Design strategies for perceived acoustic comfort in urban environments – A literature review

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ABSTRACT

Urban design in recent years has been embracing “compact city” design concepts. With such trends in urban design, and developments of mid to high-rise mixed-use buildings, noise sources are often found in close proximity to our living environment. In satisfying the need for increased population density by integrating various land uses within a mixed development zone, planners, designers and policy makers often find challenges in controlling noise in the built environment. Whilst environmental planners and the policy makers aim to reduce noise within the urban built environment by setting noise limits, acoustic consultants are typically tasked with providing cost-effective solutions to achieve the environmental noise limits with almost no tolerance. The resulting condition is “buildup” of ambient noise level cumulatively over the years though satisfying the environmental noise limits for individual development. As a result, noise annoyance is increasingly perceived in urban areas which needs to be addressed through appropriate design strategies to enhance our living environment to acoustically comfortable. Acoustic comfort in the built urban environment, beyond the traditional approach of noise control and management, has often received less attention in urban design. The quality of a “place” is highly influenced by our perception of sound in the surrounding environment. It is therefore of utmost importance that sounds in our built environment are perceived positively. In aspiring to achieve acoustic comfort, it is imperative that innovative design strategies are integrated into urban design to promote the positive aspects of sound, in addition to reducing noise level through traditional noise control techniques. This paper presents a review of relevant literature on urban soundscape and discusses the theoretical background of acoustic comfort in outdoor urban environments. A number of strategies that can be incorporated into urban design to promote acoustic comfort are also proposed.

1 BACKGROUND

Australia’s population is projected to grow by 11.8 million people in next 30 years (Australian Bureau of Statistics 2013). According to the report for Future Cities by Infrastructure Australia, this is considered equivalent to adding a new city, approximately the size of Canberra, each year for the next 30 years. Such a growing population would not only strengthen our economy, but would also provide larger domestic market for business, larger labour force and diverse business sectors (Infrastructure Australia 2016). However, to meet the need of this growing population, a well-designed robust infrastructure system with high-density urban living is recommended by the experts. In recent years, a “Compact City” design concept has been demonstrated world-wide as an ideal model in meeting the needs of urban growth and providing a sustainable urban environment (Foord 2010). Hence the Compact City design concept is also considered as a viable pathway towards meeting the future urban growth in Australian cities.

