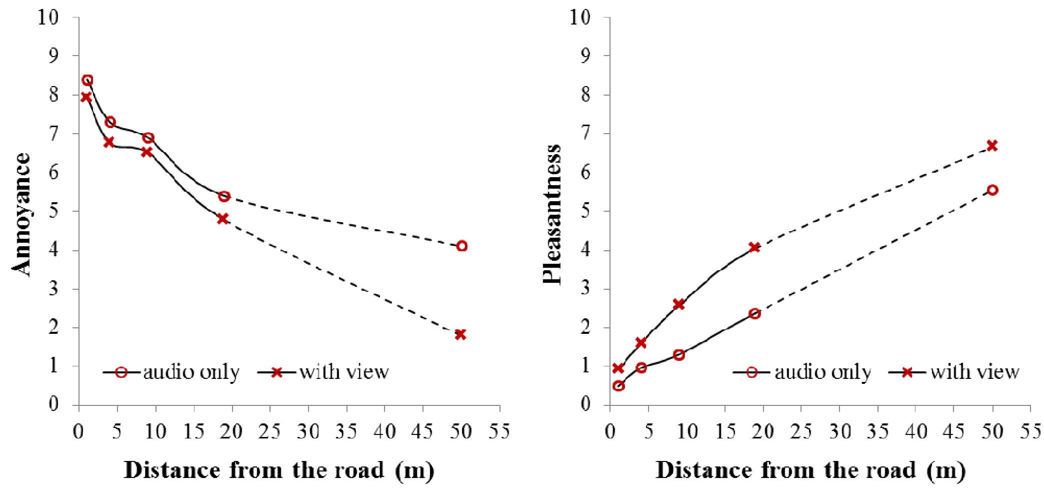
4.3.4 Effects of visibility of sound sources on masking

To initially investigate the effects of visibility of sound source on masking, five acoustic stimuli of traffic noise and birdsong in Group A (see Figure 4.5-b) were played *with* and *without* the pictures of in-situ scenes. The ANOVA shows the significant mean differences among the ten stimuli in Perceived Loudness [F (9, 290) = 112.98, p = 0.000], Naturalness [F (9, 290) = 40.84, p = 0.000], Annoyance [F (9, 290) = 70.44, p = 0.000] and Pleasantness [F (9, 290) = 45.03, p =0.000]. In *post hoc* comparisons, only Pleasantness of the traffic noise at distances of 9, 19 and 50m and Annoyance at 50m have significant differences between with and without views ($p < 0.05$).

Figure 4.12 illustrates the mean values of the four characteristics of traffic noise and birdsong environment at 1, 4, 9, 19 and 50 m with and without the pictures of in-situ scenes being played. As shown in Figure 4.12, at the distance of 50m from the road, when the in-situ view was played, Annoyance is largely reduced from 4.1 to 1.8. Pleasantness is the characteristic that is most influenced by visibility of the sound sources, with decreases of 1.3 at the distance of 9 m, 1.6 at 19 m and 1.2 at 50 m (see Figure 4.12). In general, it can be proved that the visibility of sound sources does have effects on masking effects mainly in terms of subjective feelings, i.e., Annoyance and Pleasantness, rather than objective measurements, i.e., Perceived Loudness and Naturalness.

To conclude, it appears that when the perceivers are further to the sound sources, their evaluation on Annoyance and Pleasantness is more influenced by the visibility of sound sources, of which the reason might be the increased spatial awareness (Augoyard and Torgue, 2005) by adding visual information.





(c) (d)

Figure. 4.12. The mean values of the psychological evaluation on the four characteristics of the traffic noise and birdsong environments at 1, 4, 9, 19 and 50 m from the road with and without presentation of the pictures of in-situ scenes. (a) Perceived Loudness; (b) Naturalness; (c) Annoyance; (d) Pleasantness.

4.4 Conclusions

The chapter aims to explore the impacts of the three factors, including the acoustic features (i.e. spectra of traffic noise and loudness of birdsong), occurrence frequencies of birdsong, and visibility of sound sources, using the psychological listening experiments The results of the study can be used for the assessment of the traffic noise environment with masking effects by birdsong, and also optimum design of soundscape in the context of landscape of roads and woods.

The masking effects of birdsong on traffic noise indeed exist, and the effects significantly increase when the traffic noise becomes less fluctuate and quieter. When adding birdsong, Perceived Loudness of traffic noise environments does not change, but Naturalness is largely enhanced, which can be also demonstrated by the responses of Q2 in the interview in Appendix 2. Only when the perceiver is far from traffic, e.g. further than 19m, Annoyance of traffic noise can be significantly reduced and Pleasantness increased with masking effects of birdsong.

Louder birdsong (52.5 dBA) has more significant masking effects than quieter birdsong (37.5 dBA) in terms of Naturalness, Annoyance and Pleasantness, rather than Perceived Loudness. The masking effects of birdsong are more efficient when the traffic noise environment is relatively quiet (lower than 52.5 dBA). No matter how loud the masker is, Annoyance of the traffic noise environment increases and Pleasantness decreases sharply when the traffic noise is louder than 47.5 dBA. An increase of the sound pressure level of birdsong does not decrease, but Annoyance increases when the traffic noise is loud (higher than 57.5 dBA). Therefore, attenuation of the traffic noise level is essential for the improvement of soundscape quality.

Occurrence frequency of birdsong, similar to birdsong loudness, influences the masking effects in terms of the soundscape characteristics, excluding Perceived Loudness. In relatively quiet traffic noise environments (lower than 52.5dBA), when the occurrence frequency increases from 2 to 6 times, Naturalness increases constantly from 4.7 to 6.4, Annoyance slightly decreases from 2.3 to 1.3, and Pleasantness increases significantly from 2.7 to 6.7. Compared with Naturalness and Annoyance, the occurrence frequency of birdsong plays a more important role on Pleasantness. When the traffic noise is loud, the occurrence frequency of birdsong has little influence on the masking effects.

Visibility of sound sources has an impact on masking effects of birdsong, but not as significantly as the other three factors. Only Pleasantness of the traffic noise at distances of 9, 19 and 50 m and Annoyance at 50 m are influenced by the presentation of visibility of in-situ scenes.

The relationships among the four soundscape characteristics were also examined with the scores of the evaluation on them. Annoyance has a significant positive relationship with Perceived Loudness and a negative relationship with Naturalness, while Pleasantness has a significant negative relationship with Perceived Loudness and a positive relationship with Naturalness, which indicates for the traffic noise environment, in general, either decreasing Perceived Loudness or increasing Naturalness, can reduce Annoyance and increase Pleasantness.

CHAPATER 5

TRAFFIC NOISE ATTENUATION IN THE CONTEXT OF URBAN MORPHOLOGY

According to the results of psychological experiments in Chapter 3 and 4, attenuation of traffic noise can significantly reduce annoyance and benefit masking effects of birdsong efficiently, which is essential for improvement of soundscape quality. Therefore, this chapter aims to explore whether and how urban morphology influences the capability of a residential area on attenuating traffic noise level. Particular attention is paid to low-density residential areas. Seven urban morphological parameters that are accessible and commonly used in urban design and planning are selected. Noise mapping techniques have been employed; and a MATLAB program has been developed to obtain the spatial noise level indices, L_n. which is calculated using sound levels at grid points on a noise map. The relationships between urban morphological parameters, the spatial noise level attenuation and the size of noisy areas have then been revealed.

5.1 Introduction

Sound environment plays a significant role on human restoration, affection and physical and psychological health (Passchier-Vermeer and Passchier; 2000; Gidlöf-Gunnarsson and Öhrström; 2007; Sobotova et al, 2010). However, in urbanised areas, studies show that noise is one of the most frequently mentioned stressors of what people like and dislike in their neighbourhood and community (Bell et al, 1996); noise intrudes on a variety of human activities (Passchier-Vermeer and Passchier; 2000). The Directive 2002/49 of the European Parliament (END) emphasized preservation and protection of 'quiet areas' in the assessments and managements of environmental noise (European Commission, 2002). Sound level (L_{day}) of 40 to 45 dBA for moderately sensitive areas and 45 to 50 dBA for areas for outdoor activities have been proposed as noise limits for urban quiet areas by the Working Group on Assessment of Exposure to Noise and Working Group on Health and Socio-Economic Aspects (2004). Among various urban noise sources, traffic noise is one "cacophony" of urban sound (Ko et al, 2011) that attracts considerable notice. In the European Union, it is estimated that 170 million individuals are exposed to traffic noise at levels between 55-65 dBA, and approximately 80 million citizens are exposed to constant day-time outdoor transport noise of levels above 65 dBA (European Commission, 1996). In particular, inhabitants of residential areas are generally aggravated by traffic noise during times of relaxation, sleep and recuperation (Brown and Muhar, 2004; Di et al, 2012).

To reduce the nuisance of urban traffic noise, solutions have been suggested, including designing quieter vehicles, improving road surfaces (Sandberg and Ejsmont, 2002), designing environmental noise barriers (Joynt and Kang, 2010; Van Renterghem and Botteldooren, 2012; Maffei et al, 2013; Joynt and Kang, 2003) and designing buildings with higher capability of noise reduction, e.g., building façade improvement and the use of green roofing (Kim and Kim, 2007; Van Renterghem and Botteldooren, 2009; H.S. Yang and Kang, 2012). Particular attention has recently been given to soundscape approaches with an emphasis on human perception. Emphasis concerning the tranquillity and pleasantness of environmental sound with multiple sound sources beyond the control of noise (Brambilla and Maffei, 2010), reducing traffic noise levels and enlarging quiet area are still essential for the improvement of the quality of soundscape, both inside and outside in urban open public and private spaces (Nilsson and Berglund, 2006).

As mentioned in Section 2.4, urban morphology has been referred in the studies on traffic noise propagation. For example, Kang compared the attenuation of broadband sound among different street patterns with particular reference to detached houses, semi-detached houses and terraced houses, respectively (Kang, 2007). Raydan and Steemers indicated that buildings could act as sound barriers to induce quiet sides of residential areas in traffic noise environments; however, the research on traffic noise attenuation through various urban forms has been limited (Raydan and Steemers, 2006). Salomons and Pont (2012) proved that on a citywide scale, the spatial distribution of traffic noise is related to traffic volume, building density and general urban form, by means of numerical calculation of Amsterdam and Rotterdam, as well as from conceptual urban fabrics. Different aspects of urban environment have been widely studied about urban settings. However, research has been limited regarding how to improve the resistance to traffic noise in residential areas by systematically controlling a set of urban morphological parameters, especially at a mesoscale area with groups of buildings, crucial for practical zoning plan.

Therefore, three main research questions are addressed in this chapter as follows: How does traffic noise spatially distribute on façades and in open areas in existing urban morphologies? How can planners enhance the capability of noise attenuation on façades by controlling urban morphological parameters? How can planners also enhance the capability of noise attenuation in open areas and enlarge quiet areas by controlling urban morphological parameters? This paper first presents a method of studying the relationships between traffic noise resistance and urban morphology, using low-density residential areas as case study areas. A set of quantitative urban morphological parameters commonly used or accessible in urban design and planning are also considered. Furthermore, this study discusses the results of the above research questions. Finally, a number of linear regression models are derived to indicate the relationship between traffic noise attenuation and the various parameters.

5.2 Methods

5.2.1 GIS database and grid sampling

The study sites were selected in Assen, the capital of the province of Drenthe, because it is the fastest-growing city in the north of the Netherlands in Europe. This city has seen an increase of approximately 5,000 residences every ten years from 1960 to 2009 (Assen Municipality, 2011), bringing about very diverse low-density residential zoning plans. By 2011, the district population density had varied from about 500 to over 4,400 persons/km^2 (Assen Municipality, 2011). Figure 5.1 shows the terrain, building and traffic network of Assen (Kadaster, 2004). To the west of the city is a motorway; a hierarchical traffic network that connects the motorway covers the entire city (see Figure 5.1-b), generating widespread traffic noise. Generally speaking, Assen can be regarded as a typical European low-density city which has different urban morphological and traffic characteristics.

A GIS database of 763 grids (each 250m x 250m) of the populated areas of Assen, each with unique identification, was established in terms of the factors that may influence sound environment. These factors include housing density, population density, land use, and acoustic features (e.g., main road). According to the analysis results, approximately 30% of the grids are for residential use, and 17% of the grids are for mixed-use (i.e., residential and commercial usage). Given that the main aim of this study is to compare the traffic noise resistance of different urban morphologies of residential areas, 65 grids, which have the land use type of residential and mixed-use land, and also main roads with similar traffic volume defined by Assen local zoning plan, were then randomly sampled from the database to obtain the representative characteristics of the general residential morphologies. In total, 20 grids were selected for analysis, as can be seen in Figure 5.1-a.

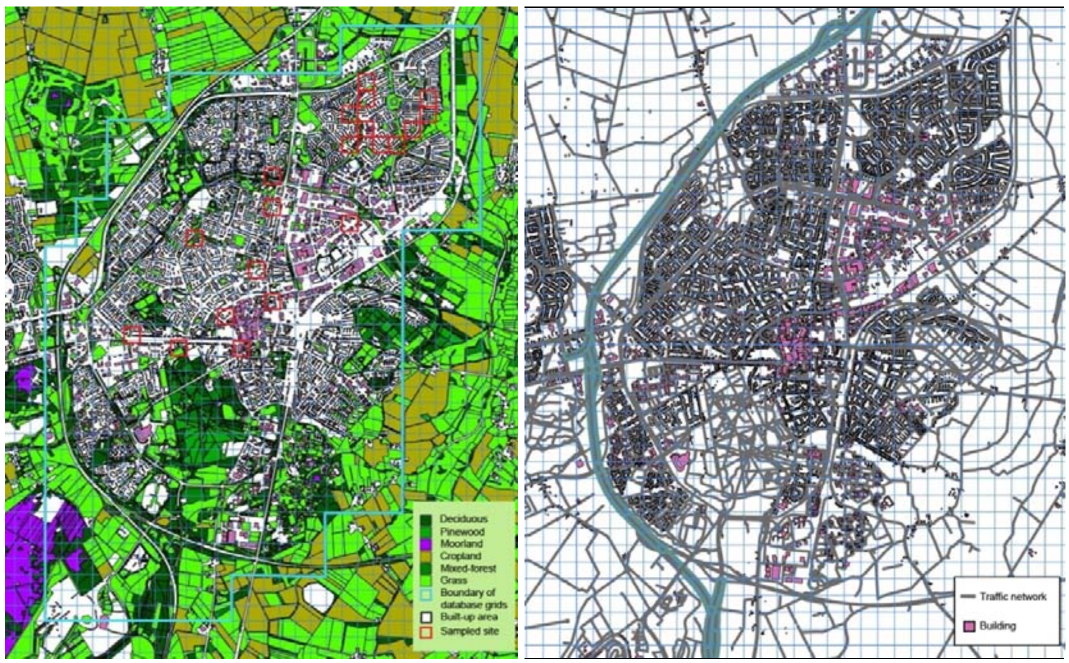


Figure. 0.1. GIS information of Assen from TOP10NL of Kadaster (Kadaster, 2004). (a) Terrain and locations of the sampled grids; (b) Building and traffic network.

5.2.2 Selection and calculation of urban morphological parameters

A number of quantitative urban morphological parameters have been explored, developed and studied from the perspectives of environmental performance, landscape, land use, atmospheric and wind environment (Adolphe, 2001; Esbah, 2009; Ng, 2011; Van de Voorde et al, 2011) to make the diverse urban urban morphology quantitatively comparable. The urban morphological parameters include those likely related to traffic noise resistance based on the potential effects of urban morphology on outdoor sound propagation, such as distance and ground effects, the barrier effect and the canyon effect. Accordingly, seven quantitative parameters were defined, including the following: the Building Plan Area Fraction, the Road Area Fraction, the Distance of the First-row Building to Road, the Complete Aspect Ratio, the Building Surface Area to Plan Area Ratio, the Building Frontal Area Index, and the Height-to-Width Ratio. The first three parameters chiefly concern the 2D characteristics of urban morphology; the last four parameters concern the 3D characteristics. The calculations of these parameters are shown in Table 5.1. It is noted that the Height-to-Width Ratio (i.e., the street aspect ratio) is calculated by dividing the average height by the distance between two buildings (Burian et al, 2005). In this study, assuming an idea situation, sites with multiple buildings utilize the value of an average Height-to-Width Ratio as calculated by the average building height divided by the average width between buildings (Grimmond and Oke, 1999).

Table 0.1. Calculations of the seven urban morphological parameters.

Parameter	Definition	Formula	Notes
Building Plan Area Fraction (*BPAF*)	The ratio of the plan area of buildings to the total surface area of the study region	$BPAF = \frac{A_p}{A_T}$	A_p is the plan area of buildings at ground level and A_T is the total plan area of the region of interest. Floor Area Ratio is roughly estimated as 2-2.5 times of *BPAF* in this study.
Road Area Fraction (*RAF*)	The ratio of the plan area of roads (A_R) to the total surface area of the study region (A_T)	$RAF = \frac{A_R}{A_T}$	A_R is the plan area of roads at ground level.
Distance of the First-row Building to Road (DFBR)	The mean of the distances from the frontal façades of the first-row buildings to the road	$DFBR = \frac{1}{n}\sum_{i=1}^{n} d_i$	n is the total number of first-row buildings, and d_i is the distance from the first-row building to the road.
Complete Aspect Ratio (*CAR*)	The summed area of roughness elements and exposed ground divided by the total surface area of the study region (Voogt and Oke 1997)	$CAR = \frac{A_C}{A_T} = \frac{A_W + A_r + A_G}{A_T}$	A_C is the combined surface area of the buildings and exposed ground, A_W is the wall surface area, A_r is the roof area, A_G is the area of exposed ground (Burian et al, 2005).

Building Surface Area to Plan Area Ratio (*BSAPAR*)	The sum of building surface area divided by the total surface area of the study region	$BSAPAR = \frac{A_r + A_W}{A_T}$	A_r is the plan area of rooftops, A_W is the total area of non-horizontal roughness element surfaces (e.g. walls) (Burian et al, 2005).
Building Frontal Area Index (*BFAI*)	The total area of the façade areas parallel with the road direction (A_{para}) divided by the total surface area of the study region	$BFAI(\theta) = \frac{A_{para}}{A_T}$	θ is the road direction.
Height-to-Width Ratio (*HWR*)	The average of the building heights (H_{avg}) is divided by the average of the horizontal distances between two adjacent buildings on the direction vertical to the road direction (S_{avg}) in the whole study region	$HWR(\theta) = \frac{H_{avg}}{S_{avg}}$	θ is the road direction.

Because the residential area in Assen is mostly covered by low-rise terraced and detached buildings, with a ratio of more than 70% in total residential buildings (Assen Municipality, 2011), the building height was assumed as 8 meters (2-2.5 floors) in the simulation. Figure 5.2 shows the range of calculated urban morphological parameters of the study sites, where it can be seen that the Building Plan Area Fraction varies from 0.13 to 0.38; Road Area Fraction from 0.03 to 0.12; Distance of the First-row Building to Road from 10.3m to 84.3m; Complete Aspect Ratio from 1.17 to 1.53; Building Surface Area to Plan Area Ratio from 0.36 to 0.88; Building Frontal Area Index from 0.04 to 0.14; and Height-to-Width Ratio from 0.12 to 0.60. It is noted that the Floor Area Ratios of the sampled sites is from 0.26 to 0.95, which are lower than other low-density sites in high-density cities, such as Ju'er Hutong, Beijing, China (1.3) and Cite des Fleurs, Paris, France (1.5) (Density Atlas, 2012). Overall, there is a relatively wide coverage of all the parameters for such typical urban areas of low-density urban morphology.

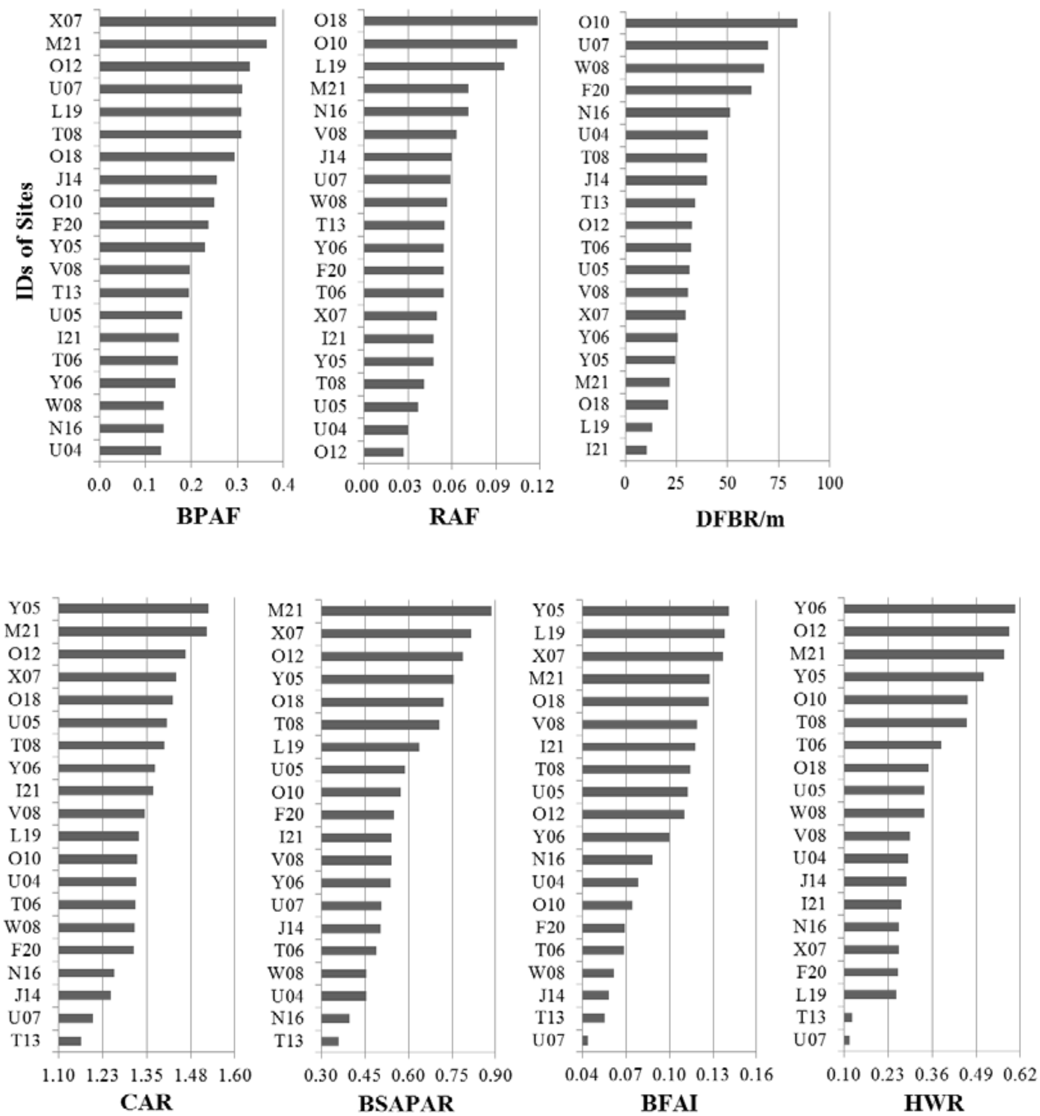


Figure. 0.2. Values of the seven urban morphological parameters of the 20 sampled sites.

Considering the possible inherent relationships among the seven parameters, a Bivariate Analysis was conducted to determine their independence, as shown in Table 5.2. The results indicate that among the seven parameters, the Road Area Fraction (RAF) is the most independent parameters, without any significant correlation (*p<0.05*) to any other parameter, followed by the Building Plan Area Fraction (BPAF), the Distance of the First-row Building to Road (DFBR) and the Height-to-Width Ratio (HWR). However, the Complete Aspect Ratio (CAR) and the Building Surface Area to Plan Area Ratio (BSAPAR) are the most dependent parameters (see Table 5.2). Given the relatively scattered significant correlations in Table 5.2, all the seven parameters are used in the following analysis.

Table 0.2. *p* values of the significant correlations ($p<0.05$) in Bivariate Correlation between two of the seven morphological parameters.

	BPAF	RAF	DFBR	CAR	BSAPAR	BFAI	HWR
BPAF	-	-	-	-	.000	-	-
RAF	-	-	-	-	-	-	-
DFBR	-	-	-	.034	-	.000	-
CAR	-	-	.034	-	.000	.000	.000
BSAPAR	.000	-	-	.000	-	.000	.008
BFAI	-	-	.000	.000	.000	-	-
HWR	-	-	-	.000	.008	-	-

5.2.3 Noise mapping

To simulate the spatial traffic noise distribution in the sites, noise maps were calculated with a commonly used noise-mapping package, Cadna/A (DataKustik GmbH, 2006; Szulecki et al, 2010; McGowan, 2012). The 2D polygon maps of Assen were converted into 2D vector maps in AutoCAD after being obtained from the local zoning plan (Dutch government, 2012). The conditions of building façades and of the ground were obtained from the in-situ investigation and Google Map.

To separate the effects of urban morphology from that of different sound levels of road traffic noise, in the calculation the 'L_{10} dBA' of all road emissions was set to 70 dBA for daytime, 65 dBA for evening and 55 dBA for night time, corresponding to the noise levels of main roads in a large-scale noise map of Assen (Noise & Traffic, 2011). Based on the research by Kang and Huang, the reflection value was set as 1 (Kang and Huang, 2005). The noise maps were generated with grid calculation. The height of receiver was set to 4 meters. The calculation was based on the calculation model CRTN (Calculation of Road Traffic Noise). The accuracy of the calculation has been validated by the measurements, with an inaccuracy of less than 2 dB for traffic noise (Kang and Huang, 2005).

Based on the results of the noise maps, the open areas are categorised into four groups in terms of noise level range: SPL <50dBA (Quiet Area), 50-60dBA (Less Quiet Area), 60-70dBA (Less Noisy Area) and SPL >70 dBA (Noisy Area). 50dBA corresponds to the up-limit sound level (L_{day}) for quiet area (EU Working Group on Assessment of Exposure to Noise and Working Group on Health and Socio-Economic Aspects, 2004) and good soundscape quality (Nilsson and Berglund, 2006) and 70dBA corresponds to the effective noise level in terms of human health (WHO, 2001). Figure 5.3 shows the percentages of the categories at each site; the mean percentages of the categories of the 20 study sites are 36% (Quiet Area), 33% (Less Quiet Area), 18% (Less Noisy Area), and 13% (Noisy Area).

