URBAN SOUNDSCAPE

J Kang University of Sheffield, School of Architecture, Western Bank, Sheffield S10 2TN

1. INTRODUCTION

Reducing sound level, the focus of current practice and policies on urban sound environment, will not necessarily lead to improved quality of life in urban areas, as suggested by recent research findings. Soundscape represents a step change in the field of environmental acoustics in that it combines physical, social and psychological approaches [1].

This paper reviews and summarises our recent work in urban soundscape research [1-50]. Starting with a discussion on the tendency of moving from purely controlling noise to designing soundscape, the soundscape evaluation, simulation/auralisation, creation and prediction are systematically explored. Particular attention is given to urban open public spaces, which are important components of a city.

2. FROM NOISE REDUCTION TO SOUNDSCAPE CREATION

2.1. Environmental noise reduction

Significant attention has been paid to environmental noise problems in the last decade, especially in Europe [2]. Following the Green Paper on future noise policy in 1996 [51], a Directive of the European Parliament relating to the assessment and management of environmental noise (END) was published in 2002 [52], aiming at establishing a common EU framework in terms of noise indicators and assessment methods. The Directive has led to a series of major developments in terms of research and practice, such as the exploration of novel prediction methods for sound propagation, and methods for estimating number of exposed individuals above certain sound levels of noise.

While noise-mapping has become an essential requirement, especially in Europe, and corresponding software/techniques have been widely used in practice, there are still debates about their usefulness, accuracy and strategic application [3]. Much effort has been made to improve the accuracy in noise-mapping, especially through a number of research projects funded by the European Commission, including Harmonoise (Harmonised Accurate and Reliable Methods for the EU Directive on the assessment and management Of environmental Noise) and IMAGINE (Improved Methods for the Assessment of the Generic Impact of Noise in the Environment). Moreover, a significant need in current noise-mapping techniques is for a more accurate consideration of the effects of buildings and ‘urban furniture’ on the sound propagation. In this respect, a number of simulation-based models for micro-scale as well as meso-scale urban environment have been developed [1,53-58], although those models are still yet to be integrated into noise-mapping software packages.

2.2. Soundscape

Although considerable efforts have been made in environmental noise reduction in terms of policies, prediction models/tools and control measures, recent researches have shown that reducing sound level does not necessarily lead to a better acoustic comfort in urban areas [1,59].

The importance of quiet areas is recognised in the EU Directive END but no clear definition is given and there is no method by which ‘good’ or ‘restorative’ sound environments can be measured. The EU project CALM (Coordination of European research for advanced transport noise mitigation) network indicated in their strategic papers a need for perception related research for identifying indicators and parameters influencing public’s perception of quiet areas, but no coordination activity has been performed.

Soundscape, different from noise control engineering, is about relationships between the ear, human beings, sound environments and society [60]. Research in soundscape relates to many disciplines across science, engineering, social science, humanity and art. Soundscape research has been carried out by researchers in various fields including acoustics, aesthetics, anthropology, architecture, ecology, ethnology, communication, design, human geography, information, landscape, law, linguistics, literature, media arts, medicine, musicology, noise control engineering, philosophy, pedagogics, psychology, political science, religious studies, sociology, technology, and urban planning. Soundscape also has significant practical relevance, in terms of policies as well as planning and design process [1].

Soundscape research will bring a step change in the field of environmental acoustics by considering environmental sounds as a ‘resource’ rather than a ‘waste’. This will support the design and implementation of urban sound environment that promote health, attract investment, convey cultural uniqueness and enhance quality of life.

3. SOUNDSCAPE EVALUATION

3.1. Soundscape evaluation in urban open public spaces

Based on a series of large scale field surveys in nineteen urban open spaces in Europe and China, the effects of various acoustical, environmental, social, demographical, psychological, cultural and behavioural factors on the soundscape evaluation have been examined [4-15]. In Europe, fourteen urban open spaces were studied, located in seven cities of five countries including Germany, Greece, Italy, Switzerland and the UK. Two case study sites were selected in each city. In China the surveys were carried out in five urban open spaces, two in Beijing and three in Shanghai.

Among the nineteen case study sites, there was a wide range of variation in terms of their physical conditions and urban morphology, as well as the social and demographical characteristics of the users. Five sites were in residential areas, and the other sites were located in various types of public areas, including city centres, tourist locations, and railway stations. In terms of soundscape, traffic noise existed in nearly all the case study sites, although less so in some sites. Seven case study sites were featured by water sounds. A number of other unique sound elements contributed to the soundscapes of several case study sites, such as music, church bells, and construction/demolition sounds. Other sounds included people’s chatting, children’s shouting, and sounds from sport activities and foot steps.