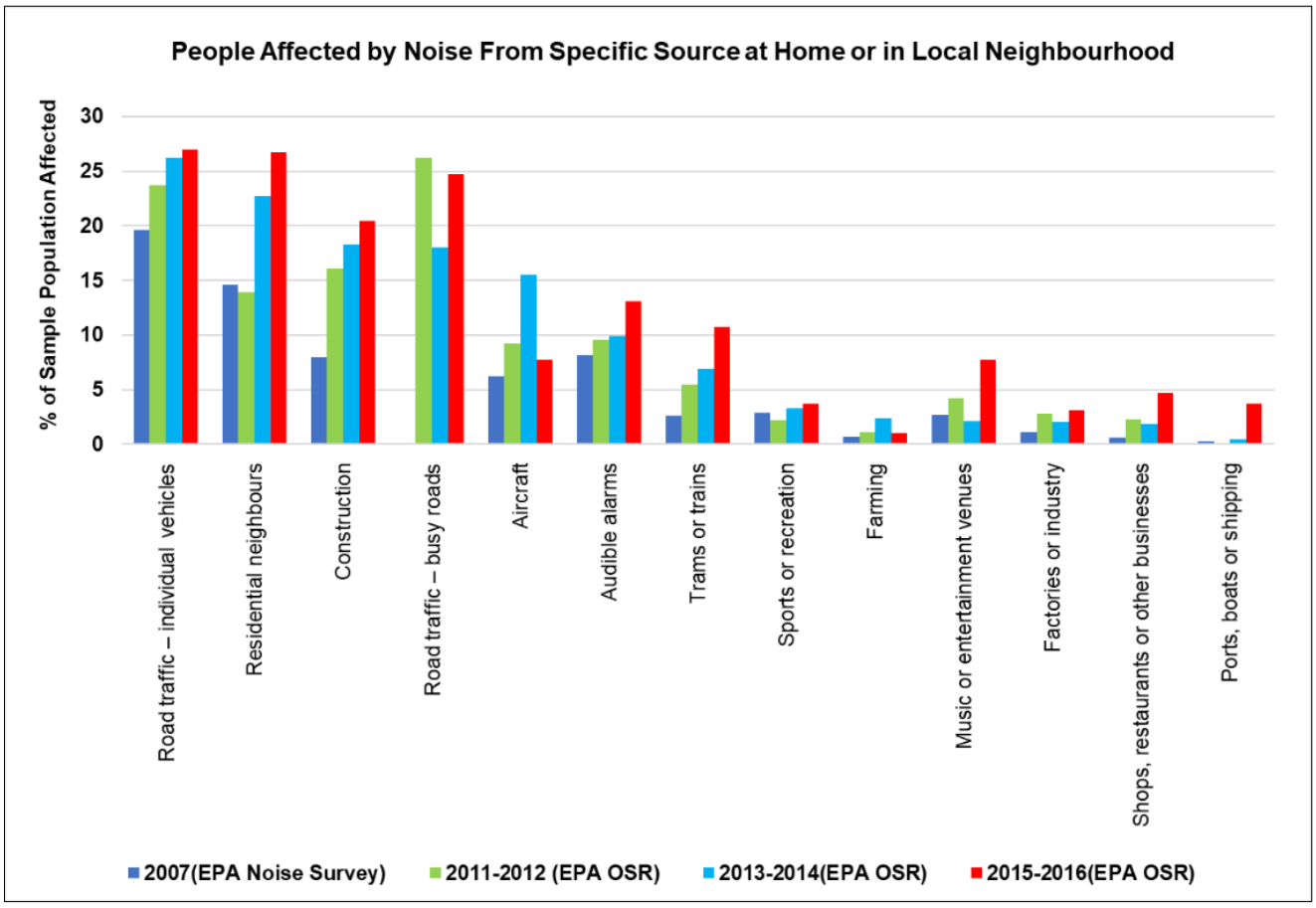
Mixed land-use planning is one of the core elements of the Compact City design concept, and “mixed-use” buildings have emerged as a key design paradigm in recent years (Horsfield, 2015).

Mixed-use developments offer the community with a variety of options for entertainment and social gathering. In satisfying the need for increased population density by integrating mixed-use developments within a mixed development zone, planners, designers and policy makers often find challenges in controlling noise in the built environment. Whilst environmental planners and the policy makers aim to reduce noise within the urban built environment by setting noise limits, acoustic consultants are typically tasked with providing cost-effective solutions to achieve the environmental noise limits with almost no tolerance. As a result, although the environmental noise limits are achieved by an individual development, the resulting ambient noise level at the surrounding environment keeps growing due to noise contributions from newer developments and the growth of surrounding amenity. With this repeating over the years, the “quality” of an outdoor urban space is often less enjoyable and noise annoyance in outdoor urban living area becomes an inevitable situation. As such, noise in outdoor living environment needs to be addressed through appropriate design strategies to enhance our living environment. This paper presents a review of relevant literature on urban soundscape and discusses the theoretical background of acoustic comfort

in outdoor urban environments. A number of strategies that can be incorporated into urban design to promote acoustic comfort are also discussed in this paper.