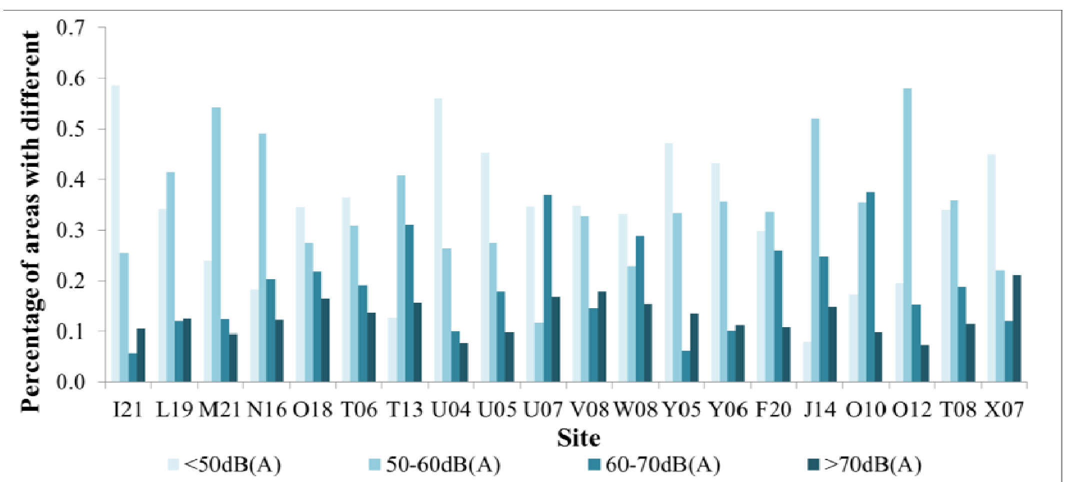


Figure. 0.3. Percentages of the four noise area categories in each site.

5.2.4 MATLAB data processing

A MATLAB program was developed to transform the RGB raster noise maps into the matrices of spatial noise level values in dBA. Figure 5.4 shows how the 2D grids of the sound indices represent the noise map for the overall area, with 0 representing buildings (white in the noise map) and 100 representing roads (black in the noise map). The sound level values on building façades and in open areas are separately processed. In each case, all the spatial noise level values for each site are arranged in a descending order to obtain the indices of *spatial* L_n, including L_{max}, L_{10}, L_{20}, L_{30}, L_{40}, L_{50}, L_{60}, L_{70}, L_{80}, L_{90} and L_{min}. In particular, L_{max} indicates the highest value in the ranking order, L_{min} denotes the lowest value, and L_{avg} is the mean of all the spatial noise levels of a given site. n of L_n specifies *one* certain sound level value at the position of n% in all of the descending values. For example, L_{10} is the value located at the top 10% in the rankings of all the spatial sound level values (Wang and Kang, 2011).

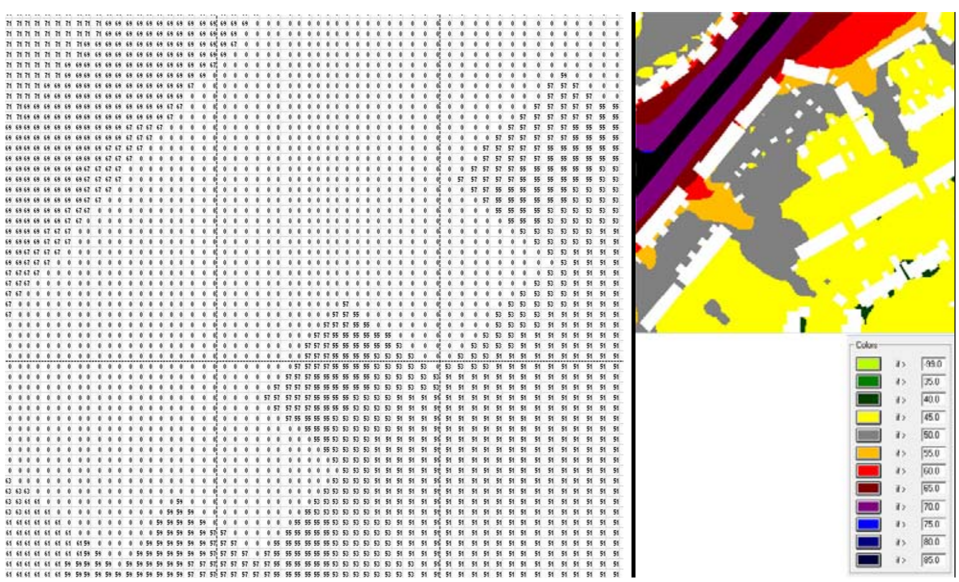


Figure. 0.4. Representation of spatial noise level values in a noise map. (a) Initial arrays obtained by the Matlab data processing program, including points representing noise levels and buildings; (b) Noise map of one site as an example.

5.2.5 Data analysis and sample size examination

Bivariate analysis and 2-order polynomial regression have been employed for the correlation studies on the relationships between individual urban morphological parameters, traffic noise level attenuation and quiet area enlargement. Linear regression has been conducted to explore the relationships of multiple parameters to the aforementioned parameters.

A Simple Random Sample (SRS), meaning that each individual has the same chance to be chosen at any stage during the sampling process (Moore and McCabe, 2006), has been randomly completed on the 20 sample sites to discover how much the site sample size influences the findings. Three random samples with 15, 14 and 13 sites were generated. The spatial noise level attenuation indices of L_{avg}, L_{10} and L_{20} on façades, as well as two urban morphological parameters, Building Plan Area Fraction (BPAF) and Road Area Fraction (RAF), have been chosen for examination. Table 5.3 shows the high agreement of the relationships between the two parameters and the indices amongst the four samples, suggesting that a sample size of 20 is valid.

Table 0.3. Relationships between L_{avg}, L_{10} and L_{20} on façades and BPAF, RAF in terms of R-squared values of 2-order polynomial regression, where * indicates p<0.05 level (2-tailed), and ** indicates p<0.01 level (2-tailed) in Bivariate Correlation.

Sample Size	**Building Plan Area Fraction**			**Road Area Fraction**		
	L_{avg}	***L_{10}***	***L_{20}***	***L_{avg}***	***L_{10}***	***L_{20}***
20	.419**	.638**	.623**	-	-	-
15	.579**	.579**	.668**	-	-	-
14	.599**	.611**	.665**	-	-	-
13	.422*	.496**	.637**	-	-	-

5.3 Results

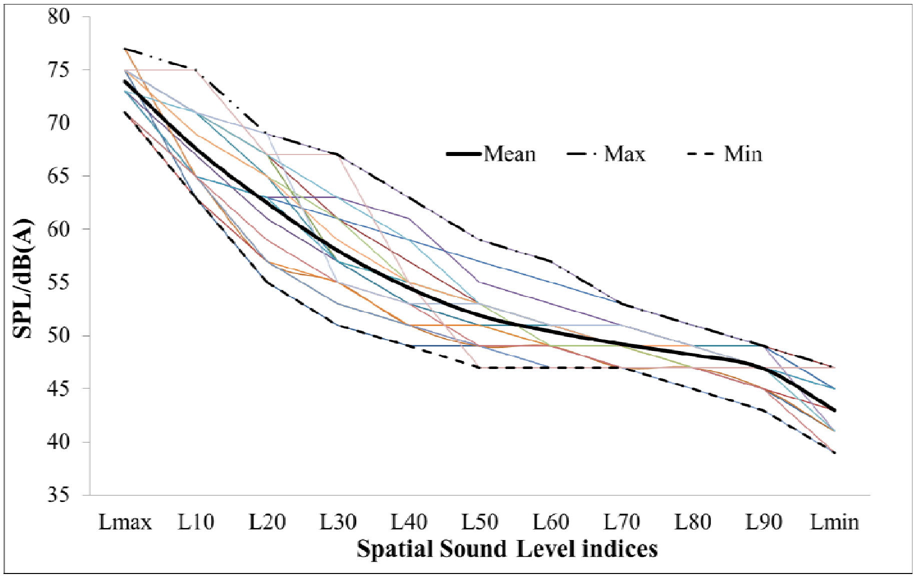
This section examines four issues: (1) What are the properties of the spatial noise level indices *on façades* and *in open areas*? (2) What urban morphological parameters influence spatial noise levels *on façades* and how do they influence these areas? (3) What urban morphological parameters influence spatial noise levels and area categories *in open areas* and how they influence these areas? (4) Whether it is possible to have regression models consisting of multiple urban morphological parameters to calculate spatial noise level indices and noise area sizes.

5.3.1 Spatial traffic noise attenuation on façades and in open areas

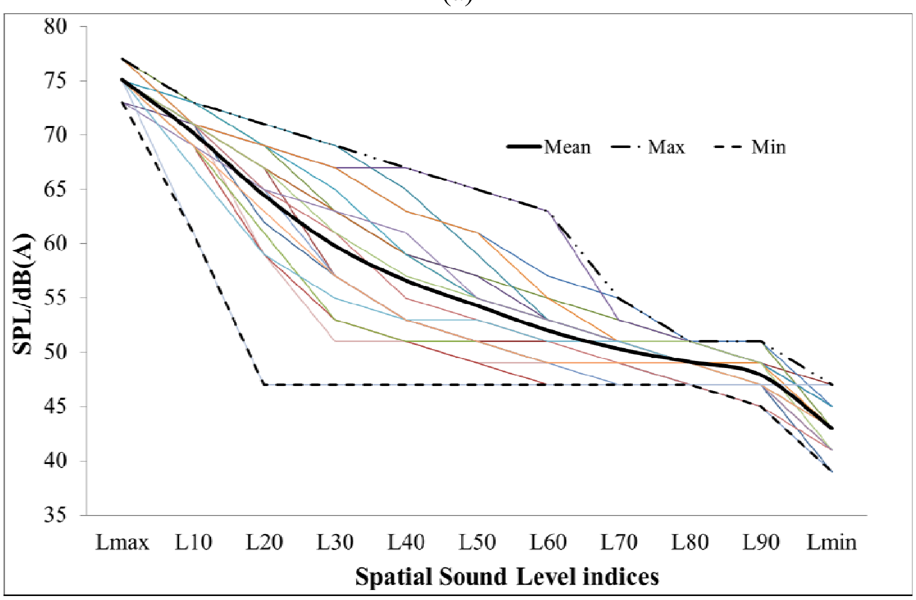
5.3.1.1 Spatial traffic noise attenuation on façades

Figure 5.5-a shows the spatial noise level values on façades of the 20 sites in terms of spatial sound level indices L_n. The mean L_n of the 20 sites on façade attenuates sharply from L_{max} to L_{50} and relatively slowly from L_{50} to L_{90}, with a mean difference between L_{60} and L_{90} of less than 4 dBA (see Figure 5.5-a). This suggests that the traffic noise attenuation primarily occurs on the relatively noisy façades, and the quieter façades have less level changes. Among the 20 sites, the maximum difference in noise occurs at L_{30}, varying from 67 to 51 dBA; whereas, L_{max}, L_{70}, L_{80} and L_{90} have the minimum difference, at 6 dBA. This is further demonstrated in Figure 5.6-a, where the variance of the spatial sound level indices, L_n, is shown. It can be observed that the attenuation on façades is most sensitive with L_{20} and L_{30}; much less sensitive with L_{70}, L_{80} and L_{90}. These results indicate that urban morphology influences the traffic noise attenuation on the noisy façades that are indicated by the indices of L_{20} and L_{30}. The morphology has

little influence on the attenuation on quieter façades, represented by L_{70}, L_{80} and L_{90}.



(a)



(b)

Figure. 0.5. Spatial noise level indices of the 20 sites, with the mean, maximum, and minimum values shown for each index. (a) Façades; (b) Open areas.

5.3.1.2 Spatial traffic noise attenuation in open areas

In open areas, the mean L_n of the 20 sites attenuates more from L_{max} to L_{30} than from

L_{30} to L_{90}, as can be seen in Figure 5.5-b. The difference between the mean values of L_{60} and L_{90} is also very small, less than 4 dBA. The maximum difference among the 20 sites is 24 dBA at L_{20}, followed by22 dBA at L_{30}, and 20 dBA at L_{40}. However, L_{max} and L_{80} have the minimal differences, with 4 dBA. Again, L_{30} has the highest variance, followed by L_{20} and L_{40}, whereas L_{70}, L_{max}, L_{80}, L_{90} and L_{min} have very low variance, as shown in Figure 5.6-b. This suggests that similar to façades, in open areas, the noise attenuation mainly happen in the noisy areas, and also urban morphology play a more significant role on the attenuation in the noisy areas rather than the quiet areas.

These results indicate that the sound level variation on both façades and in open areas, L_{10}, L_{20}, L_{30}, L_{40}, L_{50}, and L_{60} that are more sensitive to urban morphology can be used.

To further examine open areas and the percentages of the four noise area categories, namely the Quiet Area (<50dBA), the Less Quiet Area (50-60dBA), the Less Noisy Area (60-70dBA) and the Noisy Area (>70dBA), and how these spatial noise level indices are related, a correlation study was carried out between each, as shown in Table 5.4. It can be observed that, except for L_{10}, the other indices correlate to either the 'Quiet Area' or the 'Less Noisy Area' in Bivariate Correlation, but only the 'Less Noisy Area' have significant, positive linear regressions and R^2>0.5, with L_{40}, L_{50} and L_{60} in open areas (see Table 5.4), which means that in this case the percentage of 'Less Noisy Area' constantly increases with the increase of either L_{40}, L_{50} or L_{60}. The percentage of 'Quiet Area' has no significant linear regressions with the indices in open areas, and neither the 'Less Quiet Area' nor 'Noisy Area' has any correlations with the indices (see Table 5.4). In other words, the site has a larger quiet area, not always the case when a site has a lower value at a certain spatial noise level index. Therefore, it is necessary to study the relationships between urban morphological parameters and the spatial noise indices, as well as those pertaining to the noise area categories.

Table 0.4. Relationships between spatial noise level indices in open areas and percentages of the four noise area categories in terms of R-squared values of linear regression, where * indicates p<0.05 level (2-tailed), and ** indicates p<0.01 level (2-tailed) in Bivariate Correlation.

Indices	Area Categories			
	Quiet	***Less Quiet***	***Less Noisy***	***Noisy***
L_{10}	-	-	-	-
L_{20}	.288*	-	.232*	-
L_{30}	.314**	-	.444**	-
L_{40}	.260*	-	**.548****	-
L_{50}	**.288***	-	**.551****	-
L_{60}	**.269***	-	**.524****	-
L_{avg}	.319**	-	.411**	-

5.3.1.3 Relationships between spatial traffic noise attenuation on façades and in open areas

It is important to note that the spatial noise level distribution on façades and in open areas demonstrates different characteristics. The spatial noise level variations are generally greater in open areas than those on façades as shown in Figure 5.5. Comparing Figure 5.6-a&b, using bivariate analysis and linear regression can also illustrate this ides; a correlation study, shows that the sound levels of L_n on façades and in open areas are only positively correlated at L_{70} ($p<0.01$, $R^2=0.51$) and L_{80} ($p<0.01$, $R^2=0.63$), while they are not correlated at any other indices. Accordingly, this study further investigates traffic noise resistance from the viewpoints of both façades and open areas, concerning not only indoor traffic noise but also acoustic comfort in open spaces.

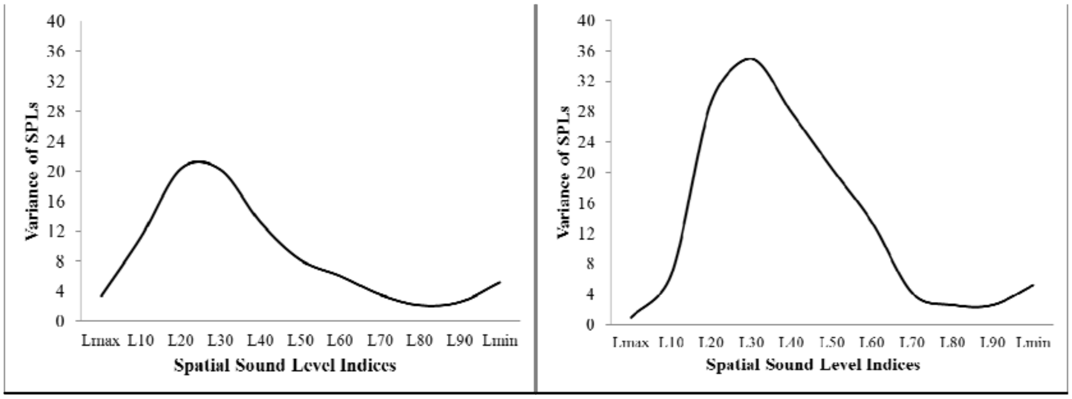


Figure. 0.6. Variance of the spatial noise level indices of the 20 sites. (a) Façades; (b) Open areas.

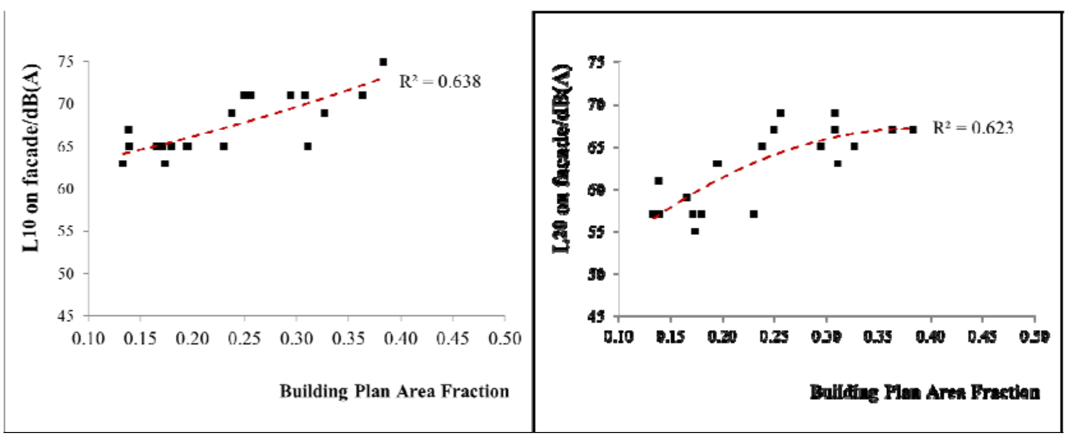
5.3.2 Relationships between spatial traffic noise levels *on façades* and urban morphological parameters

Table 5.5 shows the relationships between spatial noise level indices on façades and urban morphological parameters. It is important to note that there are significant correlations between these parameters. L_{10} and L_{20} on façades are both highly related to the Building Plan Area Fraction (BPAF) (p<0.01), with R^2=0.638 and 0.623, respectively. Figure 5.7 further shows the 2-order polynomial regressions for the R^2>0.5 cases in Table 5.5. It is interesting that L_{10} and L_{20} on façades increase with increasing BPAF (see Figure 5.7), indicating that the sites with a higher building coverage are prone to have more noisy façades and potentially noisy indoor spaces in terms of L_{10} and L_{20}. A possible reason for the noise increases is that a higher building coverage may result in more buildings closer to traffic and thus more noisy façades.

The Complete Aspect Ratio (CAR), Building Surface Area to Plan Area Ratio (BSAPAR) and Building Frontal Area Index (BFAI) also have correlations with the spatial noise level indices. The Height-to-Width Ratio (HWR), however, has no correlation with any of the indices, suggesting that the canyon effect is not significant for traffic noise attenuation on façades with such an urban texture. Surprisingly, Road Area Fraction (RAF) has no significant correlation either, suggesting that road coverage has little influence on traffic noise level on façades at such a meso-scale.

Table 0.5. Relationships between spatial noise level indices on façades and urban morphological parameters in terms of the R-squared values of 2-order polynomial regression, where * indicates p<0.05 level (2-tailed), and ** indicates p<0.01 level (2-tailed) in Bivariate Correlation.

Indices	**Urban Morphological Parameters**						
	BPAF	***RAF***	***DFBR***	***CAR***	***BSAPAR***	***BFAI***	***HWR***
L_{10}	**.638****	-	-	-	.373**	-	-
L_{20}	**.623****	-	-	-	-	-	-
L_{30}	.324**	-	-	-	-	-	-
L_{40}	-	-	-	.374*	-	-	-
L_{50}	-	-	-	.405*	-	.281*	-
L_{60}	-	-	-	.459**	-	.281*	-
L_{avg}	.419**	-	-	-	-	-	-



(a) (b)

Figure. 0.7. Relationships between spatial noise level indices on façades and urban morphological parameters. (a) L_{10} and Building Plan Area Fraction; (b) L_{20} and Building Plan Area Fraction.

5.3.3 Relationships between spatial traffic noise *in open areas* and urban morphological parameters

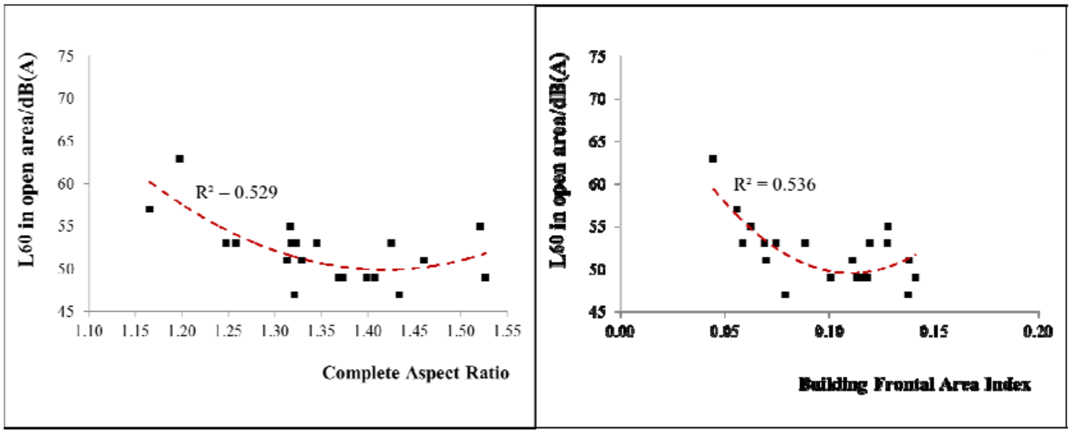
Table 5.6 shows relationships between the traffic noise in open areas and the urban morphological parameters. As shown in the table, L_{60} in open areas has a significant relationship with both the Complete Aspect Ratio (CAR) and the Building Frontal Area Index (BFAI). It can be seen in Figure 5.8 that, when either CAR or BFAI increase, the sound levels of the open areas decrease with a slight increase in terms of L_{60}. These findings suggest that a site with a greater total building coverage and ground surface area or greater façade area, parallel to roads, would not necessarily result in quieter open spaces in terms of L_{60}. This is possibly caused by certain specific building geometries and layouts; however, in general, according to the regressions, when CAR is 1.42 or BFAI is 0.11, the lowest L_{60} in open areas is achieved (see Figure 5.8). None of the spatial noise level indices in open areas is related to the Building Plan Area Fraction (BPAF), meaning that merely increasing building coverage cannot enhance spatial noise level attenuation in open areas.

The percentage of 'Less Noisy Area' is highly related to the Distance of the First-row Building to Road (DFBR) (p <0.01, R^2=0.667) and the Building Frontal Area Index (p <0.01, R^2=0.604) (see Table 5.6). The percentage of the 'Less Noisy Area' decreases when the DFBR decreases or when the BFAI increases, as shown in Figure 5.9. When the DFBR is 80m, the percentage of 'Less Noisy Area' is 36.3%, much higher than the value of 9.0% when the DFBR is 10m, and when BFAI is 4.0%, the percentage of the 'Less Noisy Area' is 37.0%, 25.0% higher than when BFAI is 14.0% (see Figure 5.9). This is feasible because the noise barrier effect is greatly enhanced by either shortening the distance between the traffic road and first-row buildings or by enlarging the façade areas along the traffic road. However, it should be noted that the BFAI has no influence on the percentage of ‘Quiet Area’, perhaps because the barrier effects of buildings largely reduce the middle and high frequency components of traffic noise. This reduction results in considerable changes in dBA in noisy areas, but diffraction of the low frequency portion reduces the barrier effects in relatively quiet areas.

Table 0.6. Relationships between traffic noise in open areas and urban morphological parameters in terms of R-squared values of 2-order polynomial regression, where * indicates p<0.05 level (2-tailed), and ** indicates p<0.01 level (2-tailed) in Bivariate Correlation.

		Urban Morphological Parameters						
		BPAF	***RAF***	***DFBR***	***CAR***	***BSAPAR***	***BFAI***	***HWR***
Indices	L_{10}	-	-	-	-	-	-	-
	L_{20}	-	.372**	-	-	-	-	-
	L_{30}	-	.345*	-	-	-	.267*	-
	L_{40}	-	.315*	.226*	.326*	-	.359*	-
	L_{50}	-	-	-	.448*	-	.450**	-
	L_{60}	-	-	-	**.529***	-	**.536****	-
	L_{avg}	-	.325*	-	.405*	-	.297*	-
Area	***Quite***	-	-	-	-	-	-	-
Categories	***Less***	-	-	-	-	-	-	-
	Less	-	-	**.667****	.440*	-	**.604****	-
	Noisy	-	-	-	-	-	-	.243*

The percentage of the ‘Less Noisy Area’ is correlated with CAR (p <0.05); the percentage of the ‘Noise Area’ is correlated to the Height-to-Width Ratio (HWR) (p <0.05) (see Table 5.6). However, the percentages are not correlated with the Building Plan Area Fraction (BPAF), the Road Area Fraction (RAF) or the Building Surface Area to Plan Area Ratio (BSAPAR). The percentage of the ‘Quiet Area’ is not correlated with any of the morphological parameters, so it seems that the increase of quiet open areas cannot be achieved merely through the control of any individual parameter in this study.



(a) (b)

Figure. 0.8. Relationships between L_{60} in open areas and urban morphological parameters. (a) Complete Aspect Ratio; (b) Building Frontal Area Index.