In total, more than 10,000 interviews were made, typically 500-1000 in each site. For social/demographic factors, the interviewees were classified into eight categories in terms of age: <12, 13-17, 18-24, 25-34, 35-44, 45-54, 55-64, and 65; three categories in terms of occupation: 1- students, 2- working persons, and 3- others (including pensioners, unemployed and housekeepers); three categories in terms of educational level: 1- primary, 2- secondary, and 3- higher; and two categories in terms of residential status: local and non-local. Interviewees’ behaviours were also observed, including wearing earphones, grouping, reading/writing, watching, and various moving activities, namely 1- sitting, 2- standing, 3- walking, 4- playing with children, and 5-sport.

In the questionnaire interviewees were asked to evaluate the soundscape quality, with a five linear scale, in terms of sound level (-2, very quiet; -1, quiet; 0, neither quiet nor noisy; 1, noisy; 2, very noisy) as well as acoustic comfort (-2, very uncomfortable; -1, uncomfortable; 0, neither uncomfortable nor comfortable; 1, comfortable; 2, very comfortable). The sound pressure level (SPL) measurement was carried out, together with a series of other physical factors including air temperature, wind speed, relative humidity, brightness and sunshine.

The analysis of the survey results using SPSS show that the background sound level is an important index in evaluating soundscape in urban open public spaces. A lower background sound level can make people feel quieter. In other words, to create a comfortable acoustic environment in an urban open public space, it is important to reduce the background sound level [5].

Considerable differences have been found between the subjective evaluation of sound level and the acoustic comfort evaluation. The latter is much more complex and its correlation with measured SPL is systematically less [5]. More importantly, people tend to show more tolerance in terms of acoustic comfort evaluation.

3.2. Influencing factors on the soundscape evaluation

In terms of the sound level evaluation, occupation and education have more influence than other factors including age, gender and residence status. The effects of some behavioural factors including wearing earphones, reading/writing, and moving activities, are insignificant on the sound level evaluation, but the watching behaviour is highly related to the sound level evaluation, indicating visual/aural interactions. In terms of acoustic comfort evaluation, the effects of view assessment and watching behaviour are even more significant. Moreover, the long-term sound experience, namely the evaluation of acoustic environment at home, significantly affects the soundscape evaluation in urban open spaces. The effects of other physical factors such as temperature, wind speed and brightness are significant in about 50% of the case study sites [12].

It is important to note that between the social/demographical factors studied, there are some significant correlations, although the correlation coefficients may not be high. It is therefore important to consider these correlations when studying the effects of a given factor.

3.3. Semantic differential analysis

The semantic differential method has been used to determine the key factors that characterise the soundscape in urban open spaces. The indices, including both connotative and denotative meanings, covered various aspects of soundscape, for example, satisfaction: pleasant-unpleasant, like-dislike, comfort-discomfort, quiet-noisy, interesting-boring, calming-agitating, happy-sad and beautiful-ugly; strength: gentle-harsh, high-low, hard-soft, light-heavy and strong-weak; fluctuation: sharp-flat, directional-everywhere, varied-simple, fast-slow, echoed-deadly, far-close, smooth-rough, pure-impure and steady-unsteady; and social aspects: meaningful-meaningless, bright-dark, friendly-unfriendly, safe-unsafe and social-unsocial.

The results of the semantic differential analysis show that although the soundscape evaluation in urban open spaces is rather complicated, it is still possible to identify several major factors, including relaxation, communication, spatiality and dynamics, both in the UK and China [13]. It is interesting to note that these factors cover the main facets of designing the acoustics of an urban open space: function (relaxation and communication), space, and time, although the typical coverage of the total variance is only about 50-60%, indicating the complicated features of soundscapes of urban open spaces. A comparison between general public and architectural students shows that the soundscape characterisation is generally similar between the two groups, but the latter is slightly more ‘tolerant’ and also, shows a greater diversity [14].