2 URBAN SONIC ENVIRONMENT AND THE CHALLANGES

With the increase in urban growth, development of high-density mixed-use developments, and the growth of "amenity" (i.e. restaurants, cafeteria, bar & bistro, gymnasium, etc) to serve the wider community, noise in urban living spaces in Australian cities is considered a growing concern. This is evident from the EPA community survey (Strahan Research 2007) (Environment Protection Authority Victoria 2018) data, presented in Figure 1, on noise in our living environment. Figure 1 is plotted based on the noise data published in the EPA Victoria 2007 Noise Survey (Strahan Research 2007) and the Outcomes Social Research (OSR) by EPA (Environment Protection Authority Victoria 2018). The graph presents the percentage of the survey population that have been affected at home or in their local neighborhood by various types of noise. Observing the trend of the survey data, it is evident that people are becoming increasingly affected by road traffic noise, residential neighbours' noise, construction noise and noise from music and entertainment venues. This is essentially an effect of urban growth on our outdoor living environment. The Outcomes Social Research (OSR) by EPA (Environment Protection Authority Victoria 2018) show that the residential noise is both widespread and the most annoying source of noise in Victoria. Key impacts associated with this problem include sleep disturbance (almost 60% of those annoyed by residential noise) and impaired use and enjoyment of one's home (Environment Protection Authority Victoria 2018).



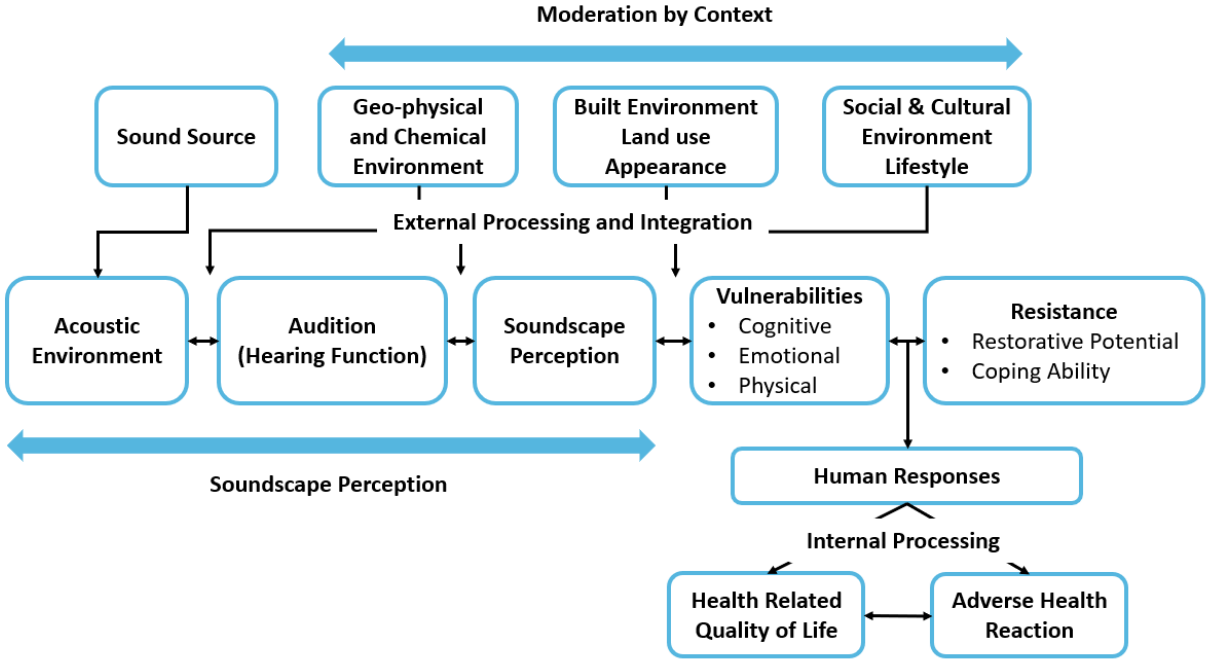
Source (Environment Protection Authority Victoria 2018) (Strahan Research 2007)
Figure 1 Proportion of people affected by noise from specific sources