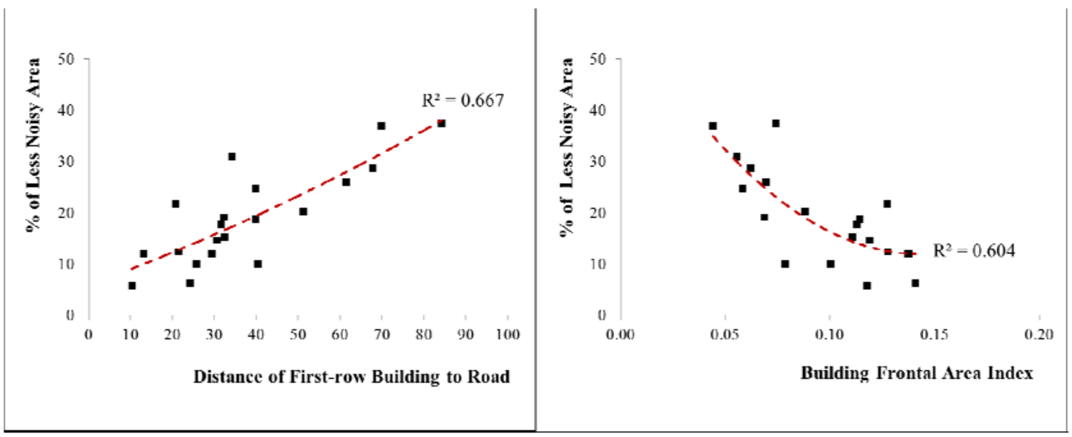


Figure. 0.9. Relationships between the percentage of Less Noisy Area and urban morphological parameters: (a) Distance of First-row Building to Road; (b) Building Frontal Area Index.

5.3.4 Regression models with multiple urban morphological parameters

A number of linear regression models have been generated to explore the relationships between the spatial traffic noise levels, area size and the multiple urban morphological parameters, so that the acoustic features in an area could be estimated based on the urban morphological parameters. This is useful for the evaluation of the traffic noise resistance of low-density residence in urban planning. Table 5.7 shows the models with relatively high coefficients, with adjusted R^2>0.5. λ_N is the ratio of Less Noisy Area with traffic noise. The high significances of the models are also shown in Table 5.7. To examine the efficiency of the models, L_{10} and L_{avg} on façades of one grid randomly selected from the GIS database were compared and the differences between the noise mapping and the model prediction are only 2.0 dBA for L_{10} and 1.1 dBA for L_{avg}.

It can be observed in Table 5.7 that the spatial noise levels on façades, in other words, indoor sound environment by traffic noise, are more predictable than those in open areas. In terms of area categories, only the percentage of the 'Less Noisy Area' can be calculated using urban morphological parameters.

The BPAF appears most frequently in the models. In accordance with the results in Section 3.2, the Building Plan Area Fraction (BPAF) has a positive relationship with sound levels on façades. Complete Aspect Ratio (CAR) appears second frequently in the models. When the CAR increases, the values of the spatial noise level indices on façade decrease. In particular, the increase of the Building Frontal Area Index (BFAI) reduces L_{40} in open areas and the percentage of 'Less Noisy Area'.

Table 0.7. Linear regression models to estimate the acoustic features in an area based on urban morphological parameters, where $\lambda_{N'}$ is the percentage of 'Less Noisy Area'.

Model		**Model Summery**			
		R^2	***Adjusted R^2***	***Std. Error of Unstandardized Coefficient***	***Significance***
Façade	$\boldsymbol{L_{10} = 57.50 + 32.75BPAF + 38.47RAF}$	0.700	0.665	1.717 for constant (57.50), 6.008 for BPAF, 19.999 for RAF	.000
	$\boldsymbol{L_{20} = 86.78 + 57.00BPAF - 30.98CAR + 11.51HWR}$	0.776	0.716	11.168 for constant (86.78), 8.249 for BPAF, 9.901 for CAR, 6.243 for HWR	.000

	$\boldsymbol{L_{30} = 83.74 + 48.14BPAF - 28.61CAR + 0.04DFBR}$	0.725	0.673	10.629 for constant (83.74), 8.438 for BPAF, 7.742 for CAR, 0.035 for DFBR	.000
	$\boldsymbol{L_{40} = 99.10 + 38.19BPAF - 42.24CAR + 9.80HWR}$	0.778	0.736	8.461 for constant (99.1), 6.250 for BPAF, 7.501 for CAR, 4.730 for HWR	.000
	$\boldsymbol{L_{avg} = 78.71 + 28.85\mathrm{BPAF} - 24.29\mathrm{CAR} + 6.09\mathrm{HWR}}$	0.779	0.738	5.617 for constant (78.71), 4.149 for BPAF, 4.980 for CAR, 3.140 for HWR	.000
Open Area	$\boldsymbol{L_{40} = 58.59 + 135.77\mathrm{RAF} - 104.11BFAI}$	0.635	0.592	3.147 for constant (58.59), 34.111 for RAF, 25.510 for BFAI	.000
	$\boldsymbol{\lambda_{N'} = 0.16 + 0.29BPAF + 1.21RAF - 1.83BFAI + 0.002\mathrm{DFBR}}$	0.877	0.845	0.058 for constant (0.157), 0.122 for BPAF, 0.378 for RAF, 0.429 for BFAI, .001 for DFBR	.000

5.4 Conclusions

This chapter aims to explore whether and how urban morphology influences the capability of a residential area to reduce traffic noise level and enlarge quiet area. Particular reference is made to the generic morphology of low-density residential areas with a standard building height of 8 m. Seven urban morphological parameters that are accessible and commonly used in urban design and planning are selected. Noise mapping technique has been employed and a MATLAB program has been developed to obtain the spatial noise level indices.

The results show that, to indicate the spatial noise level variations both on façades and in open areas, L_{10}, L_{20}, L_{30}, L_{40}, L_{50}, and L_{60} can be used. The spatial noise level attenuation mainly occurs on noisy façades and in noisy open areas. Additionally, the spatial noise level attenuation is more sensitive in open areas than on façades; the attenuation on façades and in open areas is generally not correlated in terms of spatial noise level.

With regards to the spatial noise levels on façades, the Building Plan Area Fraction, surprisingly, has a significant positive relation to the spatial noise levels on noisy façades. These findings indicate that a site with a higher building coverage will probably have more noisy indoor spaces with noise by traffic. Street configurations (i.e., the Height-to-Width Ratio), namely the canyon effect, hardly play any role in noise attenuation in such an urban texture.

For the spatial noise levels in open areas, the total building and ground surface area (i.e., the Complete Aspect Ratio) and façade areas, parallel to roads, (i.e., the Building Frontal Area Index) influence the sound levels of quiet open areas at L_{60}. However, when the Complete Aspect Ratio is higher than 1.42 or the Building Frontal Area Index is higher than 0.11, open spaces are increasingly noisy in terms of L_{60} with an increase of either of the two parameters. The decrease of spatial noise levels in open areas cannot be achieved merely by increasing the Building Plan Area Fraction.

In terms of the noise area categories in open areas, the percentage of 'Less Noisy Area' decreases when L_{40}, L_{50} or L_{60} decreases, suggesting that the size of the relatively noisy open areas could be predicted with the indices. Neither the 'Less Quiet Area' nor the 'Noisy Area' have high correlations with the spatial noise level indices, however. The percentage of the 'Less Noisy Area' decreases significantly with the decrease of the distance from the first-row building to road (i.e. Distance of First-row Building to Road) or the increase of façade areas along traffic roads (i.e. Building Frontal Area Index). The control of any single parameter in this study cannot contribute to the increase of the 'Quiet Area'.

However, based on the results in Chapter 4, it is feasible to increase pleasantness of car traffic noise environment in the 'Quiet Area' and the 'Less Quiet Area' (69% in total area) by the masking effects of birdsong, with woods as bird habitats. Even in the 'Less Noisy Area', with birdsong, the naturalness of the traffic noise environment can be improved. In Chapter 3, adding water features is also an option to reduce audibility of traffic noise through 'Energetic masking' because of the acoustic characteristics of water sounds.

A series of linear regression models have been established, of which the independent variables are the urban morphological parameters and dependent variables are spatial traffic noise level indices and percentage of noise area categories. Based on the models, the decrease of the Building Plan Area Fraction and the increase of the Complete Aspect Ratio can contribute to the attenuation of the traffic noise levels on façades. The increase of Building Frontal Area Index significantly benefits both the attenuation of the traffic noise levels in open areas and the reduction of the noisy open areas.

CHAPATER 6

FLYOVER AIRCRAFT NOISE ATTENUATION IN THE CONTEXT OF URBAN MORPHOLOGY

As suggested in Chapter 3, attenuating the sound pressure levels of flyover aircraft noise is the most essential for the enhancement of the Naturalness, the Annoyance and the Pleasantness of soundscape. Therefore, this chapter investigates the influence of urban morphology of low-density built-up areas on spatial noise level attenuation of flyover aircrafts which has much higher sound sources than car traffic noise at a meso-scale. Six urban morphological parameters, including the Building Plan Area Fraction, the Complete Aspect Ratio, the Building Surface Area to Plan Area Ratio, the Building Frontal Area Index, the Height-to-Width Ratio, and the Horizontal Distance of the First-row Building to Flight Path, have been selected and developed. Effects of flight altitude and horizontal flight path distance to site on spatial aircraft noise attenuation are examined, considering the open areas and the façades. Twenty sampled sites, each of 250 m x 250 m, are considered.

6.1 Introduction

The concerns on the impacts of air transport on noise, air quality, water quality and the ecology are increasing, especially for the higher density population European regions (Morrell and Lu, 2000). The annoyance caused by aircraft noise of the population who had been living near a big European airport for at least 5 years has been raised over recent years; the annoyance ratings due to aircraft noise were higher than predicted by the EU standard curves (Babisch et al, 2009). Aircraft noise has been an important cause for the degradation of soundscape in the adjacent areas of airports, especially for the regions that have strong connections between the noise annoyance and local outdoor life (Vogiatzis, 2012; Klaeboe, 2004).

Conventionally, the research on aircraft noise mapping and assessment is based on the standard conditions of the constant flight speed and the flat terrain without reflecting objects (Speakman, 1980). At present, much attention is still paid to large-scale aircraft noise modelling; (Zaporozhets and Tokarev, 1998; Khardia and Abdallahb, 2012) the aircraft flight performance rather than the effects of obstacles on noise attenuation is emphasized in the mapping (DataKustik, 2013; ATAC, 2013; Vogiatzis, 2012). Many prediction tools mainly focus on the noise from taking offs and landings; the noise mapping tools for aircraft taxing have been developed (Asensio, 2009). On the other hand, with the expansion of air transports and injection of airports and heli-pads into or close to city areas, the effects of morphology of urbanised areas, for example, the effects of urban street pattern (Ismail and Oldham, 2002; Kinney et al, 1974), have become a concern on aircraft noise distribution near the airports. It is indicated through modelling that the noise from an aircraft passing overhead in a city street is enhanced compared to that heard in an open area (Pande, 1972). Kinney et al (1974) carried out a series of field experiments to confirm the enhancement and explain the phenomenon. It has been demonstrated that relative Effective Perceived Noise Level increases with the ratio of building height to flying altitude, but the street width has little influence (Ismail and Oldham, 2002). Although the above research demonstrated the importance of considering the influence of urban morphology, there is a further important research question: are there any other parameters of urban morphology influencing the aircraft noise attenuation, with particular references to a meso-scale of urban morphology with a group of buildings rather than a street?

The aim of this chapter is therefore to explore whether and how urban morphology parameters influence noise attenuation of flyover aircrafts. Low-density residential areas are considered, because they have relatively low noise resistance and are more common near airports. The study focuses on the flyover landing aircrafts or helicopters, of which the noise is prone to be loud, lasting and annoying (Ismail and Oldham, 2002; Crooks and Langdon, 1974; Sijtsma and Stoker, 2004; Lavandier et al, 2011; Taylor, 1984). In particular, this study aims to find out (1) the effects of horizontal distance between a site and flight path; (2) the effects of altitude of flight path. Given the needs for quiet rooms for people to relax, sleep and restore and an impact of quiet side on the aircraft noise annoyance ratings (Babisch et al, 2009), the noise attenuation on façades is also investigated, besides in open areas.

6.2 Methods

6.2.1 Site selection

The study sites were selected in Assen in the Netherlands, because it is the fastest-growing city in the North of Netherlands and has an increase of 5,000 residential buildings per 10 years since 1960 (Assen Municipality, 2013), resulting in a mixture of various urban morphologies generated in different historical periods, representing typical European sub-urban morphologies which can often be found near airports. It has a long history of province capital since 1258. According to a GIS database of 763 grids of Assen built-up areas, less than 10% grids are used for industrial and commercial usages, and the main functions of the built-up areas are residence and mixed-use (residential and commercial). More than 70% of the residential buildings are low-rise terraced and detached buildings (Assen Municipality, 2013). Twenty sites, each of 250 m x 250 m, were sampled from the GIS database by Simple Random Sample (SRS) . Figure 6.1 shows the figure-ground diagrams of the sampled sites.

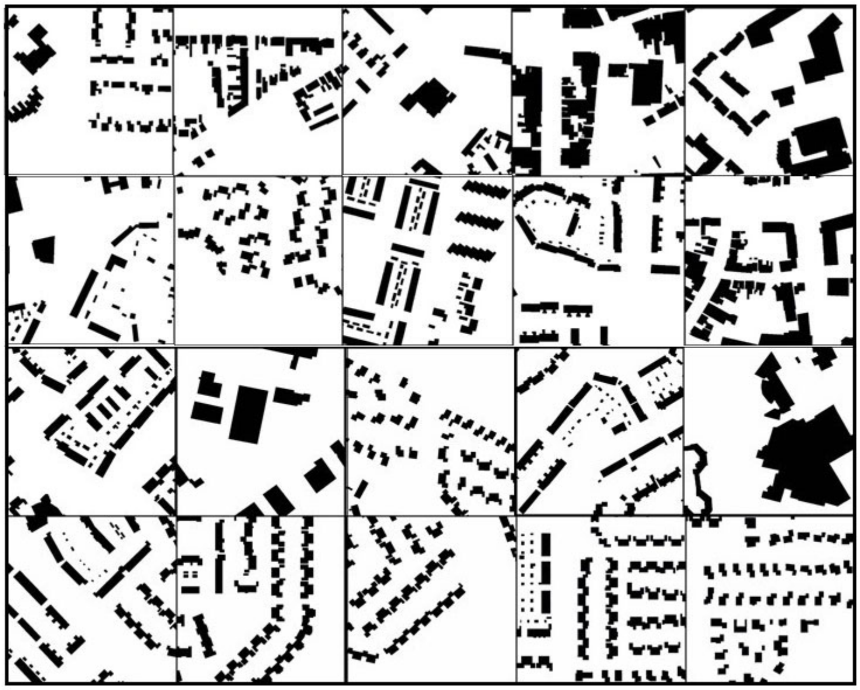


Figure. 0.1. Figure-ground diagrams of the 20 sampled sites, each of 250 m x 250 m, where buildings are in black, and open areas are in white.

6.2.2 Set-up of calculation parameters for noise mapping

Noise mapping techniques (Klæboe,et al, 2006; Szulecki et al, 2010; McGowan, 2012) were employed with the software package of Cadna/A (DataKustik GmbH, 2006) in this study. The accuracy in noise mapping calculation depends more on the quality of input data rather than specific modelling program (Kang, 2007). It has been stated that the results of calculation and measurement can generally reach a good agreement (Kang, 2007; Kang and Huang, 2005; Tompsett, 2002). For example, when considering both traffic noise and fountain sounds in the urban areas, the inaccuracy is within approximately 2 dB (Kang and Huang, 2005). The 2D polygon maps of the sampled sites were obtained from the web of Zoning Plan (Dutch government, 2012) and TOP10NL of Kadaster (Kadaster, 2004), including the 3D information of buildings.

Because the aim of this study is to examine the influence of urban morphology, the atmospheric effect is not taken into account, and generic source conditions were considered. The flyover aircraft was set as a line source, investigating five horizontal distances from a given site, namely 0m, 100m, 300m, 600m and 1000m, and two flight altitudes, namely 60.96m (200ft) and 121.92m (400ft), according to previous studies (Ismail and Oldham, 2002; Kinney et al, 1974). The receiver height was set as 1.6m. The calculation configuration is shown in Figure 6.2. Based on the research by Khardi (2008), three main frequencies of aircraft noise, 630Hz (low), 1600Hz (medium), and 3150Hz (high), were selected for calculation. The absorption coefficient was assigned as 0.3 across frequencies, with particular references to the mixture of windows and masonry façades, and the ground absorption was assigned as 0. The reflection order by buildings was set as 3, based on the previous study (Kang, 2007); comparison with no reflections was made to examine the shielding effects, as well as the effectiveness of absorptive building façades like green walls.

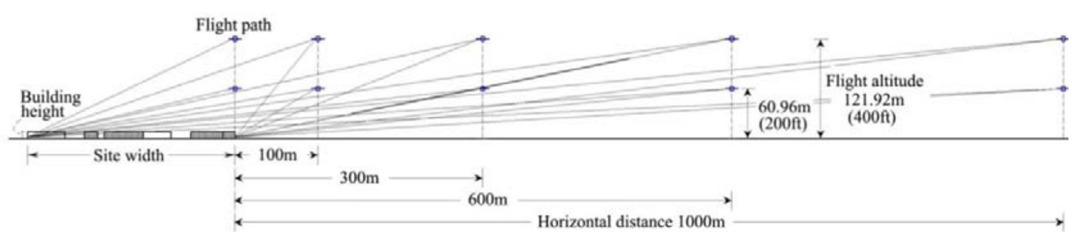


Figure. 0.2. Cross-section of the calculation configuration, showing the location of flight path.

6.2.3 Matlab processing

The same MATLAB program used in the Chapter 5 was also employed in this Chapter to obtain the values of the spatial noise indices, L_n. The spatial noise level values on building façades and in open areas were separately processed.

6.2.4 Calculation of urban morphological parameters

In this study six urban morphological parameters were selected or developed, including the Building Plan Area Fraction (BPAF), the Complete Aspect Ratio (CAR), the Building Surface Area to Plan Area Ratio (BSAPAR), the Building Frontal Area Index (BFAI), the Height-to-Width Ratio (HWR) and the Horizontal Distance of First-row Building to Flight Path (HDFBFP), as listed in Table 6.1, where the first three parameters are independent from the source condition, whereas the other three are related to sound source locations. In this chapter, they are grouped as independent and dependent parameters, respectively. Calculations of the 20 sites show that the BPAF is evenly distributed from 0.13 to 0.38, the CAR from 1.17 to 1.53, the BSAPAR from 0.36 to 0.88, the BFAI from 0.04 to 0.15, and the HWR from 0.09 to 0.62. When the horizontal distance between site and flight path is 0, the HDFBFP covers a range of 3.4m to 116.2m. The characteristics of urban morphology have been indicated by the parameters in the investigation ofthe other sound sources for urban optimisation design (Kang, 2000; Kang, 2001; Kang 2002; Kang, 2005).

Table 0.1. Calculations of the six urban morphological parameters used in this study.

Parameter	Definition	Formula	Notes
Building Plan Area Fraction (*BPAF*)	The ratio of the plan area of buildings to the total surface area of the study region	$BPAF = \frac{A_p}{A_T}$	A_p is the plan area of buildings at ground level and A_T is the total plan area of the region of interest.
Complete Aspect Ratio (*CAR*)	The summed area of roughness elements and exposed ground divided by the total surface area of the study region (Voogt and Oke, 1997)	$CAR = \frac{A_C}{A_T} = \frac{A_W + A_r + A_G}{A_T}$	A_C is the combined surface area of the buildings and exposed ground, A_W is the wall surface area, A_r is the roof area, A_G is the area of exposed ground (Burian et al, 2005).
Building Surface Area to Plan Area Ratio (*BSAPAR*)	The sum of building surface area divided by the total surface area of the study region	$BSAPAR = \frac{A_r + A_W}{A_T}$	A_r is the plan area of rooftops, A_W is the total area of non-horizontal roughness element surfaces (e.g. walls) (Burian et al, 2005).

Building Frontal Area Index (*BFAI*)	The total area of the façade areas parallel with the flight direction (A_{para}) divided by the total surface area of the study region	$BFAI(\theta) = \frac{A_{para}}{A_T}$	θ is the flight path direction.
Height-to-Width Ratio (*HWR*)	The average of the building heights (H_{avg}) is divided by the average of the horizontal distances between two adjacent buildings on the direction vertical to the flight direction (S_{avg})	$HWR(\theta) = \frac{H_{avg}}{S_{avg}}$	θ is the flight path direction.
Horizontal Distance of First-row Building to Flight Path *(HDFBFP)*	The mean of the horizontal distances from the frontal façades of the first-row buildings to the flight path	$DFBR = \frac{1}{n}\sum_{i=1}^{n} d_i$	n is the total number of first-row buildings, and d_i is the distance from the first-row building to the flight path.

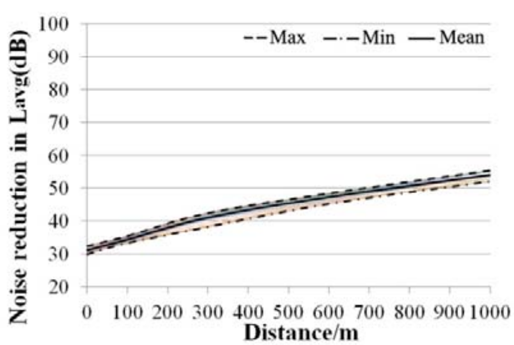
6.3 Results

6.3.1 Effects of the horizontal distance between site and flight path

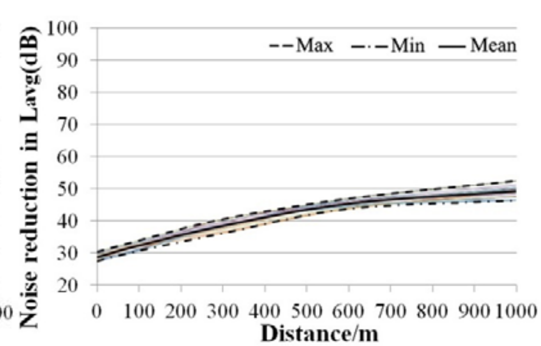
Figure 6.3 shows the maximum, minimum, and mean aircraft noise attenuation (re. source power level) among the 20 sampled sites, in terms of L_{avg} at 630, 1600 and 3150 Hz, with a range of horizontal distance between the site and the flight path, when the flight altitude is 200 ft. In Figure 6.3 the noise attenuation of each site is also shown. It can be observed that, in open areas, the difference between the maximum and minimum values among the 20 sites generally increases with the horizontal distance between the site and the flight path; the difference reaches 7.9 dB at 1000 m, at 3150 Hz (see Figure 6.3-c). It is also interesting to note that from 300 m to 600 m, i.e., when the horizontal distance between site and flight path is doubled, the mean L_{avg} difference among the 20 sites in open areas reduces by 6.9 dB at 630 Hz, 7.5 dB at 1600 Hz, and 16.1 dB at 3150 Hz, as shown in Figure 6.3-a, b&c, respectively, demonstrating the significant influence of urban morphology.

In general, the sound level variations among the 20 sites are larger in open areas than those on façades. For example, by comparing Figure 6.3-b&e, it can be observed that at 1600 Hz at 1000 m, the difference between the maximum and minimum values is 7.7 dB in open areas and 4.5 dB on façades. However, the façades have higher noise attenuation than the open areas, in terms of the mean L_{avg} of the 20 sites. For example, by comparing Figure 6.3-a&d, it can be seen that at 630 Hz at 1000 m, the value is 54.0 dB on façades and 49.2 dB in open areas.

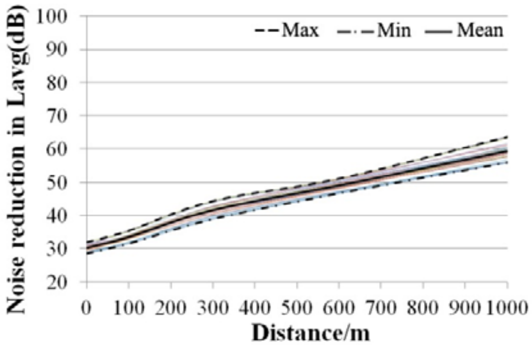
Figure 6.4 and 6.5 indicate the variances of the aircraft noise attenuation at L_{avg} among the 20 sites, in open areas and on façades. It can be observed in Figure 6.4 that, generally speaking, with the increase of distance, the variances at all the frequencies go up. Corresponding to Figure 6.3, the variances at 1000 m are the largest, where the variance is 4.6 dB at 3150 Hz and altitude of 200 ft, higher than that at 1600 Hz and 630 Hz (see Figure 6.4a, b&c). By comparing Figures 6.4 and 6.5, it can be observed that the variances of noise attenuation on façades, mostly below 2 dB, are lower than those in open areas.

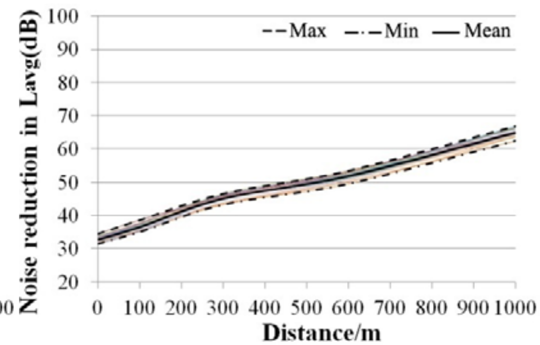


(a) 630Hz, open areas

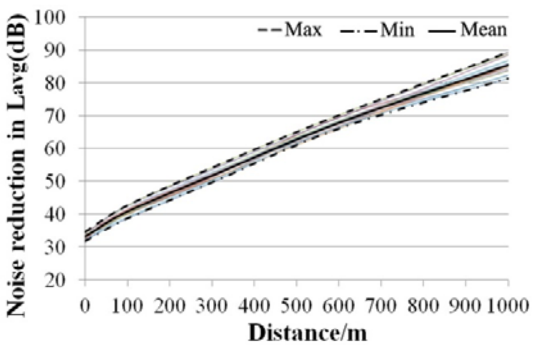


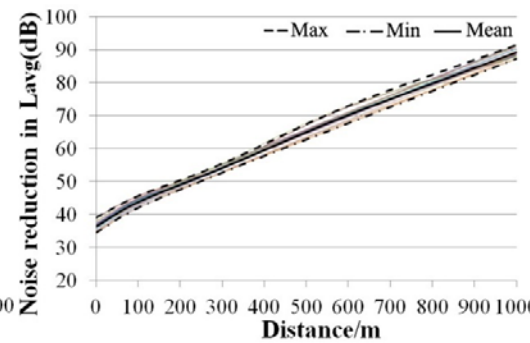
(d) 630Hz, façades





(b) 1600Hz, open areas (e) 1600Hz, façades





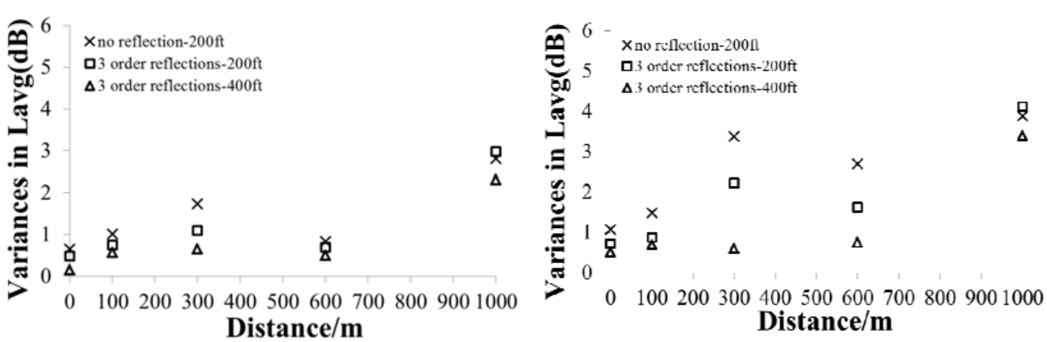
(c) 3150Hz, open areas (f) 3150Hz, façades

Figure. 0.3. The maximum, minimum, and mean aircraft noise attenuation (re. source power level) among the 20 sampled sites, in terms of L_{avg} at 630, 1600 and 3150Hz, with horizontal distances between site and flight path of 0m, 100m, 300m, 600m and 1000m, where the flight altitude is 200ft. In the figure the noise attenuation of each site is also shown, although individual sites are not identified.