3.4. Sound preference

While people generally share a common opinion when ranking natural and artificial sounds in urban open public spaces, significant difference exists for some sounds among the cities, which is likely caused by cultural factors. In the same city, the difference between various sites is considerably less than that between cities [11]. The effect of cultural factors has also been confirmed in another comparative study (see section 3.5). For example, 70% of Sheffield people chose bird songs as a preferred sound in their living environment, but only 32% of Taipeiners and 25% of Beijingers ticked the box. Conversely, many people in Taipei, 26%, and in Beijing, 43%, tended to prefer music in their living environment (music from outside), whereas only 4% of the interviewees in Sheffield showed the same interest [16-20].

Based on the results in the two urban open public spaces in Sheffield, it is interesting to note that in perceiving the sound elements in a given soundscape, the first noticed sounds do not have to be the loudest - people always mention the soundmarks as their first noticed sounds. Moreover, the preferences of soundscape elements are proved to influence people's choice of using an urban open public space. It has been further confirmed that natural sounds as a group are generally preferred in open public spaces [4].

In terms of the effects of demographic factors in soundscape preferences, it has been shown that the differences amongst age groups are rather significant. Generally speaking, with the increase of age, people are more favourable to, or tolerant towards, sounds relating to nature, culture or human activities. By contrast, younger people are more favourable to, or tolerant towards, music and mechanical sounds. Between males and females there are only slight differences [4].

3.5. Soundscape in urban living environment

A series of surveys were carried out in Sheffield, Beijing and Taipei, aiming at comparing the perception of soundscape as a part of the general urban living environment [16-21]. Three residential areas were sampled in each city, representing typical urban textures as well as residents' social/demographic/cultural backgrounds.

In terms of the importance of various factors when people choose a living environment, it has been shown that there are generally significant differences between the three cities for most factors. The factor 'quietness' was ranked as the 6th important factor in Sheffield, 4th in Taipei, and 7th in Beijing, among 11 factors. In terms of the evaluation of general living environment, sound quality of the living area, and sound quality at home, people felt worse in Taipei and Beijing than in Sheffield, by about 0.5 at a five-point scale. Among water, air, noise and waste pollutions, noise was ranked as 2nd in Sheffield and Taipei, and 3rd in Beijing. In terms of main activities at home, it is interesting to note that in Sheffield the percentage of reading and listening music was considerably higher than that in Taipei and Beijing, suggesting that Sheffield people could be more sensitive in terms of disturbance of activities.

4. SOUND FIELD SIMULATION AND AURALISATION

4.1. Micro-scale simulation models

Energy-based image source methods have been developed for street canyons and urban squares with geometrically (specularly) reflecting boundaries [22-23]. Ray-tracing models have also been developed, for more complex geometries [24]. In the models some special methods relating to micro-scale urban environments have been implemented in order to reduce the computation time. A radiosity model has been developed for urban squares and streets with diffusely reflecting boundaries [25-26], since there are always some irregularities on building or ground surfaces — the back-diffusion effect of reverberation has been demonstrated through measurements. In the model the boundaries are divided into a number of patches, and the patches and receivers are replaced with nodes in a network. The sound propagation in the space can then be simulated by energy exchange between the nodes. A combined ray-tracing and radiosity model, CRR, has also been developed [27-29]. It can simulate sound propagation with various geometrically and diffusely reflecting boundary conditions, with multiple sound sources and receivers in complex geometrical settings. Based on both analytic theories and regression of data obtained using computer simulation models, a series of formulae have been developed for calculating the reverberation time (RT) and SPL under various boundary conditions [1,30].

A number of models have also been developed by other researchers, such as the image source method considering interference [53], models based on the transport theory [54], the equivalent source method [55], and the combined finite-difference time domain method and parabolic equation method [56].

4.2. Auralisation for urban open public spaces

To aid urban soundscape design as well as for public participation, it would be useful to present the 3D visual environment with an acoustic animation/auralisation tool, where considerations should be given to various urban sound sources, dynamic characteristics of the sources, and the movements of sources and receivers. The calculation speed should be reasonably fast, so that a designer can adjust the design and then immediately listen to the difference. A key issue of achieving fast acoustic animation/auralisation for urban soundscape is to simplify the simulation algorithms, whilst retaining reasonable accuracy [30-31].

To explore such simplifications, the changes in SPL and RT with various combinations of reflection order and ray number have been systematically examined [1,30]. It is shown that for SPL, a reflection order of 5 and a ray number of 5k is already acceptable, whereas for RT, a reflection order of 20 and a ray number of 5k is a good combination with an approximate accuracy of 10-15%.