Similar trends can be observed in other Australian Cities. Data from New South Wales, Environmental Incident reports (complaints) for the period 2008/2009 (DECCW NSW, 2010) indicates that noise is the second most frequent cause of environmental complaints at 21% of complaints. Environmental complaint data published by the

South Australian EPA (SA EPA, 2015) for the period from 2011 – 2014 indicate that noise is overwhelmingly the most significant cause of environmental complaints (Richardson, 2016). City of Perth advises prospective inner-city residents to experience the sounds of the city during the day and at night before making a permanent move for living (City of Perth 2018). This advice reflects growing concerns of noise in Perth's outdoor living environment. Due to rapid urbanization, the gap between wanted and unwanted sounds will decrease or even disappear. Consequently, urban areas where people can temporarily withdraw themselves from stressors such as noise may change or become increasingly scarce (Van-Kempen et al, 2014).
Noise exposure in the outdoor living environment not only affects our enjoyment of the outdoor space but may also affect our health, hearing and cause annoyance. However, reducing sound levels, will not necessarily lead to improved quality of life in urban areas (Alves et. al.2015, Andringa et al, 2013). It is therefore important to understand the "quality" of the sound that enhances (or degrades) the acoustic environment in a particular context. Sound quality is not an inherent property of the sound, rather something that develops when listeners are exposed to the sound and judge it with respect to their desires and/or expectations in a given context. Additionally, sound quality cannot be simply determined using a sound level meter with commonly used A-weighted metric, since soundscape is a multifaceted phenomenon. A-weighted sound pressure level is unable to consider mutual masking among the components in a complex sound or the asymmetry of masking patterns produced in the auditory system (Zwicker 1990), both which have an influence on the subjective perception of an aural environment (Morel et al, 2012). As a result, A-weighted sound pressure level is a poor indicator of annoyance. It is therefore important to understand the "quality" characteristics of sounds. These are the acoustic factors that influence the appreciation and enjoyment of an outdoor living space. The design of the urban space should integrate such acoustical qualities that can enhance the positive aspects of sound to make the outdoor space acoustically enjoyable.