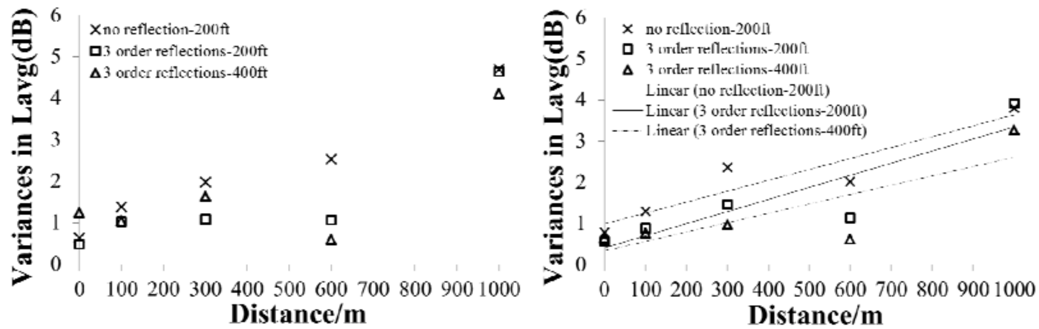
In Figures 6.4 and 6.5 two conditions, with the reflection orders of 0 and 3, are considered. Compared with the reflection order of 0, the variances with 3 reflections are lower at almost all the distances, indicating that sound reflections by buildings reduce the influence of morphology on the noise resistance. At a large horizontal distance between site and flight path, say 1000 m, the differences in variances between reflection orders of 0 and 3 can be neglected, both in open areas and on façades. The variances at L_{10}, L_{50} and L_{90} are illustrated in Table 6.2. It can be seen that the variances at L_{50} and L_{90} are generally higher than those at L_{10}, and the variances in open areas are higher than those on façades, suggesting that urban morphology may have more significant influence on the noise attenuation at the middle level and the quiet level in open areas. The highest variance occurs is 19.7 dB at L_{50} at 1600 Hz at 1000 m.

Table 0.2. Variances of the aircraft noise attenuation among the 20 sites in terms of L_{10}, L_{50} and L_{90}, both in open areas and on façades.

	Spatial noise level index	**L_{10}**			**L_{50}**			**L_{90}**		
Frequency(Hz)		630	1600	3150	630	1600	3150	630	1600	3150
	Distance(m)									
Open Areas	0	1.4	2.6	0.0	0.6	1.2	3.8	1.8	1.0	5.7
	100	0.8	1.4	2.0	4.6	5.2	8.1	0.0	3.4	1.2
	300	3.0	0.5	3.0	3.6	7.6	3.8	2.2	0.9	3.3
	600	6.8	2.1	5.8	2.1	5.3	1.6	1.0	1.6	2.2
	1000	0.0	0.8	1.2	8.6	19.7	8.9	1.8	6.2	3.2
Façades	0	0.4	0.9	0.4	0.2	0.8	1.2	1.7	6.0	6.4
	100	1.2	0.5	1.0	0.6	1.0	0.6	7.4	9.0	4.2
	300	1.0	0.4	0.8	4.6	0.8	1.0	5.0	3.3	3.6
	600	3.3	0.4	0.4	1.0	1.6	2.0	2.2	6.1	8.5
	1000	1.0	1.6	2.4	1.0	1.2	4.6	3.7	0.9	0.8

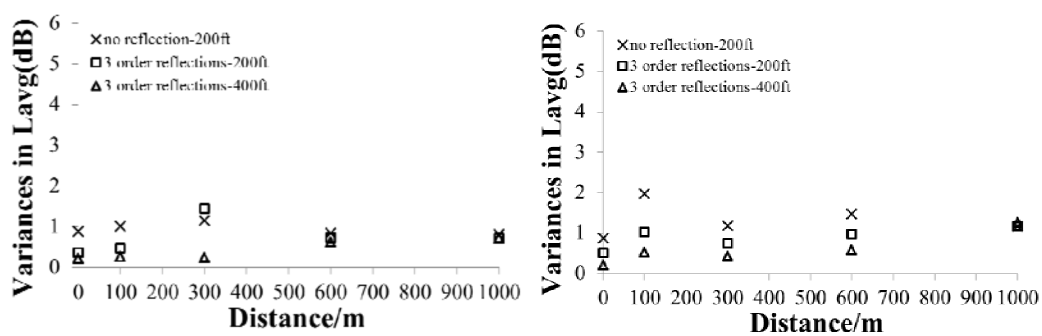


(a) 630Hz (b) 1600Hz

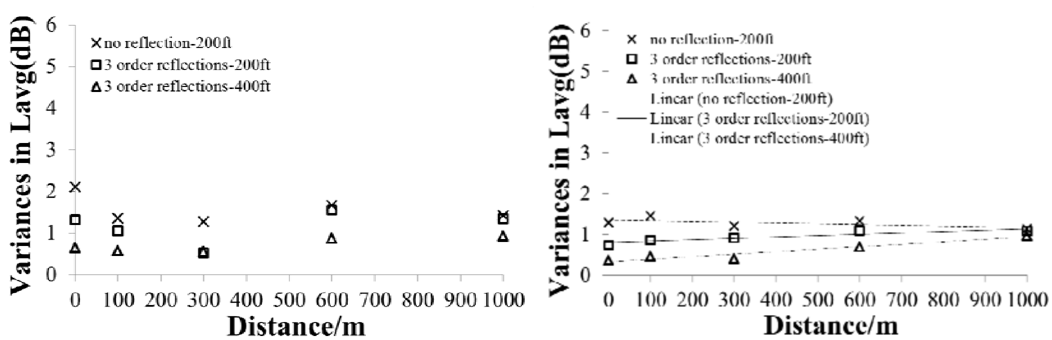


(c) 3150Hz (d) Average of 3 frequencies

Figure. 0.4. Variances of the aircraft noise attenuation L_{avg} *in open areas* among the 20 sites, with increasing horizontal distance between site and flight path of 0m, 100m, 300m, 600m and 1000m.



(a) 630Hz (b) 1600Hz



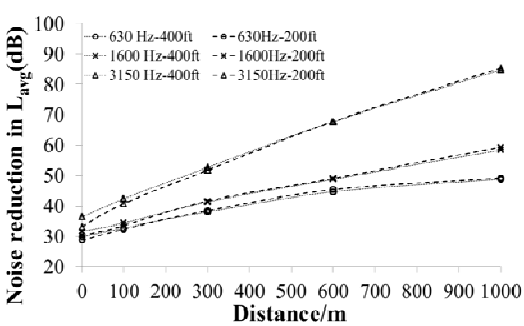
(c) 3150Hz (d) Average of 3 frequencies

Figure. 0.5. Variances of the aircraft noise attenuation L_{avg} *on façades* among the 20 sites, with increasing horizontal distance between site and flight path of 0m, 100m, 300m, 600m and 1000m.

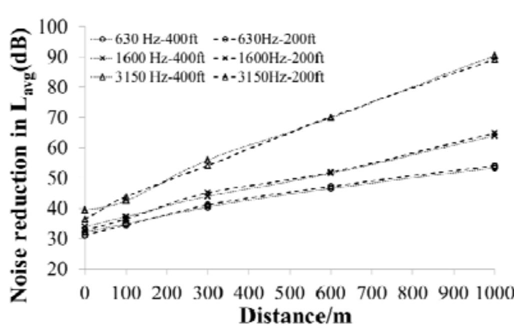
6.3.2 Effects of flight altitude

Figure 6.6 compares the mean values of aircraft noise attenuation (re. source power level) of the 20 sites between the flight altitude of 200 ft and 400 ft, in terms of L_{avg}, L_{10} and L_{90}. It is interesting to note that the increase from 200 ft to 400 ft in flight altitude generally does not benefit the noise attenuation. This is perhaps because although the increase of the flight altitude results in larger source-receiver distances, it also decreases the shielding effects of the buildings. The previous study demonstrates that the enhancement of sound level by streets relative to that in the open field decreases with the increase of flight altitude, from 5.0 dBA at 200 ft to 2.0 dBA at 400 ft (Kinney et al, 1974). In Figure 6.6, it can be observed that at 1000 m, there is almost no difference in noise attenuation between the two altitudes.

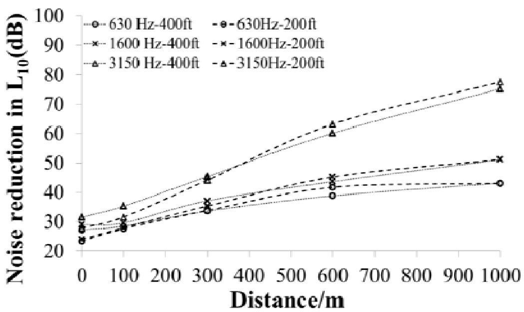
In Figures 6.4 and 6.5, comparisons of variances of spatial noise attenuation between the two flight altitudes are also illustrated. The increase of altitude does not significantly diminish the variances. In other words, the effect in the change of altitude on the influence of urban morphology on noise resistance is small, less than 1 dB mostly.



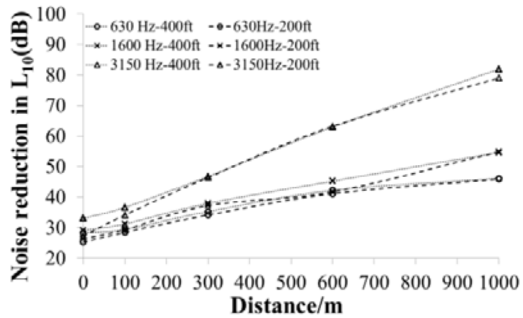
(a) L_{avg} in open areas



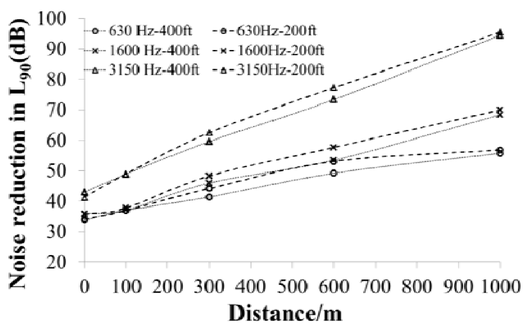
(d) L_{avg} on façades



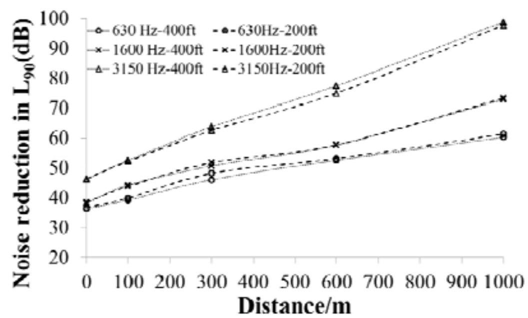
(b) L_{10} in open areas



(e) L_{10} on façades



(c) L_{90} in open areas



(f) L_{90} on façades

Figure. 0.6. The mean values of aircraft noise attenuation (re. source power level) of the 20 sites between the flight altitude of 200ft and 400ft, in terms of L_{avg}, L_{10} and L_{90}, with increasing horizontal distance between site and flight path of 0m, 100m, 300m, 600m and 1000m.

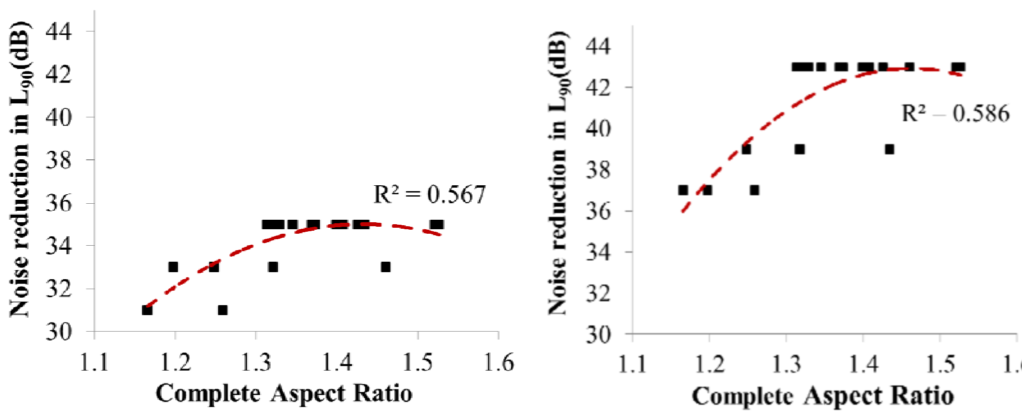
Compared with on façades, the influence of altitude on noise attenuation in open areas is more significant at L_{90}, as can be observed by comparing Figures 6.6-c&f. However, surprisingly, the noise attenuation is generally higher at the altitude of 200 ft than 400 ft, suggesting that, in certain situations, the increase of altitude does not decrease, but increase the sound levels in relatively quiet areas. The reason might be that the shielding effect that plays a key role in quiet area protection decreases with the increase of the flight altitude.

6.3.3 The relations between aircraft noise attenuation and independent urban morphological parameters

Relationships between the aircraft noise attenuation and the independent morphological parameters have been examined at the flight altitude of 200 ft, because the variances at 200 ft are higher than those at 400ft. Three typical horizontal distances between the site and the flight path are investigated, i.e., 0 m, 300 m, and 1000 m. Among the three independent urban morphological parameters, including the Building Plan Area Fraction (BPAF), the Complete Aspect Ratio (CAR), and the Building Surface Area to Plan Area Ratio (BSAPAR), at the distances of 0 m, 300 m and 1000 m, the BPAF is not significantly correlated to any of the acoustic indices, i.e., spatial L_n and L_{avg}, suggesting that the coverage has little influence on aircraft noise resistance, while the CAR and the BSAPAR have more significant correlations ($p < 0.05$) with the indices, as shown in Tables 6.3 and 6.4. It can be observed in Table 6.3 that the CAR is more correlated with the indices in open areas, mostly at L_{90}, indicating that the total surface area of building and ground may significantly influence the noise level in quiet areas. Figure 6.7 further illustrates the tendencies of L_{90} at 630Hz (R^2=0.567) and 3150Hz (R^2=0.586) with a change of the CAR, as examples. When the CAR increases the regression line of either L_{90} of 630 Hz or 3150 Hz in open areas goes up and then becomes stable after the CAR is higher than approximately 1.4. In other words, the importance of the CAR on noise attenuation in open areas becomes less when it is higher than 1.4. The correlations also exist between the CAR and the acoustic indices on façades, but they are not at a statistically significant level.

Table 0.3. Significances of the correlations between acoustic indices and Complete Aspect Ratio in terms of *p* values, where * indicates *p*<0.05 level (2-tailed), and ** indicates *p*<0.01 level (2-tailed) in Bivariate Correlation.

Distance(m)		0			300			1000		
Frequency(Hz)		630	1600	3150	630	1600	3150	630	1600	3150
Open Areas	L_{10}	.721	.084	-	0.59	.148	.805	-	.449	.377
	L_{50}	.402	.371	.917	.272	.614	.199	.363	.627	.180
	L_{90}	**.005****	.151	**.001****	.082	.170	.477	**.008****	**.005****	**.037***
	L_{avg}	.070	.060	.536	**.036***	.169	.261	.100	.130	.222
Façades	L_{10}	.712	.121	.712	.072	.712	.072	.250	.060	.919
	L_{50}	.325	.757	.499	.061	.523	.061	**.040***	.081	.147
	L_{90}	.681	.779	.800	.741	.820	.741	.429	**.029***	.597
	L_{avg}	.150	.553	.565	.284	.806	.284	**.044***	.067	.168



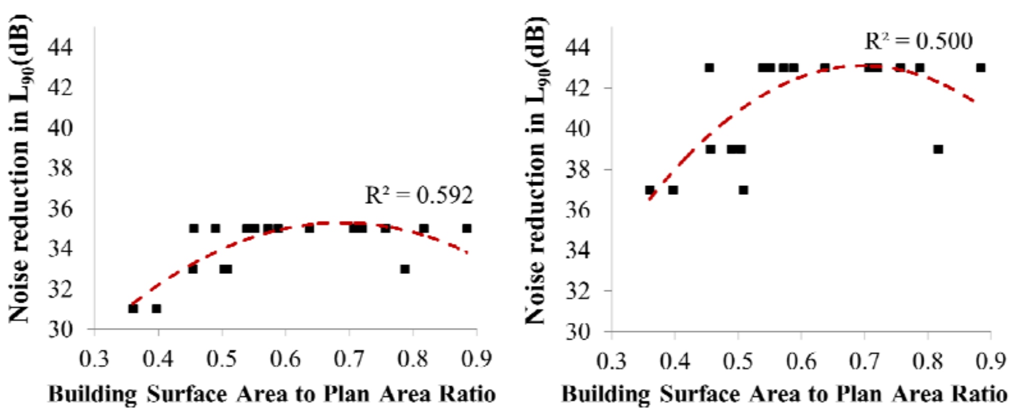
(a) 630Hz (b) 3150Hz

Figure. 0.7. Relationships between L_{90} in open areas and the Complete Aspect Ratio (CAR).

From Table 6.4 it can be observed that the Building Surface Area to Plan Area Ratio (BSAPAR) also tends to have high correlations with the acoustic indices, especially at L_{90} in open areas. The tendencies of L_{90} in open areas at 630 Hz (R^2=0.592) and 3150 Hz (R^2=0.500) with a change of the Building Surface Area to Plan Area Ratio are further illustrated in Figure 6.8.

Table 0.4. Significances of the correlations between acoustic indices and Building Surface Area to Plan Area Ratio in terms of *p* values, where * indicates $p<0.05$ level (2-tailed), and ** indicates $p<0.01$ level (2-tailed) in Bivariate Correlation.

Distance(m) / Frequency(Hz)		0			300			1000		
		630	1600	3150	630	1600	3150	630	1600	3150
Open Areas	L_{10}	.379	.140	-	**.019***	.143	.264	-	.373	.499
	L_{50}	.466	.470	.810	.453	.192	.322	.150	.520	.083
	L_{90}	**.021***	.297	**.022***	.173	.158	.966	**.027***	**.018***	.088
	L_{avg}	**.050***	.064	.883	.151	.101	.157	.064	.089	.264
Façades	L_{10}	.379	.108	.379	.051	.379	.051	.512	**.050***	.773
	L_{50}	.177	.854	.578	.115	.584	.155	**.039***	.106	.352
	L_{90}	.665	.695	.941	.691	.916	.691	.239	**.010****	.735
	L_{avg}	.260	.718	.758	.315	.504	.315	.071	.097	.319



(a) 630Hz (b) 3150Hz

Figure. 0.8. Relationships between L_{90} in open areas and the Building Surface Area to Plan Area Ratio (BSAPAR).

Figure 6.8 indicates that the noise attenuation in open areas at L_{90} increases before the Building Surface Area to Plan Area Ratio is about 0.7 and then decreases, both at 630

Hz and 3150 Hz. The reason might be that the increase of the building surface area induces more sound reflections between the buildings, further increasing noise levels.

6.3.4 The relations between aircraft noise attenuation and sound source dependent urban morphological parameters

Three sound source dependent parameters, including the Building Frontal Area Index (BFAI), the Height-to-Width Ratio (HWR) and the Horizontal Distance of First-row Building to Flight Path (HDFBFP), have been also investigated. No significant correlation is shown between the HWR and the acoustic indices. This corresponds to a study by Ismail and Oldham (2002) on the effects of street canyon on the noise from low flying aircraft, showing that street width indicated by the HWR in the current study hardly plays a role in the noise attenuation. The correlations between acoustic indices and the BFAI and the HDFBFP are illustrated in Tables 6.5 and 6.6. By comparing Tables 6.3&6.4 and 5&6, it can be concluded that, generally speaking, the sound source dependent parameters are more correlated with the acoustic indices than the independent ones.

From Table 6.5 it can be observed the that Building Frontal Area Index generally has more correlations with the acoustic indices than the independent parameters when the distance is 1000 m (see Table 6.3, 6.4 and 6.5), suggesting that, for aircraft noise attenuation, the barrier effect of urban morphology may play a more crucial role than the other effects when the distance is relatively large. However, when the horizontal distance between the site and the flight path becomes smaller, e.g., 300 m, there are fewer correlations between acoustic indices and BFAI, because the barrier effect by the building façades plays a less significant role.

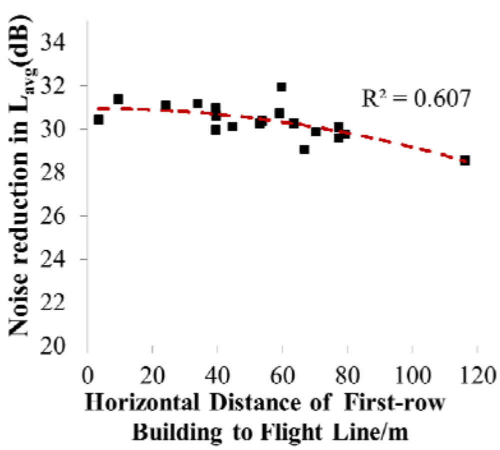
Table 0.5. Significances of the correlations between acoustic indices and Building Frontal Area Index in terms of *p* values, where * indicates $p<0.05$ level (2-tailed), and ** indicates $p<0.01$ level (2-tailed) in Bivariate Correlation.

Distance(m)		0			300			1000		
Frequency(Hz)		630	1600	3150	630	1600	3150	630	1600	3150
Open Areas	L_{10}	.640	**.027***	-	.160	.238	.583	-	.390	.265
	L_{50}	.258	.401	.778	.544	.221	.321	.065	.156	.013
	L_{90}	.159	.060	**.022***	.065	.239	.533	**.002****	**.002****	**.002***
	L_{avg}	.149	**.049***	.323	.110	.078	.328	**.018***	**.032***	**.029***
Façades	L_{10}	.640	**.016***	.640	.174	.640	.174	.181	.060	.421
	L_{50}	.601	.842	.918	.303	.158	.303	**.002****	**.020***	.067
	L_{90}	.839	.635	.868	.913	.399	.913	.662	.798	.187
	L_{avg}	.244	.638	.555	.551	.847	.551	**.029***	**.033***	.064

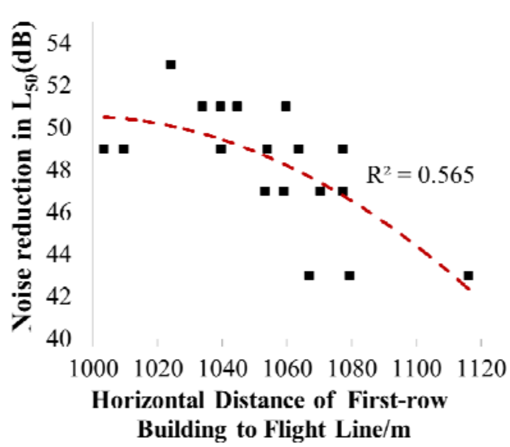
The Horizontal Distance of First-row Building to Flight Path (HDFBFP) has the most correlations among the six parameters, especially with the acoustic indices in open areas, as can be observed in Table 6.6. Unlike the Complete Aspect Ratio, Building Surface Area to Plan Area Ratio and the Building Frontal Area Index, which have fewer correlations at L_{avg} and L_{50} (see Table 6.3, 6.4 &6.5), the HDFBFP is highly correlated with L_{avg} (e.g. p=0.000, at 1600 Hz at 0 m) and L_{50} (e.g., p=0.000, at 630 Hz at 1000 m) in open areas, although on façades it is almost not correlated with the acoustic indices, as shown in Table 6.6. Figure 6.9 further illustrates the relationships between acoustic indices in open areas and the HDFBFP. In Figure 6.9-a, at 0 m, the mean L_{avg} at 1600 Hz decreases slowly with the increase of the HDFBFP, indicating that, if a given low-density site has a row of buildings that are close to the flyover aircraft horizontally, the average noise level in open areas might be considerably reduced, due to the barrier effect. At 1000 m, the noise attenuations at L_{50} at 630 Hz and 3150 Hz both decrease constantly when the HDFBFP increases; the difference between the maximum and minimum level is high, at approximately 10 dB, as shown in Figure 6.9-b&c. In other words, the distance between the first row buildings to the flight path might play a very significant role in the protection of quiet open areas at L_{avg} and L_{50}.

Table 0.6. Significances of the correlations between acoustic indices and Horizontal Distance of Building to Flight line in terms of *p* values, where * indicates $p<0.05$ level (2-tailed), and ** indicates $p<0.01$ level (2-tailed) in Bivariate Correlation.