Since human sensitivity to a particular sound source might be reduced within a complex sound environment with multiple and moving sources, to provide a fast urban acoustic animation/auralisation, further simplifications of calculation parameters have been explored through a series of subjective experiments [24,31]. The initial results suggest that a reflection order of 5 is generally acceptable in urban squares, for many typical sound sources such as music, fountain and car. For certain sounds, such as human voice, more reflection orders are needed.

5. SOUNDSCAPE CREATION

Whilst most previous studies on soundscape in urban open public spaces have considered soundscape as a passive perception factor, it is important to put soundscape into the intentional planning and design process comparable to landscape [39-43]. A framework for describing the soundscape of urban open public spaces has been proposed [39], where important influencing factors are listed and four key components are identified, including: (1) sound – characteristics of each sound source, (2) space – acoustic effects of the space, (3) people – social/demographic aspect of the users as well as their activities and behaviours, and (4) environment – other aspects of the physical conditions. Considering these key components, a series of design guidelines have been developed.

5.1. Sound

There is a great potential in the planning and designing of various sounds. It would be important to consider soundmarks, reflecting traditional and cultural characteristics. Moreover, spectrum analysis is vital, both for individual sounds and for the overall acoustic environment, especially when psychoacoustic magnitudes are considered. Furthermore, the design of soundscape in an urban open space should be considered as a dynamic process.

Whilst conventionally sounds in an urban open public space can be classified as keynotes, foreground sounds and soundmarks [60], from the design viewpoint it is more appropriate to divide preferred sounds into the following two categories: (1) passive sounds, namely sounds from the landscape elements, for functional and aesthetical purposes, and (2) active sounds, namely sounds from human activities [10].

A typical passive sound, water, in the form of fountains, springs or cascades, is often used as a landscape element in open public spaces, and has been proven to have endless effects in colouring the soundscape. It can be defined as a ‘primary soundscape quality’. From the detailed spectrum and dynamic range analysis, it has been found that most water sounds have significant high frequency components around 2-8kHz and some of them also have notable low frequency components. This can probably explain why water sounds are always more distinctive than other background sounds. The diversity in spectrum leads to great potentials of designing the acoustic effects of water features. Different flow methods result in different frequencies. Generally speaking, high frequency components come from the water splash itself, whereas when a large flow of water is raised to a very high level and then dropped to a water body or hard surface, notable low frequency components can be generated [6].

As a typical active sound, live music is always very popular. People are not only interested in the music itself, but are also attracted by the activities of the players. In this case, the type of music, namely, whether it is classical music or pop music, is not a very important issue. Conversely, when music is from a store or played through a public address (PA) system, the type of music and the sound level needs to be considered carefully. Most people do not like loud music played from loudspeakers, whatever the music type is. While the low frequency components in music are often not loud enough to mask traffic sounds, the high frequency components can bring the music sound out from other background sounds and make the soundscape more pleasant [1].

5.2. Space

In urban open public spaces, architectural changes and urban design options could affect the sound field significantly [22-38]. For example, computations in a number of hypothetical urban squares using the radiosity and image source models have shown that [26,32]: (1) With either diffusely or geometrically reflecting boundaries, the SPL initially decreases significantly with increasing source-receiver distance and then becomes approximately stable. The RT is rather long, about 2s with diffusely reflecting boundaries and around 8-10s with geometrically reflecting boundaries in a typical square of 50x50m. The RT is very even across a square. (2) Compared to diffusely reflecting boundaries, with geometrically reflecting boundaries the RT is significantly longer, typically by 200-400%, and the SPL attenuation along a square is generally smaller unless the height/side ratio is high, say 1:1. (3) When the boundary diffusion coefficient is increased from d=0 to about 0.2, the decrease in SPL and RT is significant, whereas when d is further increased, the changes become much less. (4) If a relatively far field is considered, the SPL is typically 6-9dB lower when the square side is doubled; 8dB lower when the square height is decreased from 50m to 6m (diffusely reflecting boundaries); 5dB (diffusely reflecting boundaries) or 2dB (geometrically reflecting boundaries) lower if the length/width ratio is increased from 1 to 4, and 10-12dB lower if the boundary absorption coefficient is increased from 0.1 to 0.9. (5) When one façade is removed or made absorbent, the sound field near this façade is mostly affected, whereas when two or more façades are removed or made absorbent, the direct sound plays a much more important role.