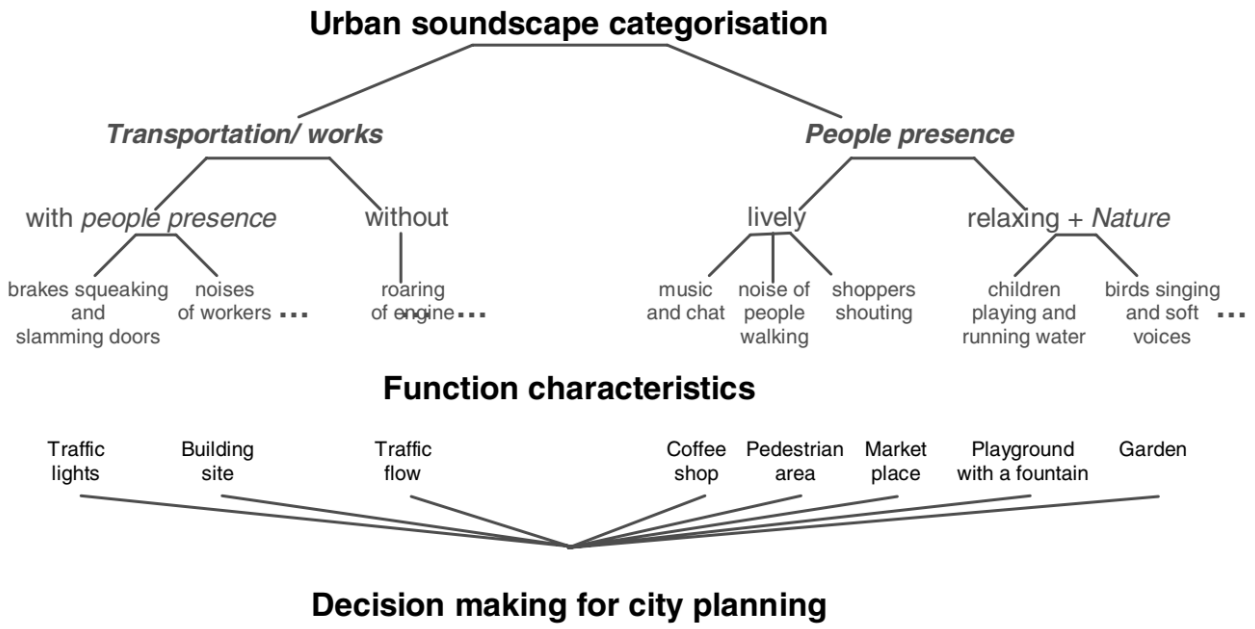
3 FACTORS SHAPING "QUALITY" OF URBAN SOUNDSCAPE

The acoustic environment of an urban space such as a park or recreation area is related to the surrounding physical phenomena, such as roads, railways, and anthropological sources, while the perceived comfort of sound is a subjective interpretation of the sound in that particular context. This is known as "Soundscape" which is defined as the acoustic environment as perceived and understood, by people, in context (International Organization for Standardization 2014). Assessment of soundscape, rather than noise levels alone, is considered to be a key paradigm shift that is required if the sonic environment in urban areas is to be evaluated effectively and improved for the benefit of those living there (Schomer et al, 2014).



Source: (Schulte-Fortkamp et al, 2013)
Figure 2 Linking Health and Wellbeing to Soundscape

A framework by Schulte-Fortkamp et al, 2013 linking health and wellbeing of people to soundscape is presented in in Figure 2. Soundscapes of different urban outdoor spaces are different. Soundscape in a context might comprise sounds from several sources, some of which attract the attention more than others, depending not only on the physical characteristics of the signal (such as the intensity, spectral content etc.), but also on its meaning and relevance to the listener (Manon et al, 2005). In an outdoor urban environment, sounds with specific characteristics often attract attention and become auditory objects as the listener starts paying attention to them. Furthermore, the composition of the surrounding acoustic environment, the attentiveness, current activities, and expectations of the listener and his/her prior knowledge of the sounds that could be heard would determine the alertness and the subjective perception (Kang, 2016).
Therefore, the "quality" of an urban outdoor space is context dependent and also depends on a person's preferred outcome with respect to the surrounding acoustic environment. For example, a soundscape in a park is preferred to be tranquil whereas the soundscape in an urban town center is often preferred to be lively and exciting. It is, therefore, important to understand how these preferred outcomes are translated into the urban design to shape the desired soundscape of the urban outdoor environment. Manon et al, 2005 suggests that soundscapes can be classified into two key categories: a) Transportation or Works and b) People Presence as presented in Figure 3. Transportation or works soundscapes are dominated by transport and building-related noise such as road traffic, railway, and construction sites which are people operated or automated. People Presence soundscapes are attributed to both lively human environments, dominated by sources such as voices, entertainment, music, and relaxing environments when linked to patterns of nature (such as birds in trees, fountains) (Manon et al, 2005). Therefore, a preferred outcome in a context such as "liveliness" often relates to lively activities by people (i.e. music and chat, noise of people walking, shoppers shouting etc.) which are associated with restaurants, coffee shops, pedestrian areas or market places. Similarly, a preferred outcome in a context such as "Relaxation" might often be related to playground, parks and garden.