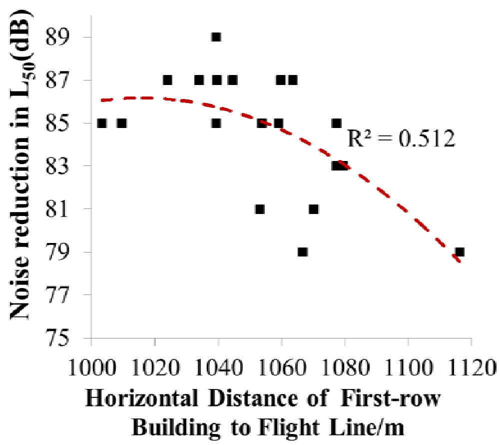
Distance(m)		**0**			**300**			**1000**		
Frequency(Hz)		630	1600	3150	630	1600	3150	630	1600	3150
Open Areas	L_{10}	.481	**.050***	-	.768	.110	.147	-	.909	.088
	L_{50}	.194	.062	.450	.650	**.003****	**.010****	**.000****	**.010****	**.002****
	L_{90}	.687	.513	.355	.334	**.032***	.861	.132	.091	**.034***
	L_{avg}	**.021***	**.000****	.774	.712	**.001****	**.007****	**.001****	**.002****	**.003****
Façades	L_{10}	.481	.936	.481	**.033***	.481	**.033***	.165	.253	.309
	L_{50}	.570	.360	.297	.991	.194	.991	.330	.401	.728
	L_{90}	.657	.643	.661	.994	.844	.994	.337	.833	.750
	L_{avg}	.530	.202	.321	.894	.797	.894	.922	.830	.583



(a) L_{avg} at 1600Hz



(b) L_{50} at 630Hz



(c) L_{50} at 3150Hz

Figure. 0.9. Relationships between acoustic indices in open areas and the Horizontal Distance of First-row Building to Flight Path (HDFBFP).

To overview the above results about the correlations between urban morphological parameters and acoustic indices, Table 6.7 shows the numbers of correlations according to the acoustic indices; Table 6.8 gives the numbers of correlations according to the horizontal distances between the site and the flight path. It can be observed from Table 6.7 that L_{90} (15) and L_{avg} (13) in open areas are more correlated with the urban morphological parameters than L_{10}, suggesting that control of urban morphological parameters can benefit aircraft noise attenuation for both the relatively quiet areas and the whole area of a given site. Table 6.8 shows that, when the distance is 1000 m, urban morphology has greater influence on the aircraft noise attenuation, both on façades and in open areas. Overall, two parameters, the Building Frontal Area Index (BFAI), (14) and the Horizontal Distance of First-row Building to Flight Path (HDFBFP) (17) have more correlations than the others.

Table 0.7. The number of correlations between urban morphological parameters and acoustic indices, according to the acoustic indices L_{10}, L_{50}, L_{90} and L_{avg}, both on façades and in open areas.

Urban Morphological Parameters	**Open areas**				**Façades**				**Total**
	L_{10}	***L_{50}***	***L_{90}***	***L_{avg}***	***L_{10}***	***L_{50}***	***L_{90}***	***L_{avg}***	
BPAF	0	0	0	0	0	0	0	0	0
CAR	0	0	5	1	0	1	1	1	9
BSAPAR	1	0	4	1	1	1	1	0	9
BFAI	1	0	4	4	1	2	0	2	14
HWR	0	0	0	0	0	0	0	0	0
HDFBFP	1	5	2	7	2	0	0	0	17
Total	3	5	15	13	4	4	2	3	49

Table 0.8. The number of correlations between urban morphological parameters and acoustic indices, according to the horizontal distance between site and flight path, at 0m, 300m and 1000m, both on façades and in open areas.

Urban Morphological Parameters	**Open areas**			**Façades**			**Total**
	0m	***300m***	***1000m***	***0m***	***300m***	***1000m***	
BPAF	0	0	0	0	0	0	0
CAR	2	1	3	0	0	3	9
BSAPAR	3	1	2	0	0	3	9
BFAI	3	0	6	1	0	4	14
HWR	0	0	0	0	0	0	0
HDFBFP	3	5	7	0	2	0	17
Total	11	7	18	1	2	10	49

6.4 Conclusions

This chapter aims to explore whether and how the mesoscale urban morphology of low-density built-up areas influence the spatial noise level attenuation of the flyover aircrafts. Six urban morphological parameters have been selected and developed in the study. The effects of the horizontal flight path distance to the site and the flight altitude on the aircraft noise attenuation are both investigated.

The largest difference and variance of aircraft noise level attenuation are at 1000 m, among the five horizontal flight path distances to site, i.e. 0, 100, 300, 600 and 1000 m. The sound reflections by the buildings reduce the influence of urban morphology on noise attenuation. Compared with the distances of 0 m and 300 m, the acoustic indices have more correlations with the urban morphological parameters at 1000 m. The increase from 200 ft to 400 ft in the flight altitude generally does not benefit the noise attenuation significantly.

The façades have higher noise attenuation than open areas, but the variances of the acoustic indices on façades, including L_{10}, L_{50}, L_{90} and L_{avg}, are lower, and their correlations with the urban morphological parameters are less. In other words, urban morphology plays a more important role in the aircraft noise attenuation in open areas than on façades. Moreover, the control of the urban morphological parameters can benefit aircraft noise level attenuation more in quiet open areas and the whole area, rather than noisy open areas.

The urban morphological parameters tend to have considerable correlations with flyover aircraft noise attenuation in this study. Compared with the sound source location independent morphological parameters, the sound source dependent parameters may have greater influence. The general tendency is that the Building Frontal Area Index (BFAI) and the Horizontal Distance of First-row Building to Flight Path (HDFBFP) correlate with the noise attenuation most, while the Building Plan Area Fraction (BPAF) and the Height-to-Width Ratio (HWR) hardly influence the noise attenuation. The noise level attenuation at L_{90} in open areas tends to increase with the increase of the Complete

Aspect Ratio (CAR) and then stays stable after the CAR reaches approximately 1.4. The noise level attenuation at L_{90} in open areas has a tendency to increase when the Building Surface Area to Plan Area Ratio (BSAPAR) increase before approximately 0.7 and it then decreases. The noise attenuation in terms of L_{50} and L_{avg} shows a constant upward tendency when the HDFBFP decreases.

The flyover aircraft noise is not as much influenced by urban morphology as the car traffic noise, but according to the results in Chapter 3, the annoyance of the aircraft noise is 1.7 lower than that of the traffic noise in a scale of 0-10 when their sound pressure levels are both approximately 63 dBA. It has been also demonstrated that the masking effects of birdsong can significantly reduce the perceived loudness of aircraft noise, so it is useful to enlarge the vegetation area as bird habitats in the aircraft noise environments to compensate the role of buildings on aircraft noise attenuation.

CHAPATER 7

ENHANCEMENT OF BIRDSONG LOUDNESS AND VISIBILITY OF GREEN AREAS

Chapter 5 and 6 suggest the methods of noise attenuation by urban morphology. However, as proved in Chapter 3, the methods are only useful for annoyance reduction rather than pleasantness improvement. The soundscape naturalness and pleasantness are significantly improved with the masking effects of birdsong as mentioned in Chapter 4, so it is crucial to enhance audibility of birdsong for soundscape quality improvement. Meanwhile, it has been also demonstrated in Chapter 4 that, the visibility of sound sources can decrease annoyance and increase pleasantness, so increasing the visibility of vegetation as bird habitats is another important concern. Therefore, the aim of this chapter is to determine how to increase audibility of birdsong and the visibility of green areas in the low-density residential areas by controlling urban morphological parameters. The spatial distributions of birdsong sound levels at 12 sampled sites were simulated using noise mapping techniques and calculated with a MATLAB program on spatial sound level matrices, and the visibilities of green areas are analysed and calculated by the Visibility Analysis Graph in Space Syntax. Correlation analyses were conducted between the obtained data on spatial sound level indices, mean visibility and the urban morphological parameters.

7.1 Introduction

Green areas are an important natural resource in urban areas and can fulfill a variety of human needs (Amir and Misgav, 1990), such as natural view (Lange et al, 2008), air quality (Currie and Bass, 2008), microclimate (Shashua-Bar and Hoffma, 2000) and noise reduction (Fang and Ling, 2003; Van Renterghem et al, 2012). Green areas therefore are significant for quality of life and have high social and economic values

(Anderson and Cordell, 1988; De Hollander and Staatsen, 2003; Kirkpatrick et al, 2012). In terms of natural view, green areas have been often studied from the viewpoints of visibility (Yang et al, 2009), aesthetics, recreation, (Lange et al, 2008),safety and preference (Jorgensen et al, 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 and Kirkpatrick, 2006; Pellissier et al, 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 in urbanised areas (Ryan and Brenowitz, 1985; Halfwerk and Slabbekoorn; 2009; Cardoso and Atwell, 2011). Recently, with the emergence of the 'soundscape' concept, research on urban sound environment has been extended to perceptual assessment, beyond the conventional noise control, where sound preferences (Yang and Kang, 2005; Lam et al, 2010; Yu and Kang, 2010), as well as the influence of sound environment on physical and psychological health, rejuvenation and affection (Lee et al, 2010; Schulte-Fortkamp and André, 2006; Guastavino, 2006), have been intensively studied. Within the scope of soundscape, masking effects on urban noise have been demonstrated to significantly influence perception of sound environment (Nilsson et al, 2009; De Coensel et al, 2011) and considered as an important urban design tool (Siebein, et al, 2007). Birdsong is ranked at the top of the desired urban sounds (Yang and Kang, 2005) and studied as a noise masker (Best et al, 2005; Gidlöf-Gunnarsson et al, 2007). The masking effects of birdsong can enhance soundscape pleasantness more significantly than those of fountain sounds (De Coensel et al, 2011). Therefore, besides natural view, green areas can also benefit people's rejuvenation and health through the masking effects of birdsong (Gidlöf-Gunnarsson and Öhrström, 2007).

The main motivation of this study is to determine how to enhance the masking effects of birdsong on traffic noise because of their rather common sound interferences in the urban areas (Kang, 2007; Gold, 2010). Two aspects are concerned: One is to increase audibility of birdsong to enhance its 'energetic masking' (Moore, 1997; Zwicker and Fastl, 1999); the other is to increase the visibility of green areas to enhance 'informational masking' of birdsong that is context-dependent (Shinn-Cunningham, 2008; Kidd et al, 2008), because visual information is one of the most crucial contexts for 'informational masking'. It has also been demonstrated that people can obtain a more comfortable feeling by the aural-visual interaction when the sounds are related to the scenes (Yamaguchi et al, 2009; Jeon et al, 2011).

Urban morphology has direct and substantial influences on both outdoor sound propagation (Raydan and Steemers, 2006; Kang 2007) and space visibility (Yang, et al, 2009; Sander and Manson, 2007). However, there is a lack of integrated research on green areas in the context of urban morphology from the perspectives of both audibility of birdsong and the visibility of green areas to suggest practical landscape and urban design guidelines.

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

7.2 Methods

7.2.1 Site sampling

The study sites were sampled in the capital city of the province of Drenthe, Assen, which as indicated in Chapter 5 can be regarded as a typical European town with diverse low-density urban morphologies and traffic characteristics. Using a GIS database of 763 grids (each 250 m x 250 m) of the built-up areas of Assen, approximately 51% of the grids have traffic and arboreal green areas, which may result in masking effects between the two main sound sources at the sites (i.e., traffic noise and birdsong). The green ratio of Assen, 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 from the GIS database. Figure 7.1 shows figure-ground maps of the sampled sites, with the buildings in black, roads in grey and green areas in green. It can be seen in Figure 7.1 that the urban morphology of the 12 sampled sites are diverse.

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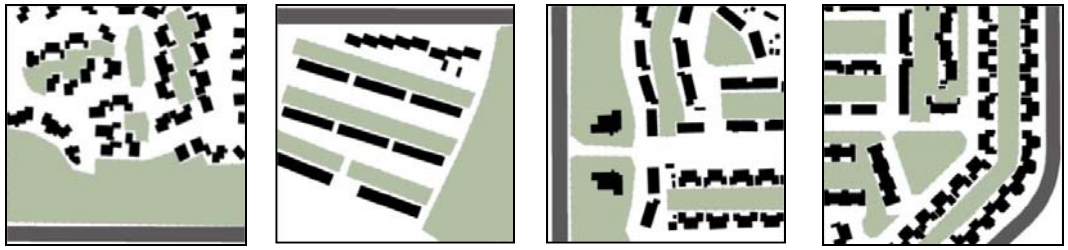


Figure. 7.1. Figure-ground maps of the 12 sampled study sites. The IDs of the sites are composed by letters and numbers.

7.2.2 Selection and calculation of urban morphological parameters

As mentioned in Chapter 5 and 6, to quantitatively compare diverse urban textures, urban morphological parameters have been explored, developed and employed in the previous studies. The urban morphological parameters which may be related to birdsong distribution and view of green areas have been selected and developed from the perspective of possible effects of urban morphology on outdoor sound propagation (e.g. distance and ground effects, barrier effect and canyon effect) and urban view block. Table 7.1 lists seven parameters can indicate the characteristics of plot and street pattern, ground and building surface condition, and building (barrier) geometry.

Table 7.1. Calculations of the seven urban morphological parameters.

Parameter	Definition	Formula	Notes
Building Plan Area Fraction (BPAF)	The ratio of the plan area of buildings to the total surface area of the study region.	$BPAF = \frac{A_p}{A_T}$	A_p is the plan area of buildings at ground level and A_T is the total plan area of the region of interest.
Complete Aspect Ratio (CAR)	The summed area of roughness elements and exposed ground divided by the total surface area of the study region (Voogt and Oke 1997; Grimmond and Oke, 1999)	$CAR = \frac{A_C}{A_T} = \frac{A_W + A_r + A_G}{A_T}$	A_C is the combined surface area of the buildings and exposed ground, A_W is the wall surface area, A_r is the roof area, A_G is the area of exposed ground (Burian et al, 2005).

Building Surface Area to Plan Area Ratio (BSAPAR)	The sum of building surface area divided by the total surface area of the study region	$BSAPAR = \frac{A_r + A_W}{A_T}$	A_r is the plan area of rooftops, A_W is the total area of non-horizontal roughness element surfaces (e.g. walls) (Burian et al, 2005).
First-row Building Frontal Length Index (FBFLI)	The total length of the first-row buildings parallel with the green area edges (L_{para1}) divided by the sum of the perimeters of building footprints of the study region (L_T)	$BFAI(\theta) = \frac{L_{para1}}{L_T}$	θ is the direction of green area edge.
Distance of First-row Building to Green Area (DFBGA)	The mean of the distances from the frontal façades of the first-row buildings to the green area.	$DFBR = \frac{1}{n}\sum_{i=1}^{n} d_i$	n is the total number of first-row buildings, and d_i is the distance from the first-row building to the green area.
Green Area Perimeter (GAP)	The sum of the perimeters of all green areas within the study region.	$GAP = \sum_{i=1}^{N} C_i$	N is the total number of green areas, and C_i is the perimeter of the green area.
Green Area Dispersion Index (GADI)	The variance of the linear distances between the geometrical centre of the study region and each vertex of green areas divided by the mean value of the linear distances.	$GADI = \frac{\sigma^2}{\mu}$	σ^2 is the variance, and μ is the mean value.

The seven quantitative parameters are the Building Plan Area Fraction, the Complete Aspect Ratio, the Building Surface Area to Plan Area Ratio, the First-row Building Frontal Length Index, the Distance of First-row Building to Green Area, the Green Area Perimeter, and the Green Area Dispersion Index. The first three parameters are for the 2D and 3D characteristics of buildings; the fourth and fifth reflect the characteristics of relative locations between buildings and green areas, and the last two parameters pertain to the 2D characteristics of green areas. Figure 7.2 shows the calculated values of the seven urban morphological parameters of the 12 sampled sites.

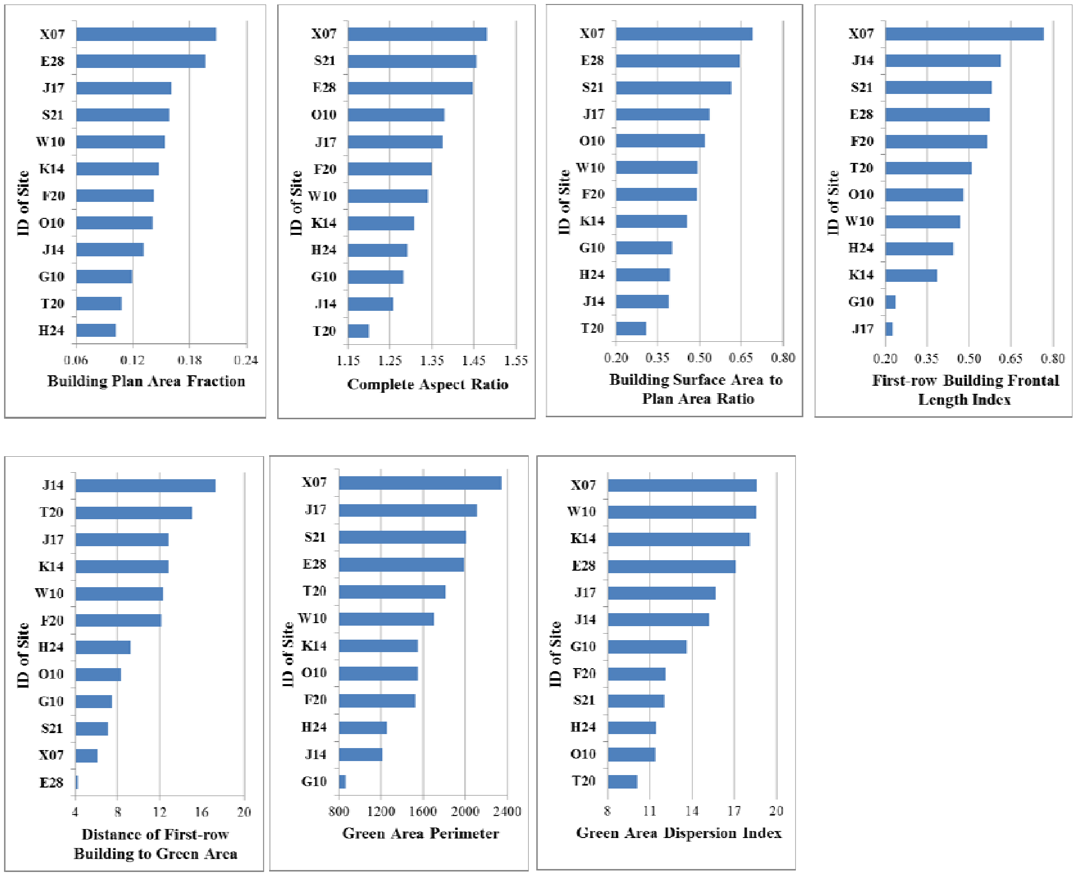
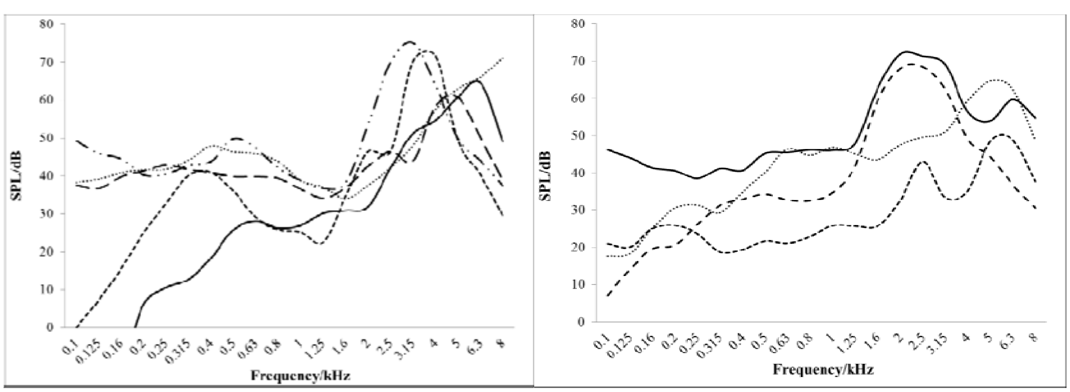


Figure. 7.2. Values of the seven urban morphological parameters of the 12 sampled sites.

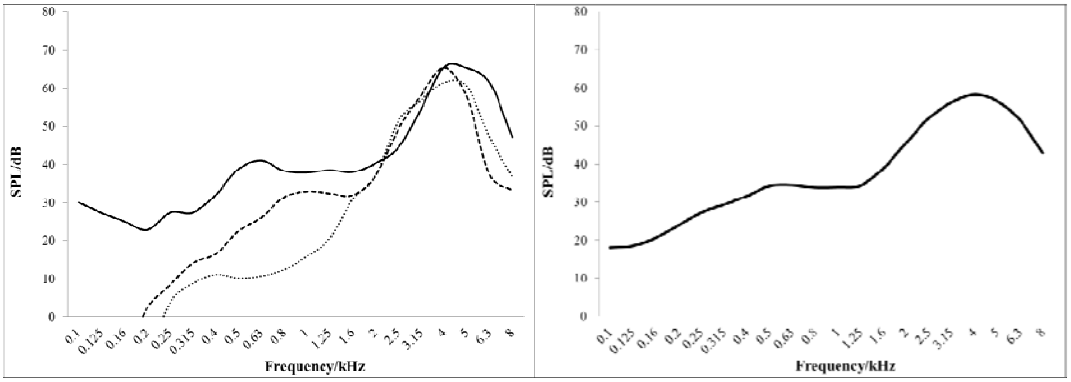
More than 70% of the residential buildings in Assen are low-rise terraced and detached buildings with heights primarily between of 8 to 10 meters (Kadaster, 2004). Building Plan Area Fraction varies from 0.10 to 0.21; Complete Aspect Ratio from 1.20 to 1.48; Building Surface Area to Plan Area Ratio from 0.31 to 0.69; First-row Building Frontal Length Index from 0.23 to 0.77; Distance of First-row Building to Green Area from 4.24m to 17.34m; Green Area Perimeter from 869m to 2340m; and Green Area Dispersion Index from 10.11m to 18.62m. In general, as shown in Figure 7.2, the values of each parameter evenly distribute in the ranges, indicating a quantitative diversity of the urban morphologies of the sites within the ranges.

7.2.3 Settings of the birdsong parameters in simulation

The homogenization effects of urbanisation has altered the composition of biological communities (Turner et al, 2004; Marzluff, 2001) and increased species similarity (Blair, 2001). In European cities, heterogeneity of avifauna species in towns is low, especially in the centre, indicating simple urban bird communities and the replacement of specialist species by generalist species (Clergeau et al, 2006; Pellissier et al, 2012). Moreover, because the homogenization of bird species has been demonstrated to be even higher in the area with high similarity of building heights (Pellissier et al, 2012), to be representative, in the urban morphology as Assen, birdsongs of the three passerine bird species that are common urban bird communities in Europe, have been selected, including Great Tit (*Parus major*), Common Blackbird (*Turdus merula*) and Sparrow (*Passer*) (Clergeau et al, 1998; Clergeau et al, 2006). Figure 7.3 shows the spectrum analysis of the recorded birdsongs of the three bird species in Europe from the database of Xeno-canto (2012). The energy of the birdsongs concentrates on the frequencies 2000 to 8000 Hz, so in this study three representative frequencies, i.e., 2000, 4000 and 8000 Hz, were used in the simulation.



(a) Great Tit (b) Common Blackbird



(c) House Sparrow (d) Spectrum in average

Figure. 7.3. The spectrum analysis of recorded birdsongs, with five high-quality recordings for Great Tit, four for Common Blackbird and three for House Sparrow. The spectrum in (d) is the average values of the total 12 spectra.

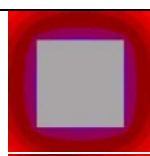
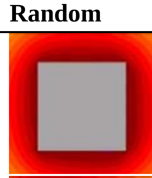
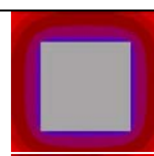
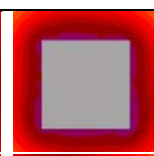
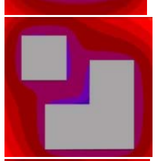
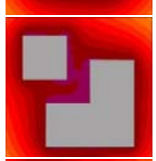
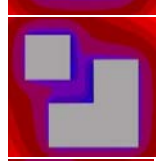
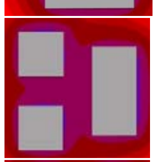
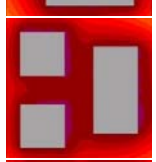
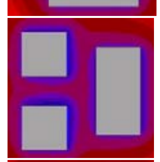
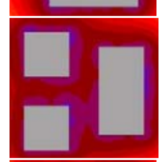
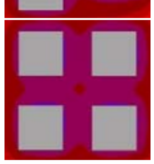
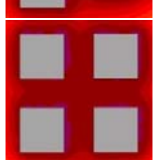
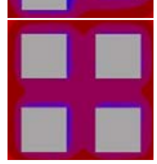
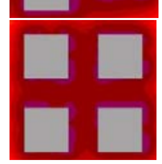
To simulate the spatial distribution of birdsong sound levels, sound maps were calculated using a common noise-mapping package, Cadna/A (DataKustik GmbH, 2006; Szulecki et al, 2010; McGowan, 2012). Urban trees are simulated as major bird habitats, because compared with countryside, birds nest more in trees than on ground or shrubbery in town centres. Approximately 70% of Passeriformes nest higher than 4m in the center of European town (Clergeau et al, 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 et al, 1999; Clergeau et al, 2006; Pellissier et al, 2012). Therefore, birdsong sources are set to two representative heights in trees at the sites: 4m (lower than the general building heights) and 10m (higher than the typical building heights); sound reflections by buildings with these two conditions can be compared.

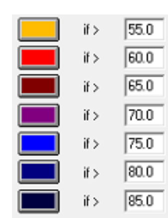
7.2.4 Simulation of birdsong in idealised wide open spaces

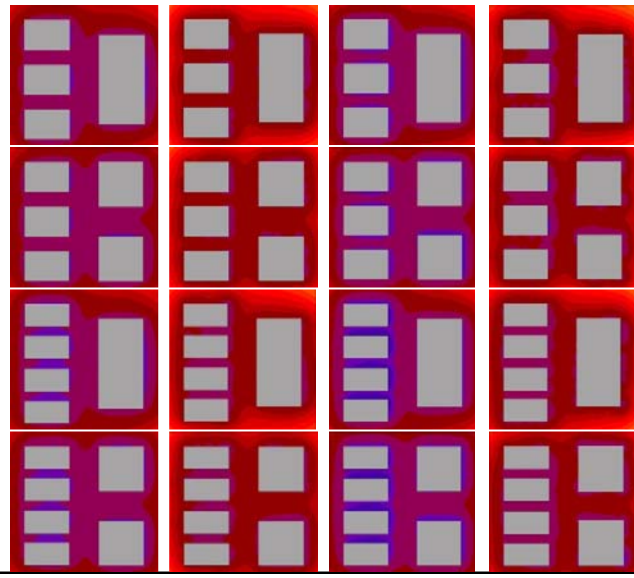
In Adolphe's study (2001) on the model of urban morphology for the environmental performance, to simplify the parameterisation of vegetation and bodies of water, 'useful area' is defined as an element in highly mineral urban spaces from the perspective of the roles of vegetation or water area on environmental performance, e.g., solar heat storage, humidity, heat island or pollutants. In accordance with this concept, the hypothesis of this study is that green area can be examined as an integrated component with a 'circumscribed cylinder' shape (Adolphe, 2001) composed of vegetation and birds in an urban morphology, without particular attention to the distributions of individual sound sources. Homogenisation effects of urbanisation on biological communities are also an important reason for the hypothesis.