An urban open public space can be designed to encourage activities which generate active sounds and soundmarks. A green space may enhance the natural appealing of a square, attract activities of wild life such as bird singing. Some patterns of design are more suitable for certain activities, for example, defined edges, such as by walls, colonnades, or shrub plantings, often encourage activities to take place. Hard spaces are useful for generating many activities, especially for young people, such as dancing and skateboarding [10].

5.3. People

Considerable research has been carried out in terms of the effects of various non-acoustic factors on the soundscape evaluation, as discussed in section 3. The results of such research works have clearly demonstrated the importance and design potentials in considering the characteristics of the users. For example, if an urban open public space is mainly designed for older people, more natural sounds like bird songs should be introduced, whereas if the users are mainly young people, more artificial sounds could be introduced or created.

It is also important to consider the design process. In a study on environmental noise barriers, the significance of public participation and pre-perception has been demonstrated [44-46].

5.4. Environment

The interaction between acoustic and other physical environments is an essential consideration in soundscape planning and design in urban open public spaces. For example, if a place is very hot or very cold, the acoustic comfort could become less critical in the overall comfort evaluation. A principal component analysis based on the large scale survey in Europe shows that there are three factors characterising the physical environment: Factor 1 (22.8%) includes temperature, sunshine, brightness and wind; Factor 2 (17.5%) is associated with visual and auditory senses; and Factor 3 (14.8%) is principally related to humidity and wind [1].

Of various physical conditions the aural-visual interactions have been intensively studied. Significant correlations have been found between landscape and acoustic satisfaction, between visual and acoustic satisfaction, as well as between view and quietness in choosing a living environment [16-19].

6. SOUNDSCAPE PREDICTION

For urban planners and architects, it would be useful to develop a tool to predict the subjective evaluation of soundscape quality by potential users, using known design conditions such as physical features of a space, acoustic variables, and characterises of the users. Models of predicting soundscape quality, including sound level and acoustic comfort evaluation, have been developed using the artificial neural networks (ANN) technique as well as the ordinal logistic regression (OLR) technique, respectively [47-50]. Since there are considerable differences in soundscape evaluation between various case study sites in terms of the effects of various factors, it is necessary to classify urban open spaces into typical categories, and develop sub-models for each category.

A model has been developed based on the data in a typical city centre open space, the Peace Gardens in Sheffield, where for the sound level evaluation prediction models the input variables include the SPL, season, time, age, occupation, education, site preference, grouping, reading/writing, watching, and the sound level evaluation at home. For the acoustic comfort models the variables used include the SPL, time, relative humidity, wind speed, age, grouping, view assessment, location on the site, sound level evaluation at home and sound level evaluation on the site. Software Qnet has been employed for the ANN modelling. The optimum architecture of the sound level evaluation model is found to be with one hidden layer and nine hidden nodes, and the model for the acoustic comfort evaluation is with two hidden layers, where there are five nodes in layer 1 and two nodes in layer 2. The trained model of the sound level evaluation has a correlation coefficient of 0.77 and 0.63 for training and test respectively, and the RMS error is 0.102 (training) and 0.145 (test). For the acoustic comfort model, the correlation is 0.88 (training) and 0.79 (test), and the RMS error is 0.08 (training) and 0.09 (test) [47].

OLR models have also been established with the same input variables. The models have five output results corresponding to the five evaluation scales. The prediction accuracy of the sound level evaluation model is 0% (very quiet), 31% (quiet), 55% (neither quiet nor noisy), 67% (noisy), and 32% (very noisy). For the acoustic comfort evaluation model the accuracy is 0% (very uncomfortable), 28% (uncomfortable), 43% (neither uncomfortable nor comfortable), 88% (comfortable), and 11% (very comfortable). The 0% accuracy is caused by the small samples in the category. The overall prediction accuracy is 53% for the sound level evaluation model and 61% for the acoustic comfort model, slightly lower than that with the ANN models, but still rather good.

The ANN models have been used to give soundscape prediction maps. In Figure 1 the acoustic comfort evaluation maps in the Sheffield Peace Gardens are compared between people who have different acoustic environments at home. The results suggest that people from nosier homes will feel less comfortable acoustically in the urban open space. Whilst results in Figure 1 are generic, the models can also map more complex social groupings, at various zones on the site, and also consider temporal variations.