The influence of geometric configurations of green areas and distributions of sound sources on birdsong propagation are initially examined without sound obstacles (e.g., buildings), as a pilot investigation for birdsong in the actual urban morphology. In the simulation, birdsong is emitted from green areas (250m x 250m) in eight idealised open sites, with a consistent green ratio of 36%. The geometric configurations of the green areas are abstracted from the commonly seen design of green areas in residential communities in the Assen GIS database. The distribution of sound sources, i.e., where birdsongs are emitted in the green areas, is a substantial issue in the simulation. Because of the edge effects on bird habitats (e.g., feeding, foraging, and net selecting), as noted in several studies (Hansson, 1994; D McCollin, 1998; Huhta et al, 1999), sources that are localised on the boundaries of green areas were considered along with uniformly distributed sources throughout the green areas. Birdsong may attenuate less rapidly at an intermediate frequency window from 1600-2500 Hz, particularly in long-range communication in low-forest habitats (Morton, 1975), the birdsong was initially simulated using a song band source at a representative frequency of 2000 Hz and a representative habitat height of 4 m.

Figure 7.4 shows sound maps of birdsong emitted from the eight green areas. Four different types of sound source distributions in trees were examined, including an idealised situation of full distribution of sound sources in rectangular arrays (RF), a random distribution of 50% sound sources in rectangular arrays (RR), full distribution of sound sources along green area boundaries (BF), and a random distribution of 50% sound sources along green area boundaries (BR). For the two types of full distributions, the tree spacing is 10 m x 10 m. To make the four types comparable, the total sound energy of birdsong of RF was the same as that of BF, based on the assumption that a same size of green area affords a same bird population. Receivers in a rectangular array of 5 m x 5 m were placed to obtain the sound levels of birdsong outside of the green areas at each site in the simulations.

	Rectangular array, Full	**Rectangular array, Random**	**Boundary, Full**	**Boundary, Random**	**Perimeter/ m**
Pattern A					600
Pattern B					900
Pattern C					1050
Pattern D-1					1200





Pattern D-2	1200
Pattern E-1	1350
Pattern E-2	1350
Pattern F	1500

Figure. 7.4. Sound maps of birdsong emitted from 8 typical patterns of green areas. Four different types of sound source distributions in green areas are considered. (Rectangular array, full distribution of birdsong and random distribution of 50% birdsong ; Boundary, full distribution of birdsong and random distribution of 50% birdsong .)

7.2.5 Simulation of birdsong in the actual urban morphology

The 3D information of the sampled sites that can be converted into vector maps in Cadna/A was obtained from a GIS database of Assen from TOP10NL of Kadaster (Kadaster, 2004). The conditions of building façades and ground were gained from the *in-situ* investigation and Google Maps. Because the study is more a parameter study on urban morphology, to make the analysis results comparable, the sound sources are all localised along the green area boundaries with a constant distance of 10 m between two trees and emit the same total amount of sound energy of birdsong at each site. The ground absorption was set to 0 outside of green areas and 0.6 inside the green areas. Figure 7.5 shows sound maps of birdsong at 4000 Hz with a sound source height of 4m, for example.

7.2.6 Matlab processing

The same MATLAB program used in the Chapter 5 was also employed in this Chapter to obtain the values of the spatial noise indices, L_n.To investigate the birdsong environments both indoors and outdoors, the sound level values on building façades and in open areas are separately processed. Because the green areas are studied as integrated components that influences the birdsong propagation outside the green areas in urban morphology, the spatial sound level values inside the green areas are excluded.

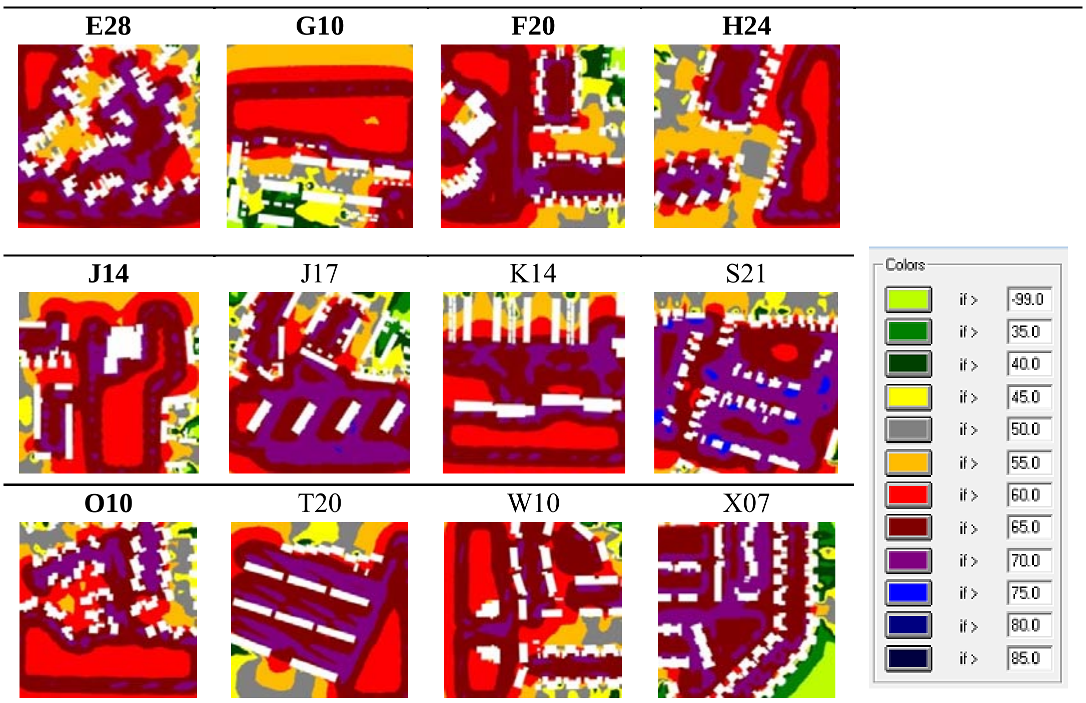


Figure. 7.5. Noise maps of birdsong at 4000 Hz at 4 m height of the 12 sites.

7.2.7 Space syntax for visibility

To evaluate the visibilities of green areas at the sites, Visibility Graphs were calculated with a commonly used Open Source application, UCL Depthmap, which performs visibility analysis of architectural and urban systems under a theory of Space Syntax related to spatial cognition (Jiang and Claramunt, 2002; Bafna, 2003; Turner, 2003; Hillier, 2012). Visibility Graphs can analyse how much any one point in a spatial network is currently visible from any other point (Turner, 2004). Desyllas and Duxbury (2001) conducted a study to test the correlation of graph measurement by both Axial Maps and Visibility Graph Analysis (VGA) with observed flow in central London, which shows that the measure of visibility by Visibility Graph Analysis performed significantly better than the Axial Map measures. Therefore, in this study, the visibility of the green areas of each site was measured as the mean value of visual connectivity in VGA. The seed points were spaced on all the green areas with a 5 m x 5 m gird, with vector plans of the sites at an eye level of 1.6 m. Figure 7.6 shows the calculation results of Visibility Graphs and the mean values of connectivity of the green areas at each site.

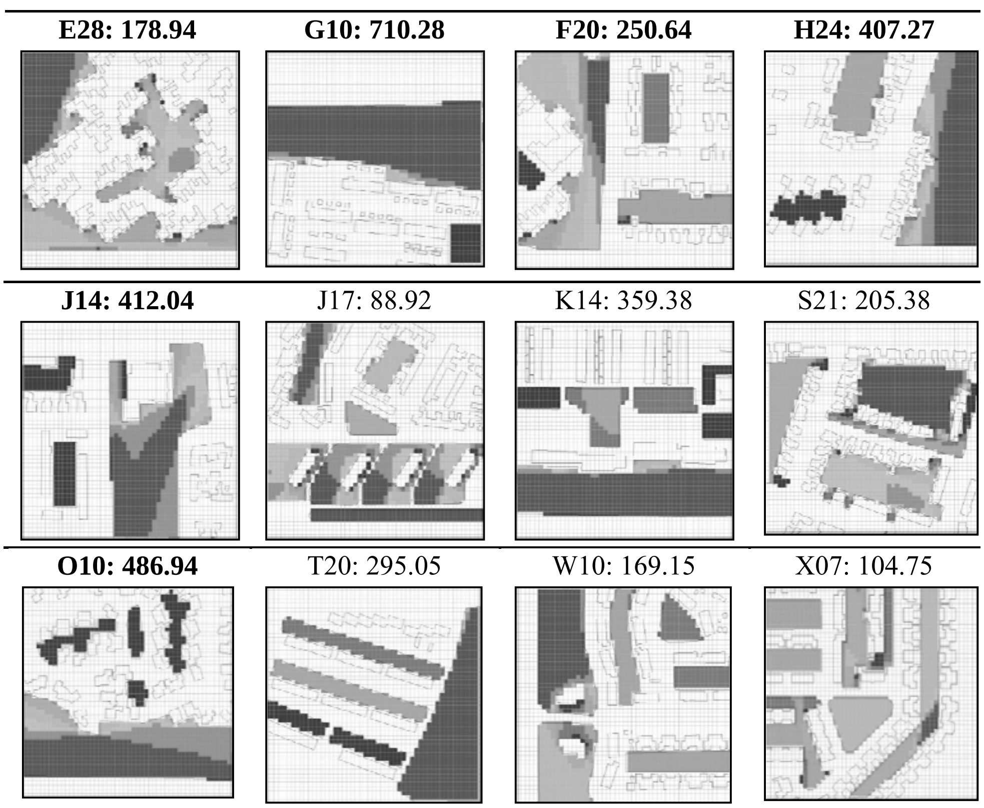


Figure. 7.6. Visibility graphs of green areas in the 12 sites and the mean value of connectivity.

7.3 Results

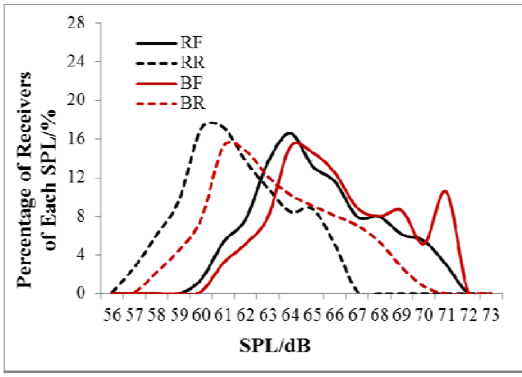
This section examines three issues: (1) how differently birdsong is spatially distributed in both the idealised wide open spaces and the actual urban areas when the green ratio is kept consistent (2) how do the urban morphological parameters influence audibility of birdsong and visibility of green areas; (3) does visibility of green areas have any relationship to birdsong loudness.

7.3.1 Audibility of birdsong

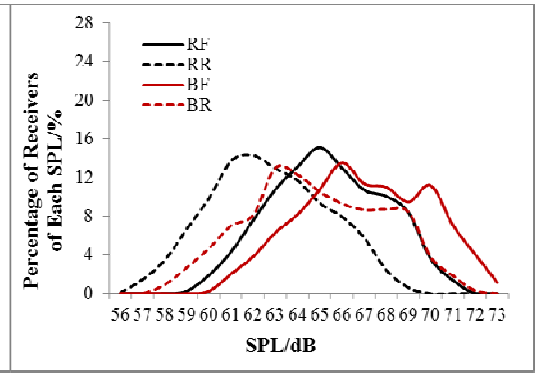
7.3.1.1 Idealised wide open spaces

Figure 7.7 shows the spatial distribution of birdsong sound levels in the idealised open spaces, for all the eight geometric configurations. Although the total birdsong energy and green area ratio are the same, certain geometric configurations have more areas with louder birdsong than the others. For example, when examining the RF (Rectangular array, full distribution of birdsong), 25.6% of the area in Pattern D-1 has 68 dB birdsong and only 10.1% of the area in Pattern B have 68 dB birdsong (shown in Figure 7.7-b&d). It is also important to note that in general, the four types of sound source distributions of each pattern have rather similar distribution curves (see Figure 7.7), which indicates that the geometric configurations of the green areas rather than the distributions of individual sound sources (i.e. in a whole area or along boundary) may influence the spatial distribution forms of birdsong sound levels outside of the green areas, even when the density of sound sources is reduced by half by random sampling.

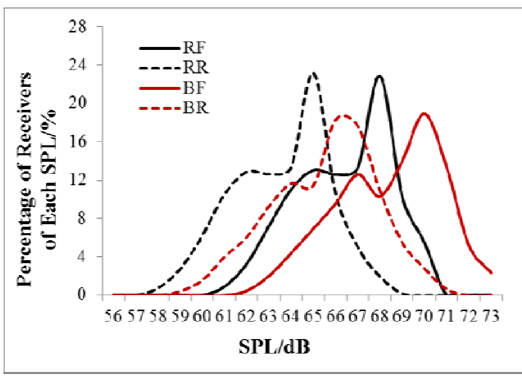
Therefore, as mentioned above in Section 7.2.4, the hypothesis can be demonstrated that the green area can be studied as an integrated component in the research on birdsong emission from green areas in urban morphology.



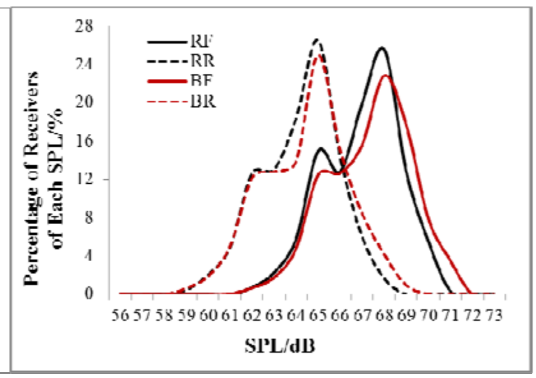
(a) Pattern A



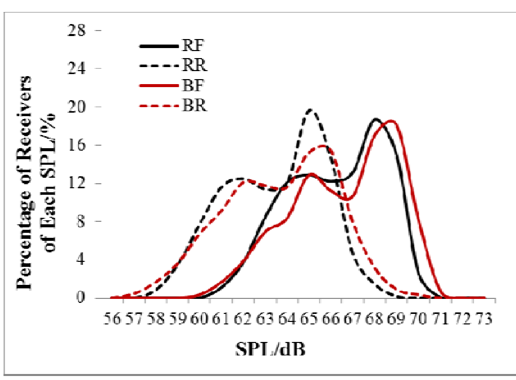
(b) Pattern B



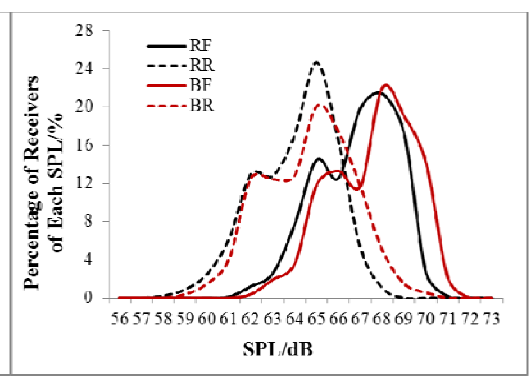
(c) Pattern C



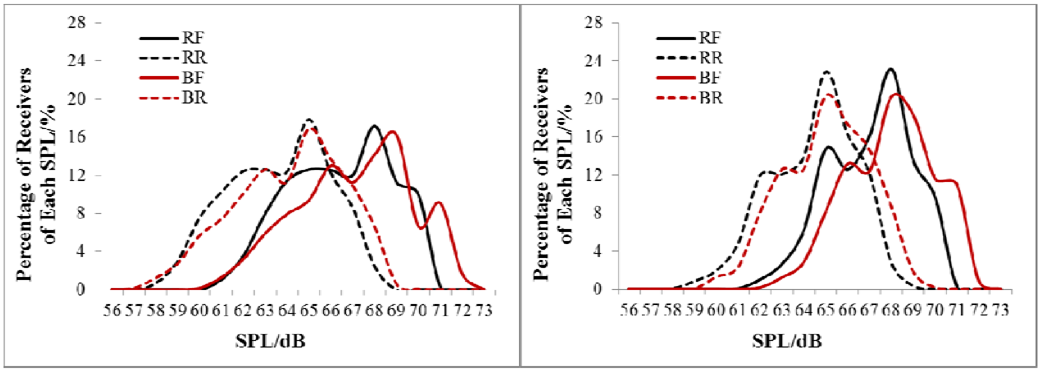
(d) Pattern D-1



(e) Pattern D-2



(f) Pattern E-1

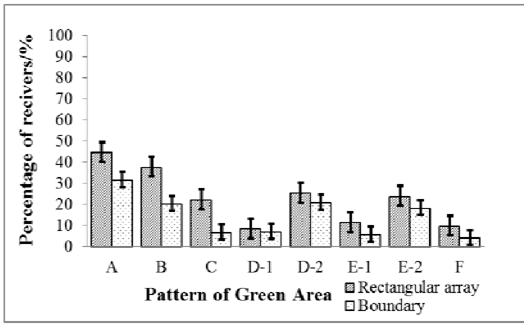


(g) Pattern E-2 (h) Pattern F

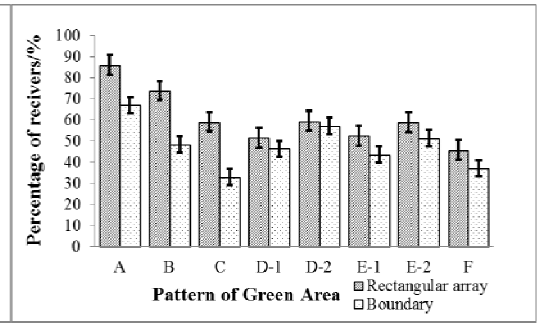
Figure. 7.7. Distributions of sound levels of birdsong at the receivers outside of the green areas, with the 4 types of sound source distributions. RF is rectangular array, full distribution of birdsong; RR is rectangular array, random distribution of 50% birdsong; BF is boundary, full distribution of birdsong; BR is boundary, random distribution of 50% birdsong.

However, from the perspective of birdsong sound levels rather than the distribution curves, birdsong outside of the green areas is generally around 0-3 dB louder when the same birdsong energy is all emitted from the boundaries than that evenly emitted from the whole green areas, as shown in Figure 7.7. In Figure 7.7-a&b, in Pattern A and B, more areas have high birdsong sound levels when birdsong energy is all emitted from boundaries. For example, 10.5% of the area has 71 dB birdsong in Pattern A when it is BF (Boundary, full distribution of birdsong), but this value is only 3.0% when it is RF. The reason may be that Pattern A and B have smaller green area perimeters, the of birdsong sound levels per meter is therefore higher than the other 6 patterns under the condition of the same total sound energy, resulting in more peak sound levels in the proximity of the green areas. With an increase of green area perimeters, this effect of peak sound levels is generally decreased, as shown in Figure 7.7-c, d, e, f &h.

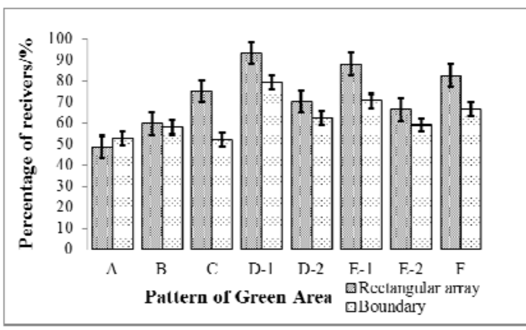
To further compare the spatial distribtion of birdsong sound levels among the eight geometric configurations, the areas with different sound levels are categoried into 3 ranges, i.e., < 65 dB, 65-69 dB and ≥ 70 dB, representing low, medium and high sound level ranges, as shown in Figure 7.8.



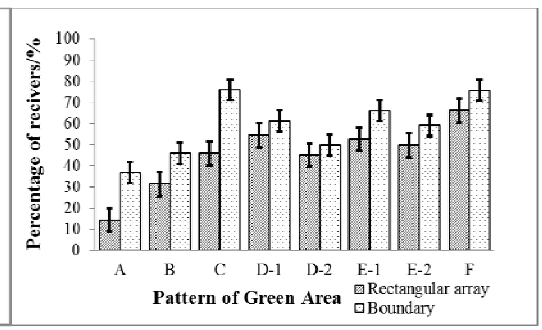
(a) < 65 dB, fully



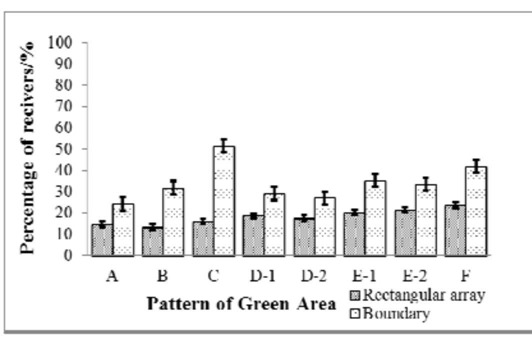
(b) < 65 dB, randomly



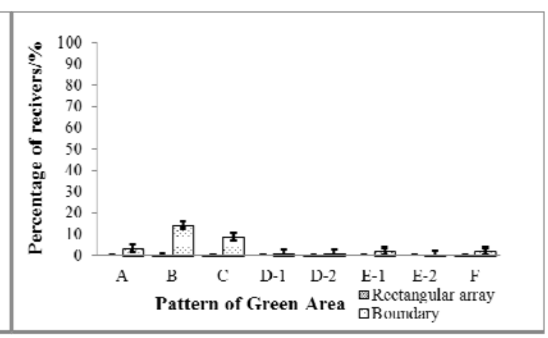
(c) 65-69 dB, fully



(d) 65-69 dB, randomly



(e) ≥ 70 dB, fully



(f) ≥ 70 dB, randomly

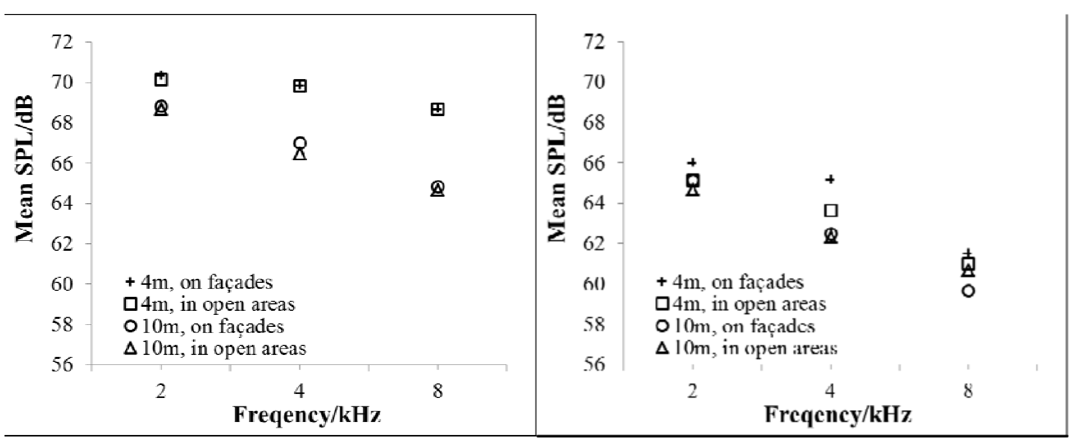
Figure. 7.8. Comparison of incidence of 2000 Hz birdsong at a height of 4 m, outside the green areas. These figures show 8 (a-f) patterns in terms of lower, medium and higher sound level ranges, with the 4 types of birdsong distribution.

Three ranges are determined to evenly divide the total sound level range from 60 dB to

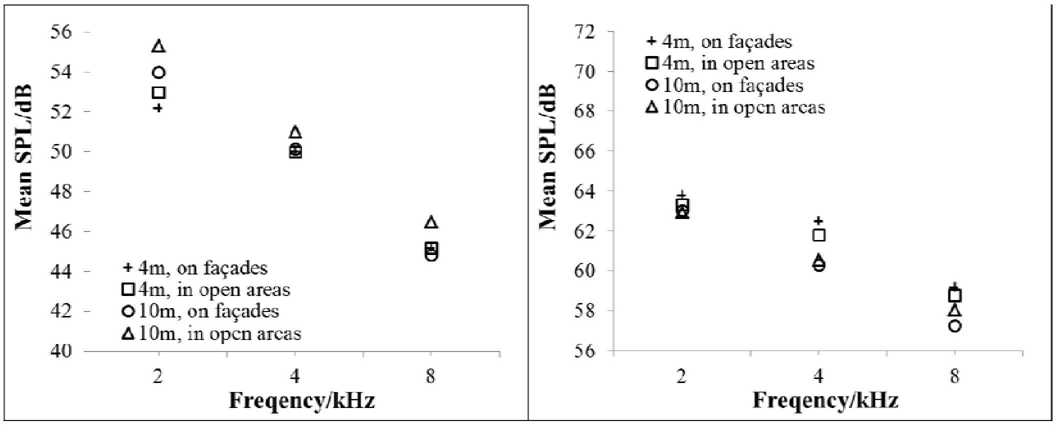
70 dB when birdsong is fully distributed (see Figure 7.7). It can be observed that the 8 geometric configurations have great differences in the three categories of birdsong sound levels. For example, in Figure 7.8-c, in Pattern F 82.7% of the area has birdsong in the range of 65-69dB, while in Pattern A only 48.6% of the area does. Even for the configurations with the same length of boundaries, e.g., D-1 and D-2, and E-1 and E-2, the percentages are more or less different (see Figure 7.8). A further analysis shows seven significant positive linear regressions (R^2> 0.5) exist among the 12 series of data on the percentages (in Figure 7.8) and the green area perimeters, indicating an increase of green area perimeters may improve birdsong loudness.

7.3.1.2 Real sites in urban area

Figure 7.9 shows the mean sound levels of birdsong of the 12 sampled sites at 2, 4 and 8 kHz (as mentioned in Section 2.3) in terms of spatial sound level indices of L_{10} L_{50}, L_{90} and L_{avg}, where it can be seen that the mean sound levels are 1-4 dB higher when the sound sources are 4 m high than 10 m for L_{10}, L_{50} or L_{avg}, in both open areas and on facades, while for L_{90}, the mean sound levels in open areas are 0-2 dB higher when the height is 10 m.



(a) L_{10} (b) L_{50}

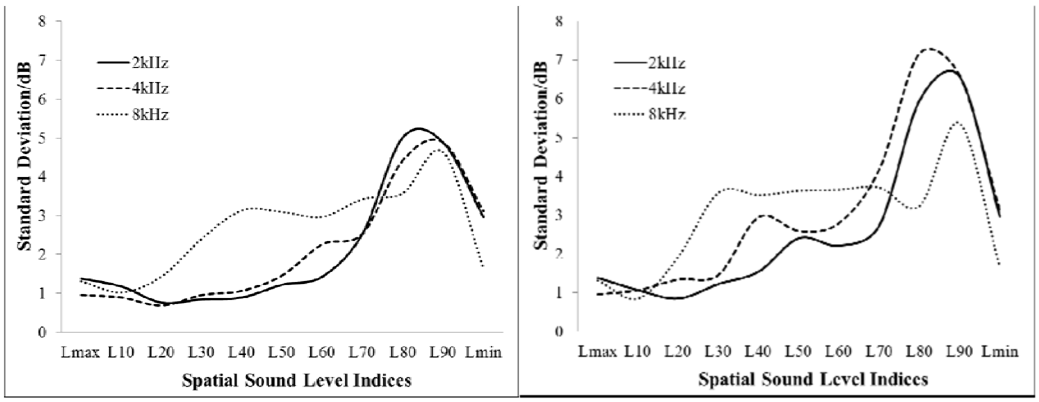


(c) L_{90} (d) L_{avg}

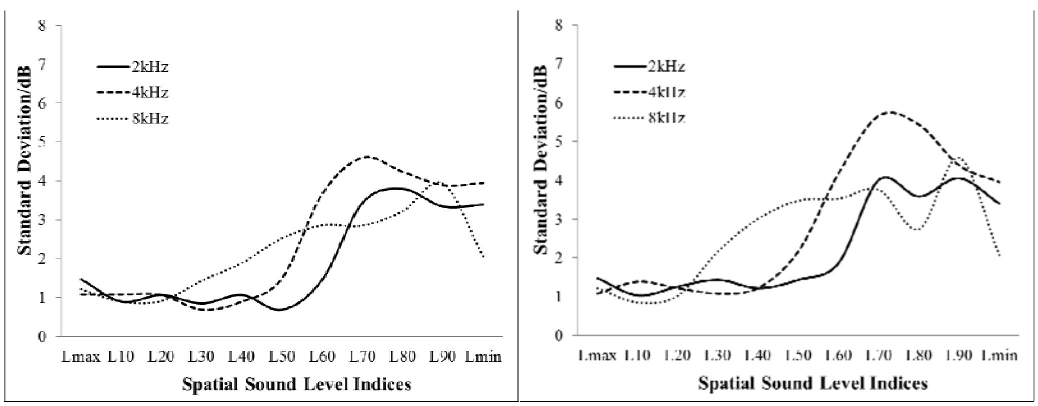
Figure. 7.9. Mean sound levels of birdsong at 2000, 4000 and 8000 Hz in the 12 sites in terms of L_{10} (a), L_{50} (b), L_{90} (c) and L_{avg} (d).

Therefore, to generally increase the birdsong loudness in low-density residential areas, the species of tree-dwelling birds that have lower habitats are preferred, whereas to raise the birdsong loudness in areas far from green areas, birds with more elevated habitats are preferred.

Different urban morphologies indeed induce different spatial birdsong distributions, as indicated by the standard deviations of the spatial sound level indices among the 12 sites in Figure 7.10. The spatial sound level indices L_{70}, L_{80} and L_{90} have higher variations than the other indices at 2000 and 4000 Hz, both on façades and in open areas, as shown in Figure 7.10, which means spatial sound level distributions of birdsong are more sensitive to urban morphology at 2000 and 4000 Hz in relatively quiet areas. The largest variation occurs at L_{80} at 4000 Hz in open areas when sound sources are 4 m high, with a standard deviation as 7.2dB, followed by L_{90} at 2kHz in open areas (6.6dB) (see Figure 7.10). The standard deviations of the indices for louder birdsong areas (e.g., L_{20}, L_{30}, L_{40} and L_{50}) at 8000 Hz are larger than those at 2000 and 4000 Hz (see Figure 7.10), especially for a height of 4 m; this may be because the building barrier effects are crucial for the attenuation of high frequency sound components at shorter distances, which increases the influence of urban morphology on birdsong environment in the proximity of the green areas.



(a) 4 m high, on façades (b) 4 m high, in open areas



(c) 10 m high, on façades (d) 10 m high, in open areas

Figure. 7.10. Standard deviations of spatial sound level indices of the 12 sites, at frequencies of 2000, 4000 and 8000 Hz.

It is also important to note that the spatial sound level distribution on façades and in open areas shows different characteristics from the perspective of variation (see Figure 7.10-a&b, c&d), although their differences of mean values of the indices are not large in Figure 7.9. Accordingly, this study will further investigate birdsong attenuation from the viewpoints of both façades and open areas, which concerns not only indoor birdsong from green areas but also the incidence of birdsong in open space, as shown in Section 7.3.2 below.

7.3.2 Relationships with urban morphological parameters

7.3.2.1 Audibility of birdsong

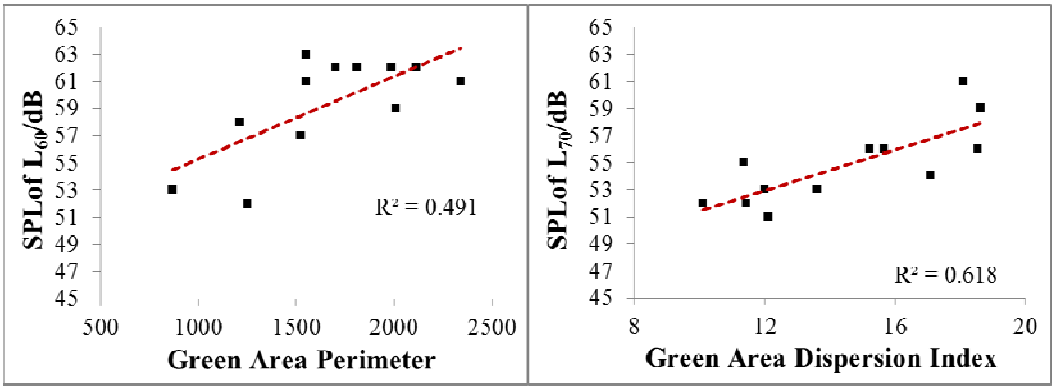
To investigate whether and how the spatial sound level distribution of birdsong is related to urban morphology, a correlation analysis was conducted between urban morphological parameters and the indices of L_{60}, L_{70}, L_{80} and L_{90}, which have higher variations, as shown in Figure 7.10. Table 7.2 shows the R-squared values of the linear regressions between the parameters and indices, which have significant bivariate correlations (p<0.05, two tailed). The results show that the spatial sound level indices are related to the urban morphological parameters. The indices are more corralted to the parameters when the sound sources are at a height of 4 m than when the sources are a height of 10 m (see Table 7.2). It is not surprising that the indices at 8000 Hz are more strongly correlated than at 2000 and 4000 Hz, because building barrier effects of buildings play a more significant role on attenuation at the relatively high frequency components of birdsong.

The parameters for the characteristics of green areas (i.e., Green Area Perimeter and Green Area Dispersion Index) have stronger correlations with the spatial sound level distribution of birdsong than those for the characteristics of buildings (Building Plan Area Fraction, Complete Area Ratio and Building Surface Area to Plan Area Ratio) and for the relative locations between buildings and green areas (First-row Building Frontal Length Index and Distance of First-row Building to Green Area), which means that the geometry of a green area has the largest influence on birdsong propagation in low-density residential urban morphology. Figure 7.11 further shows two examples of the relationships between the indices and urban morphological parameters and green areas. In the range 869 to 2340 m, when Green Area Perimeter increases, L_{60} at 8000 Hz constantly increases, and the differences among the sites are rather large (i.e., 11 dB) (see Figure 7.11-a); even the Green Ratios of the sites are constant. L_{70} at 8000 Hz increases with an increase of Green Area Dispersion Index in the range 10.1 to 18.6, and the value differences of L_{70} are up to 10 dB (see Figure 7.11-b).

In conclusion, to enhance the incidence of birdsong environment in a site with a certain Green Ratio, it is important to segment green areas, increase the boundary lengths of green areas and scatter green areas throughout the whole site.

Table 7.2. Significant relationships between spatial sound level indices of birdsong and urban morphological parameters in terms of the R-squared values of linear regression, where * indicates $p<0.05$ level (2-tailed), and ** indicates $p<0.01$ level (2-tailed) in Bivariate Correlation.

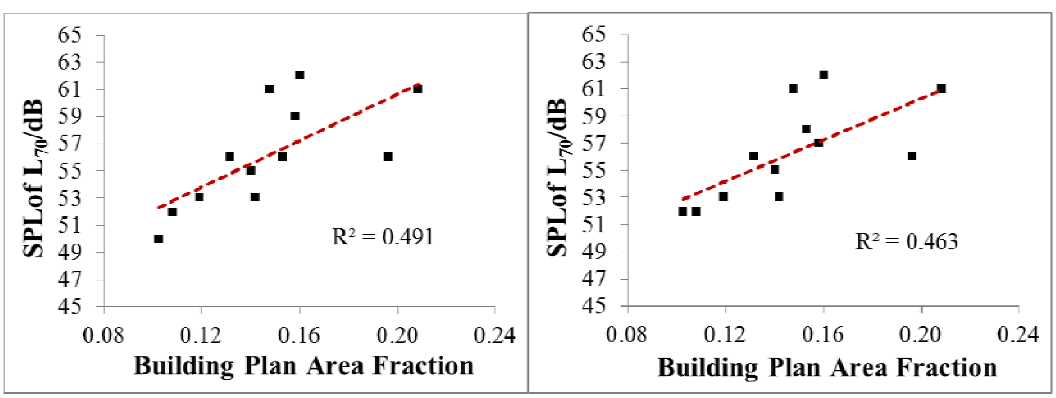
Urban morphological Parameters		**Indices**	**BPAF**	**CAR**	**BSAPAR**	**FBFLI**	**DFBGA**	**GAP**	**GADI**
4m, 2 kHz	Façades	L_{70}						.341*	
4m, 4 kHz	Façades	L_{70}							.340*
4m, 8 kHz	Façades	L_{70}	.463*					.357*	.591**
	Open Areas	L_{70}	.491*		.400*			.397*	.380*
		L_{80}				.375*			
10m, 8kHz	Façades	L_{60}	.395*					.409*	.514*
		L_{70}							.618**
	Open Areas	L_{60}						.491*	
		L_{70}	.347*						.409*



(a) 10 m, 8000 Hz, L_{60} in open areas (b) 10 m, 8000 Hz, L_{70} on façades

Figure. 7.11. Relationship between spatial sound level indices of birdsong and urban morphological parameters of green areas.

Building Plan Area Fraction (BPAF), which refers only to the 2D building information, is the most significant building-related parameter, according to the correlation analysis in Table 7.2. Figure 7.12 shows the positive relationships between the indices and BPAF in a range from 0.1 to 0.2, indicating that the reflections of birdsong by buildings are crucial for increasing birdsong loudness in relatively quiet areas. As demonstrated in Chapter 5, an increase of Building Plan Area Fraction may result in an increase of traffic noise levels in the area close to a road. However, for birdsong, BPAF influences the area further from sound sources, being indicated by the spatial sound level index L_{70}.

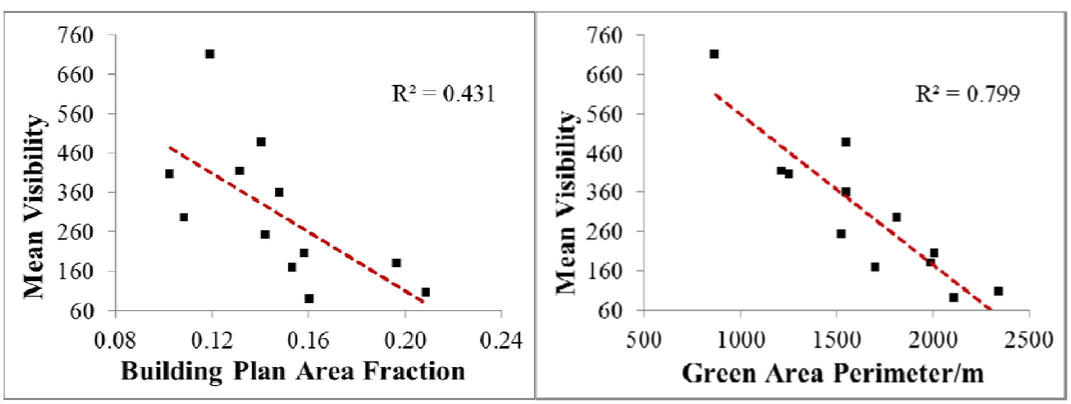


(a) 4 m high, 8000 Hz, L_{70} in open areas (b) 4 m high, 8000 Hz, L_{70} on façades

Figure. 7.12. Relationship between spatial sound level indices of birdsong and Building Plan Area Fraction.

7.3.2.2 Visibility of green areas

A correlation study was also conducted that compared the visibility of green areas and urban morphological parameters. The results show that the visibility is significantly correlated to Building Plan Area Fraction (BPAF) (p=0.020), Building Surface Area to Plan Area Ratio (BSAPAR) (p=0.043) and Green Area Perimeter (GAP) (p=0.000). In accordance with the analysis results on birdsong and urban morphology, the parameters on the relative locations between buildings and green areas (FBFLI and DFBGA) have little influence on visibility of green area. Unsurprisingly, the visibility of green area decreases when BPAF increases (see Figure 7.13-a), which means sites with lower building density have higher visibility of green areas. As shown in Figure 7.13-b, another important parameter is Green Area Perimeter, which has a rather significant negative relationship with the visibility of green areas because the segmenting of green area may enhance the effects of view block by buildings.



(a) (b)

Figure. 7.13. Relationship between visibility of green areas and urban morphological parameters.

It is important to notice that, in contrast to the positive relations between audibility of birdsong in relatively quiet areas and urban morphological parameters, the significant relations between the visibility of green area and the three correlated parameters are all negative. Hence, in practical designs, the control of the parameters in this study almost entirely depends on which aspect is the main concern.

7.3.3 Relationship between visibility of green areas and audibility of birdsong

A correlation analysis was performed to examine the relationships between the visibility of green area and spatial distribution of birdsong sound levels, as shown in Table 7.3.

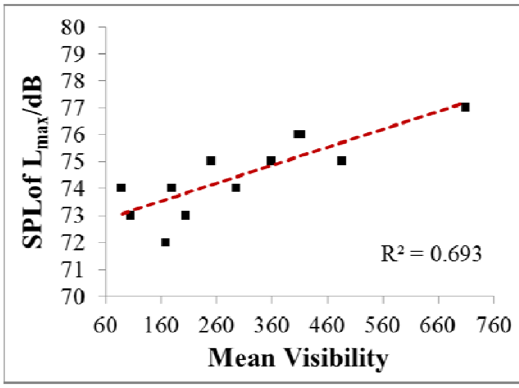
It can be observed that the mean visibility has significant correlations (p<0.050, 2 tailed) with spatial sound level indices of birdsong primarily at 4m, both on façades and in open areas; when the height is 10 m, the significant correlations merely exist at 8000 Hz. Compared to the 2000 Hz frequency, the 4000 and 8000 Hz frequencies have more significant correlations (see Table 7.3), which means that the visibility of green area is more correlated to the sound propagation of higher frequency components of birdsong.

The visibility of green area is much less correlated to the indices for relatively quiet area, i.e., L_{70}, L_{80} and L_{90}, which indicates that the site with higher visibility of green area may not necessarily have quieter birdsong than the areas far from the green areas.

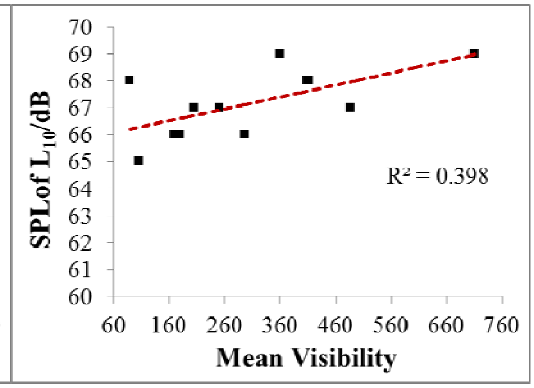
The linear regression analysis results show an interesting phenomenon between visibility and birdsong propagation. The visibility has positive relations to the indices that represent sound levels in the proximity of green areas (i.e., L_{max} and L_{10}), and negative relations to the other indices (i.e., L_{20}, L_{30}, L_{40}, L_{50}, L_{60} and L_{min}), as shown by the examples in Figure 7.14. This means that the more visible green areas are, the louder birdsong in proximity of green areas is compared to most of the areas that are further away. From the viewpoint of urban morphology, the reason for this phenomenon is that buildings close to green areas play important roles as both sound barriers and view block, but buildings further from green areas, which still block the view of green areas, are primarily sound reflectors rather than sound barriers; this enhances the audibility of birdsong in the relatively quiet areas, in accordance with the results in Section 7.3.2.

Table 7.3. Significant relationships, i.e. $p<0.05$ level (2-tailed), between spatial sound level indices of birdsong and connectivity in terms of p value in Bivariate Correlation.

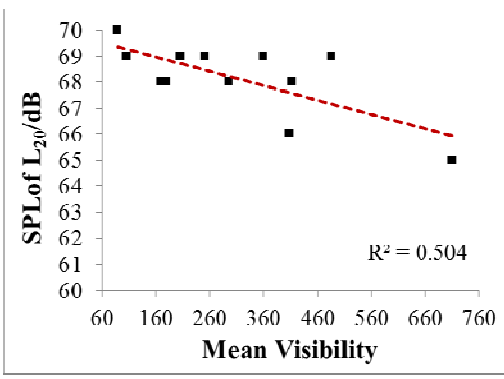
	Height of birdsong/m	**Frequency/kHz**	**Indices**	***p* value**
Façades	4	2	L_{max}	.001
		4	L_{max}	.020
		4	L_{60}	.013
		8	L_{30}	.024
		8	L_{40}	.025
		8	L_{50}	.035
		8	L_{60}	.022
		8	L_{min}	.032
	10	8	L_{max}	.028
		8	L_{20}	.034
		8	L_{40}	.039
		8	L_{min}	.034
Open areas	4	2	L_{max}	.001
		4	L_{max}	.020
		4	L_{20}	.010
		4	L_{40}	.022
		4	L_{50}	.018
		8	L_{30}	.018
		8	L_{50}	.038
		8	L_{60}	.015
		8	L_{min}	.032
	10	8	L_{max}	.028
		8	L_{10}	.029
		8	L_{60}	.036
		8	L_{min}	.034



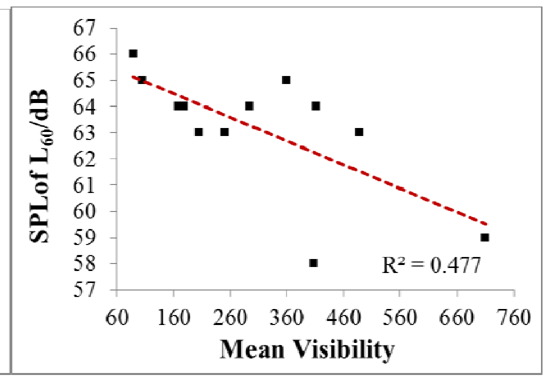
(a) 4 m, 2000 Hz, L_{max} on façades



(b) 10 m, 8000 Hz, L_{10} in open areas



(c) 4 m, 4000 Hz, L_{20} in open areas



(d) 4 m, 4000 Hz, L_{60} on façades

Figure. 7.14. Relationship between visibility of green areas and spatial sound level indices of birdsong.

7.4 Conclusions

The chapter explores how urban morphology influences the incidence of green area from the perspective of audibility of birdsong and visibility of green areas, considering meso-scale, low-density residential areas. Seven urban morphological parameters that are related to building characteristics, the relative locations of buildings and green areas, and characteristics of green areas were defined. Noise mapping techniques and Visibility Graph Analysis in Space Syntax were employed to analyses the sampled sites with diverse urban morphologies.

The spatial birdsong distribution is indeed different in both the idealised open spaces and the actual urban morphology caused by different green area geometric configurations and heights of bird habitats. Green areas should be studied as integrated components in meso-scale urban morphology for birdsong emittion. In idealised open spaces, with a consistent green ratio, an increase of green area perimeters may raise birdsong loudness. In the actual urban morphology, to generally increase birdsong loudness in a whole site, the species of tree birds that live in lower habitats are preferred because it has been demonstrated that, with either L_{10}, L_{50} or L_{avg} the mean sound levels at all of the sampled sites are 1-4 dB higher when the sound sources are 4 m (lower than the surrounding buildings at 8-10 m) than those at 10 m.. Additionally, compared to 10 m, when the height of sound source is 4 m, urban morphology has a greater impact on birdsong loudness in the low-density residential areas.

The urban morphological parameters do have effects on both audibility of birdsong and the visibility of green areas. In terms of the 2D green area geometric configuration of green areas, at 8000 Hz, and with a Green Area Perimeter increasing from 869 to 2340 m, the birdsong sound levels in the areas further from green areas can be increased by up to 11 dB; with a Green Area Dispersion Index that increases from 10.11 to 18.62, the sound levels can go up by 10 dB. However, the sites with higher Green Area Perimeters have a lower visibility of green areas. Therefore, for a given Green Ratio, segmenting green areas, increasing boundary lengths of green areas and scattering green areas throughout the whole site can increase audibility of birdsong and reduce the visibility of green areas. In terms of the characteristics of building, Building Plan Area Fraction is the most important urban morphological parameter for the audibility of birdsong. It is possible to increase the sound level of 8000 Hz birdsong at L_{70} up to 12 dB in open areas and up to 10 dB on façades by increasing the Building Plan Area Fraction from 0.10 to 0.21. However, in accordance with the Green Area Perimeter, sites with higher Building Plan Area Fractions have lower green area visibility; Mean Visibility decreases from 710.3 to 88.9. The parameters for the relative locations between buildings and green areas, i.e., Building Frontal Length Index and Distance of First-row Building to Green Area, have little influence on either audibility of birdsong or green area visibility.

It was also demonstrated in Chapter 4 that the visibility of green areas can enhance the masking effects through aural-visual interaction.. For the proximity of green areas, the more visible the green areas are, the louder the birdsong is. Conversely, in the areas further from the green areas, birdsong is quieter when the visibility is higher. Therefore, “informational masking” in the visual context can play an important role on the masking effects by compensating for the reduced “energetic masking” in these areas.

It can be proved by the results in this chapter that audibility of birdsong and the visibility of green areas, which influence masking effects in soundscape, can be enhanced by control of the urban morphological parameters. Therefore, it is practical to improve soundscape quality at the stage of urban design and planning.

CHAPATER 8

CONCLUSIONS AND FUTURE WORK

This study explores the masking effects of the various sound events in the urban soundscape, aiming at revealing the impacts of different physical (i.e., acoustic and visual) conditions on human auditory perception. The results lead to the research interests on the methods of optimising the physical conditions to achieve positive masking in the context of urban morphology. Firstly, the study examines the acoustic and soundscape characteristics of the urban sounds from different urban sound sources with a consideration of masking effects, using sound recording, measurement and sound analysis and psychological listening experiments. Secondly, the impacts of the factors on masking effects, including spectrum of traffic noise, loudness of birdsong, occurrence frequencies of birdsong and visibility of sound sources, are explored, using the psychological listening experiments. Thirdly, from the perspective of masking effects, how does urban morphology influence the capability of urban morphology on urban noise level attenuation and birdsong loudness enlargement, and the visibility of green areas, is examined. A set of urban morphological parameters that are accessible and common in the urban design and planning are selected and developed. Noise mapping techniques are employed and a MATLAB program is developed to obtain the spatial noise level indices. Visibility Graph Analysis in Space Syntax is used to analyse the visibility of green areas. The study sites are sampled from the real urban morphology.

8.1 Main contributions

8.1.1 Examination of acoustic properties and soundscape characteristics of urban sounds

In terms of acoustic features and psychological evaluation, diverse sound events in urban soundscape were examined from the perspective of masking (Chapter 3).

The study revealed a phenomenon that sense of distance from a sound source resulted in a more significant decrease of perceived loudness with distance than sound pressure levels. It can be an evidence for the role of top-down process in auditory perception and “informational masking. It was proved that the annoyance of traffic noise environment had a strongly positive relationship with sound pressure levels; although the pleasantness increases with the distance from the road, it was still low at the distance of 50m. Therefore, the most efficient way to reduce the annoyance of traffic noise environment was to reduce sound pressure levels. However, it was not enough for the increase of pleasantness

The study investigated the different water features that had big differences in the loudness (up to about 15dBA) and the pleasantness. It was revealed that the sounds of the water features could not give people strong sense of naturalness, and the increase of naturalness could significantly reduce the annoyance and increase the pleasantness of the water sounds, suggesting the importance of the naturalness in water sound environment improvement. It was also determined that the water features had larger dynamic range; more high-frequency components were perceived more natural and pleasant.

The aircraft noise with rather various spectra and loudness was recorded and analysed. The study showed that when sound pressure levels were similar, the annoyance of the traffic noise was higher than that of the aircraft noise. When adding birdsong, perceived loudness of aircraft noise was significantly reduced, but the naturalness and the pleasantness could be only efficiently increased when sound pressure levels decreased.

Therefore, attenuating aircraft noise level was essential for the improvement of soundscape quality.

The urban bird songs were found to be primarily composed by high frequency components from 2000 to 8000 Hz. Bird songs were diverse in both spectrum and dynamic process. Bird songs had high naturalness (9.4) and pleasantness (7.7), higher than the water sounds; therefore, bird songs could be considered as sound marks of nature. The study suggested a big potential of bird songs for the masking on traffic noise through attention abstraction, improving the soundscape naturalness and pleasantness.

8.1.2 Evaluation of soundscape with masking effects

The occurrence of masking effects and the physical factors that influenced masking effects were investigated with psychological evaluation. The results could be used for the assessment of the traffic noise environment with masking effects by birdsong, and the optimum design of soundscape in the context of landscape (Chapter 4).