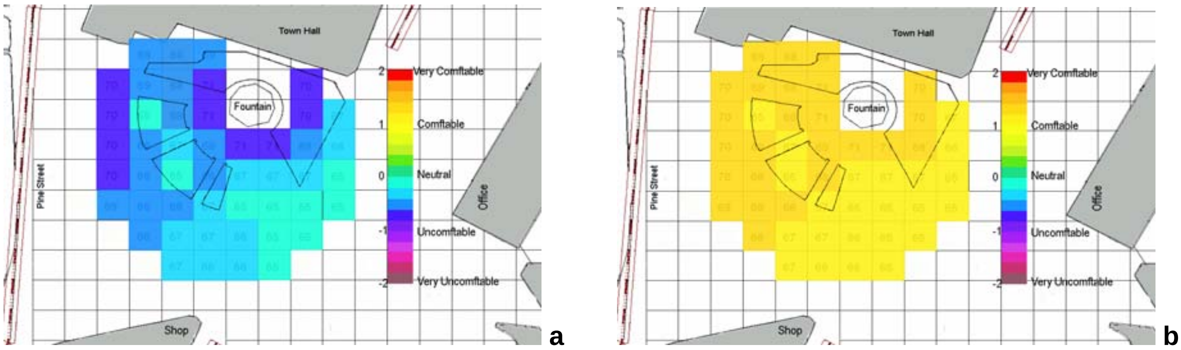

Figure 1. Acoustic comfort map in the Peace Gardens: comparison between people from noisier (a) and quieter homes (b).

7. CONCLUSIONS

Whilst there is a tendency from purely reducing noise level to overall soundscape design, the complexity as well as potentials of soundscape research and practice has been demonstrated through systematically examining soundscape evaluation, simulation, creation and prediction. Although considerable work has been carried out, further research is still needed in more facets, and practical implementation of the research work is yet to start.

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9. REFERENCES

1. Kang, J. (2006) Urban Sound Environment. Taylor & Francis incorporating Spon, London.
2. Zhang, M. and Kang, J. (2005) Environmental noise policy and research in Europe. Greenleaf – Journal of the State Administration of Environmental Protection of People Republic of China, No. 2 (2005), 32-33 (in Chinese).
3. Kang, J. and Huang, J. (2005) Noise-mapping: accuracy and strategic application. Proceedings of the 33rd International Congress on Noise Control Engineering (Inter-noise), Rio de Janeiro, Brazil.
4. Yang, W. and Kang, J. (2005) Soundscape and sound preferences in urban squares. Journal of Urban Design, 10, 69-88.
5. Yang, W. and Kang, J. (2005) Acoustic comfort evaluation in urban open public spaces. Applied Acoustics, 66, 211-229.