The study demonstrated the existence of masking effects by birdsong on traffic noise in soundscape. The masking effects increased largely when the traffic noise fluctuated less and became quieter. With masking effects by birdsong, perceived loudness of the traffic noise environments did not change, but the naturalness was largely improved. Only when the perceiver was far from the traffic, the annoyance could be significantly reduced and the pleasantness could be significantly increased with masking effects by birdsong.

The study revealed that the louder birdsong had more effective masking effects than the quieter birdsong. No matter how loud the birdsong was, the annoyance of the traffic noise environment increased and the pleasantness decreased sharply when the traffic noise was louder than 47.5 dBA. An increase of sound pressure levels of birdsong did not decrease, but increased the annoyance when the traffic noise was higher than 57.5 dBA.

The occurrence frequency of birdsong was also proved to influence the masking effects. When the traffic noise was lower than 52.5 dBA, with an increase of the occurrence frequency, the naturalness and the pleasantness increased constantly; the annoyance decreased slightly. The occurrence frequency of birdsong played a more important role on the pleasantness than the naturalness and annoyance. However, when the traffic noise was loud, the masking effects were little influenced by the occurrence frequency of birdsong.

The visibility of sound sources had an impact on the masking effects, but not as significantly as the other factors. The pleasantness of the traffic noise was only influenced by the presentation of the visibility of the in-situ scenes when the perceiver was at a distance further than 9 m.

8.1.3 Exploration of the characteristics of traffic noise environment and its improvement by urban morphology

The study revealed how the traffic noise attenuated in real urban morphology and the relationship between traffic noise attenuation and the urban morphological parameters (Chapter 5).

The results showed that the spatial noise level attenuation primarily occurred on the noisy façades and the noisy open areas. The spatial noise level attenuation was more sensitive in open areas than on façades; the attenuation on façades and in open areas were not generally correlated in terms of spatial noise levels.

The results indicated that a site with a higher building coverage (i.e. Building Plan Area Fraction) would probably have more noisy indoor spaces caused by the traffic noise. Street pattern (i.e. HWR), concerning canyon effect, hardly played a role on noise attenuation in such an urban texture. In open areas, the total building and ground surface area (i.e. CAR) and façade areas parallel to roads (i.e. BFAI) were proved to influence the sound levels of the quiet open areas. When the Complete Aspect Ratio was lower than 1.42 or the Building Frontal Area Index was lower than 0.11, the open spaces became quieter when either of the two parameters increased. Decrease of spatial noise levels in open areas could not be achieved merely by increasing the Building Plan Area Fraction.

The size of relatively noisy open areas could be predicted with the spatial indices, L_{40}, L_{50} and L_{60}. The percentage of 'Less Noisy Area' decreased significantly with an decrease of distance of first-row building to road (DFBR) or an increase of façade areas along traffic roads (BFAI), but the control of any single parameter in this study could not contribute to the increase of the 'Quiet Area'.

The study established a series of linear regression models, of which the independent variables were the urban morphological parameters and the dependent variables were the spatial traffic noise level indices and the percentage of noise area categories. Based on the models, a decrease of Building Plan Area Fraction and an increase of Complete Aspect Ratio could contribute to the traffic noise level attenuation on façades. An increase of Building Frontal Area Index significantly benefitted both the traffic noise level attenuation in open areas and noisy open area reduction.

8.1.4 Exploration of the characteristics of flyover aircraft noise environment and its improvement by urban morphology

The study revealed how the flyover aircraft noise attenuated in real urban morphology and the relationship between the flyover aircraft noise attenuation and the morphological parameters (Chapter 6).

The study showed a large difference and variance of the aircraft noise level attenuation occurred at 1000 m among different urban morphologies. Sound reflection by buildings was believed to reduce the influence of urban morphology on the noise attenuation. An increase from 200ft to 400ft in flight altitude generally did not benefit the noise attenuation significantly.

It was revealed that the façades had higher noise attenuation than the open areas, but urban morphology played a more important role on the aircraft noise attenuation in open areas than on façades. The control of urban morphological parameters could benefit aircraft noise level attenuation more in the quiet open areas and the whole area but not in the noisy open areas.

Considerable correlations between the urban morphological parameters and the flyover aircraft noise attenuation were determined in this study. Compared with the sound source location independent morphological parameters, the sound source dependent parameters had greater influence. The general tendency was that the Building Frontal Area Index (BFAI) and the Horizontal Distance of First-row Building to Flight Path correlated with the noise attenuation most, while the Building Plan Area Fraction and the Height-to-Width Ratio hardly influence the noise attenuation. The noise level attenuation in terms of L_{90} in open areas tended to increase with an increase of the Complete Aspect Ratio and then stayed stable after the Complete Aspect Ratio reached approximately 1.4. The noise level attenuation in terms of L_{90} in open areas had a tendency to increase when the Building Surface Area to Plan Area Ratio increased before approximately 0.7 and it then decreased. The noise attenuation in terms of L_{50} and L_{avg} showed a constant upward tendency when the Horizontal Distance of First-row Building to Flight Path decreased.

8.1.5 Exploration of the characteristics of birdsong environment and its improvement by urban morphology

The study revealed how birdsong distributed in real urban morphology and the relationship between birdsong distribution, the visibility of green areas and the urban morphological parameters (Chapter 7).

The results indicated that the spatial birdsong distribution was indeed different in both the idealised open spaces and the real urban areas caused by different green area geometric configurations and bird habitat height. It was found that green area should be studied as an *integrated component* in mesoscale urban morphology for its birdsong emittion. In the idealised open spaces, with a consistent green ratio, an increase of green area perimeters might increase the birdsong loudness. In the real urban areas, the species of tree birds living in lower habitats could result in 1-4 dB louder birdsong. Also, when the sound source height was lower than the surrounding buildings, urban morphology played a more important role in the birdsong loudness.

The urban morphological parameters were proved to do have effects on both birdsong loudness and the visibility of green areas. In terms of 2D green area geometric configuration, with increasing Green Area Perimeter, the sound levels of birdsong in the areas further from green areas could be increased by up to 11 dB; with increasing Green Area Dispersion, the sound levels could increase by 10 dB. However, the site with a higher Green Area Perimeter had lower visibility of green areas. Therefore, with a given Green Ratio, segmenting green areas, increasing boundary lengths of green areas and scattering green areas into the whole site could result in an increase of birdsong loudness and a reduction of visibility of green areas.

In terms of building characteristics, the Building Plan Area Fraction was the most important urban morphological parameter for the birdsong distribution. It was possible to increase the sound levels of birdsong up to 12 dB in open areas and up to 10 dB on façades by increasing the Building Plan Area Fraction. But in accordance with the Green Area Perimeter, the site with a higher Building Plan Area Fraction had lower visibility of green areas, with a decrease of Mean Visibility from 710.3 to 88.9.

It was also demonstrated that the visibility of green areas was correlated to the birdsong distribution. For the proximity of green areas, the more visible green areas were, the louder birdsong was. Conversely, in the areas further from green areas, birdsong was quieter when the visibility was higher. In view of this, “informational masking” was proposed to play a more important role in the masking effects by birdsong on traffic noise, compensating for the reduction of birdsong loudness in the areas further from green areas.

8.2 Implementation

Urban noise level attenuation by urban morphology and use of masking effects of natural sounds were the two main measures suggested for the improvement of soundscape quality. The former was related to the urban design and planning and the latter was more related to the landscape design. The former aimed at the reduction of soundscape annoyance and the latter played a role on the increase of pleasantness and naturalness.

The noise attenuation was still primary for the reduction of soundscape annoyance. The annoyance of the noise was proved to be highly related to loudness. However, in accordance with the previous studies on traffic noise and aircraft noise, the obtained acoustic properties in this study indicated the difficulty in the car traffic noise attenuation and the aircraft noise attenuation by “energetic masking”, since they were relatively loud and rather wideband. Therefore, it was essential to achieve the noise attenuation by controlling the urban morphological parameters at the early stage of design. The feasibility of this measure was proved, but it was not enough for the increase of soundscape pleasantness.

Enhancement of masking effects of natural sounds was the idea for the increase of soundscape pleasantness. Two common urban sound sources, namely water features and bird, were investigated for their potentials on masking. It was found that the water sounds of the water features were all wideband as the traffic noise and varied considerably in terms of spectrum and dynamic process, providing a lot of possibilities to design tailor-made water features and sounds to mask certain noise. They could also bring about the richness of soundscape within a relatively short distance. Moreover, the visibility of the water sound sources could increase the pleasantness of water sounds significantly; therefore, to create positive masking in soundscape by water sounds, the visibility of water features should be taken into account. However, the pleasantness and naturalness of birdsong was considerably higher than water sounds, so although it was narrowband and could not significantly mask the traffic noise and the aircraft noise in terms of “energetic masking”, it was still interesting to research its capability of masking from the perspective of the pleasantness and naturalness by “informational masking”. Birdsong had been proved to have rather significant masking effects on the traffic noise; different design of green areas as bird habitats could influence its masking effects. In addition, birdsong loudness and the visibility of sound sources were believed as important factors in the masking effects. Therefore, the design techniques of designing green areas and controlling urban morphological parameters to increase birdsong loudness and visibility of green areas were suggested, so that the soundscape pleasantness and naturalness could be improved.

Implementation of masking effects by natural sounds could improve soundscape quality in a large scale of area. As calculated in Chapter 5, ‘Quiet Area’ and ‘Less Quiet Area’ occupied 69% in the total area, where birdsong was proved to have more significant masking effects than in the noisy traffic area. Even in the ‘Less Noisy Area’, with birdsong, the naturalness of the traffic noise environment could be improved. In the large area that was impacted by the aircraft noise, the masking effects by birdsong could significantly reduce the perceived loudness of soundscape, so it was suggested to enlarge the vegetation area as bird habitats in the aircraft noise environments to compensate the role of buildings on the aircraft noise attenuation.

Therefore, the research results could be used by the urban designers in practice of urban design and planning to improve soundscape quality by controlling quantitative urban morphological parameters and designing landscape features, e.g., water features and green areas.

8.3 Limitations and future work

8.3.1 Limitations

In Chapter 3, the sound pressure levels of the different sound sources examined are limited to the certain ranges of the collected recordings. In Chapter 4, based on the actual situation of the study sites, the sound pressure levels of the traffic noise and birdsong, as well as the SNRs (Signal-to-noise ratio), are also limited to the certain ranges. For example, in the experiments of masking effects, the traffic noise are from 42.5 to 67.5 dBA; birdsong are from 37.5 to 52.5 dBA. More experiments on a wider range of sound pressure levels of the sounds can be investigated in the further studies.

The assumptions and limitations of the studies on the modelling of car traffic noise, flyover aircraft noise, and birdsong from green areas are summarised in Table 8.1.

Table 8.1. Assumptions and limitations of the studies in Chapter 5, 6 and 7 of the thesis.

	Assumptions and Limitations		
Sound source	Input data	Numerical models and software	Type of urban morphology
Car traffic	The building height was all set as 8 m. The sound pressure levels of the traffic noise of the main roads were set as constants values.	The calculation was based on the calculation model CRTN (Calculation of Road Traffic Noise) for a road, values embedded in the software package, Cadna/A, with an inaccuracy of less than 2 dB, compared with in-situ measurement.	Low density and low-rise residential areas, of which the influence is not as strong as other types (e.g., high-rise areas)

Flyover aircraft	The landing noise of flyover aircraft was set with five horizontal distances from a given site, namely 0, 100, 300, 600 and 1000 m, and two flight altitudes, namely 60.96 and 121.92 m, and three main frequencies of aircraft noise, 630Hz, 1600Hz, and 3150Hz.	The calculation was based on line source in the software package, Cadna/A, with an inaccuracy of less than 2 dB, compared with in-situ measurement.	The same as above.
Birdsong from green areas	The sources that are localised on the boundaries of green areas were considered along with uniformly distributed sources throughout the green areas. The heights of sound sources were set as 4 and 10m, with three main frequencies of 2000, 4000 and 8000 Hz.	The calculation was based on point source in the software package, Cadna/A, with an inaccuracy of less than 2 dB, compared with in-situ measurement.	Low density and low-rise residential areas with a constant green ratio of 36%. The birdsong loudness is higher than that of other types (e.g., high density areas)

8.3.2 Future work

More urban sounds can be added to the database established in Chapter 3 in terms of acoustic and soundscape characteristics. The sounds will be used as soundscape design elements. The potential energetic masking among the sounds can be predicted by their spectrum.

In this study, only the visibility of general in-situ scene of sound sources is of interested. In view of the limited previous studies of the role of aural-visual interaction on masking effects, further investigations on detailed visual stimuli settings with certain factors, such as heights of vegetation and volume of vegetation, can be conducted to study their effects on masking effects. The results can contribute to the landscape design and integrated aural and visual design.

Masking effects of the other diverse urban sounds on traffic noise can be investigated to obtain the weighting values of traffic noise level to contribute to the standards on the control of traffic noise from the perspective of human perception and the development of cognitive sensor system on the soundscape quality assessment.

Based on the current results, a programme on the generation of soundscape map with a consideration of masking effects can be developed to evaluate the soundscape quality of a given area and to predict soundscape characteristics at the stage of urban design and planning. Compared with the traditional noise map, the soundscape map takes into account multiple urban sound sources, meaning of sounds and their interaction.

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APPENDICES

Appendix 1: Questionnaire used for the psychological evaluation of soundscape characteristics in Chapter 3 and 4

Question: If the recorded sound environment is in your neighbourhood, what number, from 0 to 10, you would like to rate its characteristics? (0: not at all and 10: extremely)

Sound 1:

	Not at all										Extremely
Loud	0	1	2	3	4	5	6	7	8	9	10
Natural	0	1	2	3	4	5	6	7	8	9	10
Annoying	0	1	2	3	4	5	6	7	8	9	10
Pleasant	0	1	2	3	4	5	6	7	8	9	10

Sound 2:

	Not at all										Extremely
Loud	0	1	2	3	4	5	6	7	8	9	10
Natural	0	1	2	3	4	5	6	7	8	9	10
Annoying	0	1	2	3	4	5	6	7	8	9	10
Pleasant	0	1	2	3	4	5	6	7	8	9	10

Sound 3:

	Not at all										Extremely
Loud	0	1	2	3	4	5	6	7	8	9	10
Natural	0	1	2	3	4	5	6	7	8	9	10
Annoying	0	1	2	3	4	5	6	7	8	9	10
Pleasant	0	1	2	3	4	5	6	7	8	9	10

Sound 4:

	Not at all										Extremely
Loud	0	1	2	3	4	5	6	7	8	9	10
Natural	0	1	2	3	4	5	6	7	8	9	10
Annoying	0	1	2	3	4	5	6	7	8	9	10
Pleasant	0	1	2	3	4	5	6	7	8	9	10

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Appendix 2: Records of the interview after the psychological

experiments in Chapter 3&4

Q1: How do you feel like the sounds?

Response s:

"*I have **scenes in my mind** when I listen to the sounds. When I heard louder birdsong, I feel I am **close to nature**, while when the birdsong is not that loud, I feel I am f**urther from nature**.*"

*"I **do not have a standard** to judge how pleasant the sound is, because I did not hear the sound I think is pleasant."*

*"As long as the sound is not **loud**, I cannot say it is **annoying**."*

*"I feel it is a little more **annoying** when the sounds sound not that **realistic** for me, in other words, they are different from my **expectation**."*

*"I feel it is much better when I can **see the pictures of the sound scene**. When I can **see green**, I did not **pay much attention** to the traffic noise. The picture **attracted most of my attention**."*

*"I feel the sounds gave me quite different **experiences**. I have strong feelings on what sound I like and what sound I dislike."*

*"When there is **birdsong**, I think I can say it is partly **natural**."*

*"I do not think any of the sounds are really **annoying**, because they are only **30sec, not 1 hour or so**. I just listen to them and they **have nothing to do with me**."*

*"I cannot **tell t**he fountain sounds if I did not **see the pictures**."*

*"**With pictures**, I feel it is better."*

*"The audios sound similar. I am more annoyed by the traffic noise **at the late stage of the experiment**."*

*"I did not feel any sound was particularly annoying, but I do not like the sound of **truck**."*

*"I feel it is **natural** when I heard children."*

"The ***pictures*** *cannot influence much on my rating. If the sound is really* ***annoying****, no matter* ***with or without picture****, I feel it is* ***annoying****."*

"I heard traffic sounds. Some are ***pretty close*** *and some are* ***of a distance****."*

"I ***live close to the hospital****, so I* ***noticed*** *when I heard ambulance sounds."*

"The low frequency parts sound not ***real*** *and seem amplified. I feel them are* ***annoying****."*

"I heard some sounds ***similar****."*

"If the ***background*** *was* ***quiet*** *and* ***some events*** *happened, I feel it is* ***annoying****, even more* ***annoying*** *than the* ***constant loud one****."*

"I feel some traffic noise is really ***annoying****. Someone recorded it* ***quite close to road****. I think the* ***distant traffic noise*** *is better."*

"They are not as pleasant as ***music****."*

"The sounds which are ***variable*** *is* ***more annoying****, such as the sounds with* ***loud traffic at the end****."*

"Some sounds are very ***annoying*** *because they are* ***too loud****."*

"I think it is ***natural*** *when I heard* ***steps and human voice****."*

"I did not find any particularly sound ***annoying****. The traffic sound was* ***just loud****, and it was* ***louder than I heard in daily life****."*

"I feel the sounds became ***less annoying*** *when there was* ***birdsong*** *or* ***human voice****."*

"I ***have experience of living*** *in a very annoying traffic noise environment* ***when I was a child****, so I am* ***very sensitive to*** *the traffic noise. I feel the sounds are* ***rather annoying****."*

Q2: What sound do you think is particular pleasant for you?

Response s:

"*I did not find any sound really pleasant except for the* ***birdsong*** *one.*"

"The ***fountain sounds*** *I heard are not very pleasant."*

"I rated the sound with more **birdsong** *higher score."*

"I don't like the eventful sound environment. I feel it is pleasant when the sound is ***stable and quiet****."*

"I prefer **fountain sounds***. I did not pay much attention to the fountain sounds in Sheffield before, although I passed by."*

"I like the **birdsong** *even it is loud, but not the fountain sounds. I gave the fountain sounds higher scores when I saw the pictures."*

"I love **birdsong** *very much;* **no matter how loud it is or how many birds I can hear***."*

"I prefer birdsong to fountain sound."

"I like the **children's voice***, then* **birdsong***, but I think the reason might be that I only hear children's voice once and birdsong for many times. If I did not hear so much birdsong, it might be the most pleasant one."*

"I like the **birdsong** *and the* **water sounds***. I mark it is more natural when I heard them."*

"I think the **birdsong** *and* **water sounds** *are pleasant, but I am really annoyed by traffic noise."*

"I like the **water sound** *which is* **low running***, and also the* **birdsong***."*

"The one with **children's voice** *is pleasant for me."*

I prefer the **quietness***. I like the* **birdsong***. When I heard* **loud birdsong***, I think it is more natural. Maybe because I was born in countryside, I like the natural environment. I went to Botanic Garden for quietness yesterday.*

"I think the **natural sounds** *are pleasant, such as birdsong and water sounds. I heard noise too."*

"I like the **bird noise***,* **even they are loud***. I also feel it is pleasant when* **people talking***."*

"I heard some sounds pleasant, such as **water sounds***."*

"I feel if there is **more birdsong***, it is* **more natural***."*

"I think the ***water sounds*** *and the sounds with* ***pure birdsong*** *or* ***birdsong with distant traffic noise*** *are pleasant."*

"I like the ***birdsong*** *in* ***quiet environment*** *and the* ***sound of the fountain with colourful piles****."*

"I like the ***water sounds*** *and* ***birdsong****. If I heard them more than traffic, I rated the sound more pleasant, but if I heard more traffic, I rated it less pleasant."*

"I do like the ***bird chirping****, which makes me feel it is pleasant. I prefer* ***birdsong*** *to* ***water sounds****."*

"I like the ***water sounds****, but I dislike the human voice which is annoying."*

"I like the ***water falls****, which are really nice."*

Q3: What sound do you think is particular unpleasant for you?

Response s:

"I was more annoyed by low frequency part of the sounds."

"I feel uncomfortable with ***low frequency sounds****."*

"I dislike ***low frequency sounds****, especially when they are steady. I feel the sounds are not that annoying as long as there is event of car passing by."*

"I feel uncomfortable when I heard ***several traffic audios one by one****."*

"I do not like traffic noise, especially the ***low frequency part****."*

"I do not feel the sounds are annoying unless it is ***very loud****."*

"The ***traffic noise*** *is not pleasant and I do not like the* ***events of traffic****. Some people did drive the cars in* ***a proper behaviour****."*

I dislike the ***constant water sounds****.*

"I dislike the ***water sounds****, because I feel they are* ***not real****, even with pictures."*

"I like the ***sounds of aircraft*** *which makes me feel I would have a long trip, so I marked*

the sound with 1 for pleasant, although it is loud. It is really based on my own experience."

*"I do not like the **constant low sounds** or **high heel steps**, either."*

Q4: How much do you think the sounds you listened to are different from daily-life ones?

Response s:

*"I feel the sounds I heard in the lab are different from the sounds I heard in the real situation, for example, I did not remember I heard so **loud** fountain sound when I pass by it before, because I passed by a noisy road before I reached the fountain."*

*"I passed by the road where you recorded traffic for many times, but I did not realised it was so **loud.**"*

*"The sounds are **very similar** to what I hear in the real world."*

*"The sounds sound **similar** with the ones in real life."*

*"There is **something different** between the real-life sound s and the sound played, but I cannot tell what."*

*"The sounds are **similar** to what I hear in daily life, but some of the traffic sounds are **louder**."*

*"I am from a small town and I can feel that the sounds recorded in Sheffield are **different** from what I heard in daily life, but I have **no feelings** on the other sounds."*

*"I think some recorded traffic noise is **louder** than what I heard before."*

Appendix 3: Publications of the candidate

Book Chapters

- Kang, J., Chourmouziadou K., Sakantamis, K, Wang, B., **Hao, Y.** (ed.) (2013) Soundscape of European cities and landscapes. EU COST, Oxford. [e-book, ISBN: 978-0-9576914-1-4]

- J. Kang and **Hao, Y.** (2012) Noise mapping in horizontal and vertical planes. In R. Di Giulio, editor, Sunurbanscapes, pp: 177–182. Alinea Editrice, Florrence, Italy.

Journal Papers

- **Hao, Y.**, Kang, J. and Woertche, H (2014) Masking effects of birdsong on traffic noise environment within the scope of soundscape. *Journal of the Acoustical Society of America*, submitted.

- Kang, J and **Hao, Y.** (2014) Urban waterscape and soundscape design: A case study in Sheffield, UK. *Landscape and Urban Planning*, to be submitted.

- **Hao, Y.** and Kang, J. (2014) Influences of urban morphology on soundscape from the viewpoint of masking effects. *New Architecture (in Chinese)*, accepted.

- **Hao, Y.** and Kang, J. Krijnders, J. D. and Woertche, H (2013) On the relationship between traffic noise resistance and urban morphology in low-density residential areas. *Acustica/acta acustica - European Journal of Acoustics*, accepted.

- **Hao, Y.**, Kang, J. and Krijnders, J. D. (2013) Incidence of green area in context of urban morphology from the viewpoints of both audibility and visibility. *Landscape and Urban Planning*, under review.

- **Hao, Y.** and Kang, J. (2014) Influence of mesoscale urban morphology on the spatial noise attenuation of flyover aircrafts. *Applied Acoustics*, in press.

http://dx.doi.org/10.1016/j.apacoust.2013.12.001.

- **Hao, Y**. and Kang, J. (2010) Current Situation and Potentials of Construction Waste Minimisation by Design in China through a Comparative Survey between China an d UK. (in Chinese), *Building and Science*, Vol 26 (06), pp:04-09.

- **Hao, Y.**, Chen B. and Kang, J. (2010) Case Studies of Householder Stream in Low Carbon Buildings Programme in the UK, *Eco-city and Green Building* (in Chinese), Autumn Issue, pp: 33-35

- **Hao, Y.** and Kang, J. (2010) Comparative study on construction waste minimization in building design between China and United Kingdom. *Renewable Energy* 2010 [An official publication of the World Renewable Energy Network – affiliated to UN ESCO], pp; 82-86.

Conference Papers

- Kang, J. and **Hao, Y.** (2014) Design of urban elements to improve soundscape - water as an example. *Proceedings of the Institute of Acoustics (IOA) (UK),* Brighton, UK. *[Invited keynote]*.

- **Hao, Y.** and Kang, J. (2013) Influence of mesoscale urban morphology on the spatial urban noise attenuation in low-density residential areas. *Proceedings of the 13th UK CARE Annual General Meeting,* Reading, UK.

- Kang, J. and **Hao, Y.** (2013) Soundscapes of waterscape and squares on the Sheffield Gold Route. *Proceedings of the COST Action on Soundscape of European Cities and Landscapes Final Conference*, Merano, Italy.

- Kang, J. and **Hao, Y.** (2013) Sound field and texture of built-up areas. *Proceedings of the 20th International Congress on Sound and Vibration (ICSV16),* Bangkok,

Thailand. *[Invited paper]*

- **Hao, Y.** and Kang, J. (2013) Traffic resistance of low-density residential areas in context of urban morphology. *Proceedings of the 40th Italian Annual Conference on Acoustics (AIA), 39th German Annual Conference on Acoustics (DAGA), combined with European Acoustics Association (EAA) Euroregio*, Merano, Italy.

- Kang, J. and **Hao, Y.** (2013) On the relationships between urban morphology, noise resistance and soundscape. *Proceedings of the 40th Italian Annual Conference on Acoustics (AIA), 39th German Annual Conference on Acoustics (DAGA), combined with European Acoustics Association (EAA) Euroregio*, Merano, Italy. *[Invited paper]*

- Kang, J. and **Hao, Y.** (2012) Soundscape and urban morphology. *Sounding Brighton: Exploring practical approaches towards better soundscapes joint with the Meeting of the COST Action TD0804*, Brighton, UK. *[Invited speech]*

- Kang, J. and **Hao, Y.** (2011) Waterscape and soundscape in Sheffield. *Meeting of the COST Action TD0804 on Soundscape Examples in Community Context*, Brighton, UK. *[Invited speech]*

- **Hao, Y.**, Cance, C. and Kang, J. (2010) Auditory Masking in Soundscapes, *Proceed ings of EAA EuroRegio Congress on Sound and Vibration*, Ljubljana, Slovenia

- **Hao, Y.** and Kang, J. (2009) Construction waste minimisation design in China through a comparative study between the UK and China. *Proceedings of the 9th UK CARE Annual General Meeting*, Salford, UK.