6. Yang, W. (2005) An Aesthetic Approach to the Soundscape of Urban Public Open Spaces. PhD dissertation, School of Architecture, University of Sheffield, UK.
7. Kang, J. and Yang, W. (2002) Soundscape in urban open public spaces. World Architecture, Issue 144, 76-79 (in Chinese).
8. Kang, J. (2006) Acoustic quality in non-acoustic public buildings. Technical Acoustics, 25(6), 513-522.
9. Kang, J. (2005) Paesaggio sonoro e comfort acustico negli spazi urbani aperti (Soundscape and acoustic comfort in open urban environments). In Rogora A. and Dessi V. (ed.), Il comfort ambientale negli spazi aperti (Environmental Comfort in Open Spaces), EdicomEdizioni, Monfalcone (Gorizia), 55-62 (in Italian).
10. Yang, W. and Kang, J. (2001) Acoustic comfort and psychological adaptation as a guide for soundscape design in urban open public spaces. Proceedings of the 17th International Conference on Acoustics (ICA), Rome, Italy.
11. Yang, W. and Kang, J. (2003) A cross-cultural study of the soundscape in urban open public spaces. Proceedings of the 10th International Congress on Sound and Vibration, Stockholm, Sweden, 2703-2710.
12. Yu, L. and Kang, J. (2007) Effects of social, demographic and behavioral factors on the sound level evaluation in urban open spaces. Journal of the Acoustical Society of America, 123, in press.
13. Zhang, M. and Kang, J. (2006) A cross-cultural semantic differential analysis of the soundscape in urban open public spaces. Technical Acoustics, 25(6), 523-532.
14. Zhang, M. and Kang, J. (2004) Evaluation of urban soundscape by future architects. Proceedings of the 147 meeting of the Acoustical Society of America, New York, Journal of the Acoustical Society of America, 115, 2497.
15. Kang, J. (2007) Urban soundscape. Journal of the South China University of Technology, 35 (supplement), 11-16.
16. Yu, C. and Kang, J. (2007) Soundscape in the sustainable living environment. Proceedings of the 35th International Congress on Noise Control Engineering (Inter-noise), Istanbul, Turkey.
17. Yu, C. and Kang, J. (2006) Effects of cultural factors on the environmental noise evaluation. Proceedings of the 34th International Congress on Noise Control Engineering (Inter-noise), Honolulu, Hawaii.
18. Yu, C. and Kang, J. (2006) Comparison between the UK and Taiwan on the sound environment in urban residential areas. Proceedings of the 23rd Conference on Passive and Low Energy Architecture (PLEA), Geneva, Switzerland.
19. Yu, C. and Kang, J. (2006) Acoustic comfort in urban residential areas: A cross-cultural comparison between the UK and Taiwan. Proceedings of the 9th Western Pacific Acoustics Conference, Seoul, Korea.
20. Xing, Z. and Kang, J. (2006) Acoustic comfort in residential areas – a cross-cultural study. Proceedings of the Institute of Acoustics (IOA) (UK), 28(1), 317-326.
21. Zhang, M. and Kang, J. (2008) Subjective evaluation of urban environment: a case study in Beijing. International Journal of Environment and Pollution, in press.
22. Kang, J. (2002) Acoustics of Long Spaces: Theory and Design Guide. Thomas Telford Publishing, London.
23. Kang, J. (2000) Sound propagation in street canyons: Comparison between diffusely and geometrically reflecting boundaries. Journal of the Acoustical Society of America, 107, 1394-1404.
24. Meng, Y., Kang, J., Huerta, R. and Zhang, M. (2005) Soundscape animation of urban open spaces in an interactive virtual environment. Proceedings of the 12th International Congress on Sound and Vibration, Lisbon, Portugal.
25. Kang, J. (2002) Numerical modelling of the sound field in urban streets with diffusely reflecting boundaries. Journal of Sound and Vibration, 258, 793-813.
26. Kang, J. (2005) Numerical modelling of the sound fields in urban squares. Journal of the Acoustical Society of America, 117, 3695-3706.
27. Meng, Y. and Kang, J. (2007) Combined ray tracing and radiosity simulation for urban open spaces. Proceedings of the 19th International Conference on Acoustics (ICA), Madrid, Spain.
28. Meng, Y., Kang, J. and Smyrnova, Y. (2008) CRR - Combined ray-tracing and radiosity model. Proceedings of the Institute of Acoustics (IOA) (UK), 30(2).
29. Meng, Y. and Kang, J. (2007) CRR: Combined ray-tracing and radiosity modelling for urban squares. Journal of the Acoustical Society of America, to be submitted.
30. Kang, J., Meng, Y. and Brown, G. (2003) Sound propagation in micro-scale urban areas: simulation and animation. Proceedings of the Fifth European Conference on Noise Control (Euronoise), Naples, Italy.
31. Smyrnova, Y., Meng, Y. and Kang, J. (2008) Subjective evaluation of urban soundscape auralisation based on combined ray-tracing and radiosity (CRR) model. Proceedings of the Institute of Acoustics (IOA) (UK), 30(2).
32. Kang, J. (2002) Computer simulation of the sound fields in urban squares: comparison between diffusely and geometrically reflecting boundaries. Proceedings of the 32nd International Acoustical Conference (IAC) — European Acoustics Association (EAA) Symposium ‘ACOUSTICS BANSKÁ ŠTIAVNICA’, Slovakia, 157-160.
33. Kang, J. (2001) Sound propagation in interconnected urban streets: a parametric study. Environment and Planning B, 28(2), 281-294.

34. Kang, J. (2004) Application of radiosity method in acoustic simulation. Proceedings of the 18th International Conference on Acoustics (ICA), Kyoto, Japan, I-289-290.
35. Kang, J., Tsou, JY. and Lam, S. (2001) Sound propagation in urban streets: comparison between the UK and Hong Kong. Proceedings of the 8th International Congress on Sound and Vibration, Hong Kong, 1241-1248.
36. Kang, J. (2000) Sound field in urban streets with diffusely reflecting boundaries. Proceedings of the Institute of Acoustics (IOA) (UK), 22(2), 163-170.
37. Kang, J. (2000) Modelling the acoustic environment in city streets. Proceedings of the 17th Conference on Passive and Low Energy Architecture (PLEA), Cambridge, England, 512-517.
38. Kang, J. (1999) A radiosity-based model for simulating sound propagation in urban streets. Proceedings of the 138th Meeting of the Acoustical Society of America, Columbus, Journal of the Acoustical Society of America, 106, 2262.
39. Zhang, M. and Kang, J. (2007) Towards the evaluation, description and creation of soundscape in urban open spaces. Environment and Planning B, 34(1), 68-86.
40. Kang, J. (2007) A systematic approach towards intentionally planning and designing soundscape in urban open public spaces. Proceedings of the 35th International Congress on Noise Control Engineering (Inter-noise), Istanbul, Turkey.
41. Kang, J., Yang, W. and Zhang, M. (2004) Sound environment and acoustic comfort in urban spaces. In Nikolopoulou M. (ed.), Design Open Spaces in the Urban Environment: a Bioclimatic Approach, Jointly published by the European Commission and the Centre for Renewable Energy Sources, 32-36.
42. Kang, J. (2008) From environmental noise control to soundscape: potentials in soundscape design of urban open public spaces. International Journal of Building, in press.
43. Kang, J. (2007) The design potentials of urban soundscape. The 3rd International Symposium of Temporal Design on Architecture and Environment, Guangzhou, China.
44. Joynt, J. and Kang, J. (2003) The use of public participation and noise mapping in the design of environmental noise barriers. Proceedings of the 5th European Conference on Noise Control (Euronoise), Naples, Italy, Acustica united with acta acustica, 89, S41.
45. Joynt, J. and Kang, J. (2002) The integration of public opinion and perception into the design of noise barriers. Proceedings of the 19th Conference on Passive and Low Energy Architecture (PLEA), Toulouse, France, 885-890.
46. Joynt, J. (2005) A Sustainable Approach to Environmental Noise Barrier Design. PhD dissertation, School of Architecture, University of Sheffield, UK.
47. Yu, L. and Kang, J. (2007) Mapping soundscape evaluation in urban open spaces with ANN. Proceedings of the 19th International Conference on Acoustics (ICA), Madrid, Spain.
48. Yu, L. and Kang, J. (2006) Artificial neural network models of sound signals in urban open spaces. Proceedings of the 4th Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan, Honolulu, Hawaii, Journal of the Acoustical Society of America, 120, 3238.
49. Yu, L. and Kang, J. (2005) Soundscape evaluation in city open spaces using artificial neural network. UIA 2005 - XXII World Congress of Architecture, Istanbul, Turkey.
50. Yu, L. and Kang, J. (2005) Neural network analysis of soundscape in urban open spaces. Proceedings of the 149 meeting of the Acoustical Society of America, Vancouver, Canada, Journal of the Acoustical Society of America, 117, 2591.
51. European Commission. (1996) Future Noise Policy - European Commission Green Paper, Brussels, Belgium.
52. European Commission. (2002) Directive (2002/49/EC) of the European Parliament and of the Council – Relating to the Assessment and Management of Environmental Noise. Brussels, Belgium.
53. Iu, K. and Li, K. (2002) The propagation of sound in narrow street canyons. Journal of the Acoustical Society of America, 112, 537-550.
54. Le Pollès, T., Picaut, J. and Bérengier, M. (2004) Sound field modelling in a street canyon with partially diffusely reflecting boundaries by the transport theory. Journal of the Acoustical Society of America, 116, 2969-2983.
55. Őgren, M. and Kropp, W. (2004) Road traffic noise propagation between two dimensional city canyons using an equivalent sources approach. Acustica united with acta acustica, 90, 293-300.
56. Van Renterghem, T., Salomons, E. and Botteldooren, D. (2006) Parameter study of sound propagation between city canyons with coupled FDTD-PE model. Applied Acoustics, 67, 487-510.
57. Thorsson, P., Őgren, M. and Kropp, W. (2004) Noise levels on the shielded side in cities using a flat city model. Applied Acoustics, 65, 313-323.
58. De Coensel, B., De Muer, T., Yperman, I. and Botteldooren, D. (2005) The influence of traffic flow dynamics on urban soundscapes. Applied Acoustics, 66, 175-194.
59. De Ruiter, E. (2004) Reclaiming Land from Urban Traffic Noise Impact Zones – The Great Canyon. PhD dissertation, Technical University of Delft, The Netherlands.
60. Schafer, RM. (1977) The Tuning of the World, Knopf, New York.