Source: (Manon et al, 2005)
Figure 3 Urban Soundscape (Subjective Representation) Categories and their relationship with Potential Function of Urban Management

A recent study (Chumming et al, 2018) on worldwide soundscape investigation and evaluation using Participatory Soundscape Sensing (PSS) technique reveals that enhancing the ratio of natural sound to man-made sound is the key factor in enhancing the perceived acoustic comfort in outdoor living environment. Participatory Sensing is the process through which individuals and communities use the capabilities of mobile devices and

cloud services to collect, analyze, and contribute sensory information. The study shows that doubling the acoustic energy due to natural sources and halving the acoustic energy due to man-made sources will shift perception of an environment from very uncomfortable to very comfortable. The sound of running water or rainfall is often found as a key contributor towards acoustic comfort as compared to other natural source sounds.
The discussion above presents the link between the preferred soundscape outcome to functional characteristics of the sound sources and explains how they are connected to the urban outdoor space. This would essentially assist the planners, designers and the architects in making decision on the appropriate perception outcome for a place and enable them to look for appropriate soundscape management measures necessary for the development, expansion and revitalization of an outdoor urban space.

4 SOUNDSCAPE DESIGN APPROACH FOR THE BUILT ENVIRONMENT

Design approaches for urban soundscape planning often comprise of four key design stages as suggested by (Brown et al, 2004).
The first stage is to define the place of interest and the context. Defining the place of interest and the context involves establishing the physical parameters and boundary of the outdoor space, establishing the sound sources taxonomy, developing the perceptual characterisation and the expected outcome of the place. This characterisation includes determining the visual forms, the materials, the lights, the odours, and the people using it and then to establish the characteristics of the place by considering the current use of the place, planned use of the space, the activities involved in the space, the variations in time (along the day or the week) and also the local culture and history associated (Kang et al, 2016).
The second step of the soundscape design is to establish acoustic objectives through planning the physical features of the environment and to support the desired perceptual outcome. This planning step will thus identify the location of the noise sources, the locations of the users relative to the noise sources, contribution of noise from both current and future noise sources and the soundscape outcome in that context (Brown et al, 2004, Kang et al, 2016).
The third step of the design is to identify the “wanted” and the “unwanted” sound components in relation to the subject site and context. The dominant sounds, either wanted or unwanted, as well as time and geographical variations must be found and integrated in the plan (Kang et al, 2016).
In the final step, the specification and the extent for the noise management should be based on the context and the perceived soundscape outcome and should include the wanted sound (e.g. moving water, nature, speech, music, church bells etc) or sometimes the unwanted sound (e.g. not be able to hear the sounds of people) (Brown, 2011). Possible options for soundscape management, either using classical noise control methods, masking of unwanted sounds in the soundscape, or both should be discussed with the stakeholders, architects, urban planners, designers to achieve the optimum solution for the desired outcome of the place.

5 SOUNDSCPE DESIGN STRATEGIES

As we have discussed in the earlier section, soundscape of a place is context dependent. Therefore, soundscape design approaches for different context will be different depending on the preferred outcome of the users. Some soundscape design strategies are discussed in the following sections which can be considered in outdoor urban space design to provide a positive sound experience to the user.

5.1 Water Features

Use of water features as source of sound creating positive soundscape in an outdoor urban setting is becoming recognised as a potential soundscape approach for masking unwanted urban noise and diverting attention. Water generated sound has a distinct advantage in this application as it is typically a “wanted” sound capable of enhancing soundscape perception due to its inherent positive qualities (Watts et al, 2009, Kang, 2007, Brown et al, 1994) of low fluctuation strength and a wide range of loudness (Yang et al, 2013). Fluctuation Strength is a key psychoacoustic metric. A sound which has a strong time-dependent fluctuation in sound pressure level is more annoying than a steady sound. The unit of fluctuation strength is 'Vacil'. One Vacil is defined as the fluctuation strength generated by a 1000Hz tone of 60dB which 100% amplitude is modulated at 4Hz.
Height of the waterfall, flow rates, the surface on which water drops and the location of the water feature are the most important factors in designing a water feature. Research shows that water splashing onto hard surfaces tends to produce high frequency components, whilst low frequency components are associated with large flows of water dropping onto water. Water sounds are found effective as a masker at mid-frequencies but not at low frequencies (Watts et al, 2009). This suggests that water sounds are not a good masker for road traffic noise, but

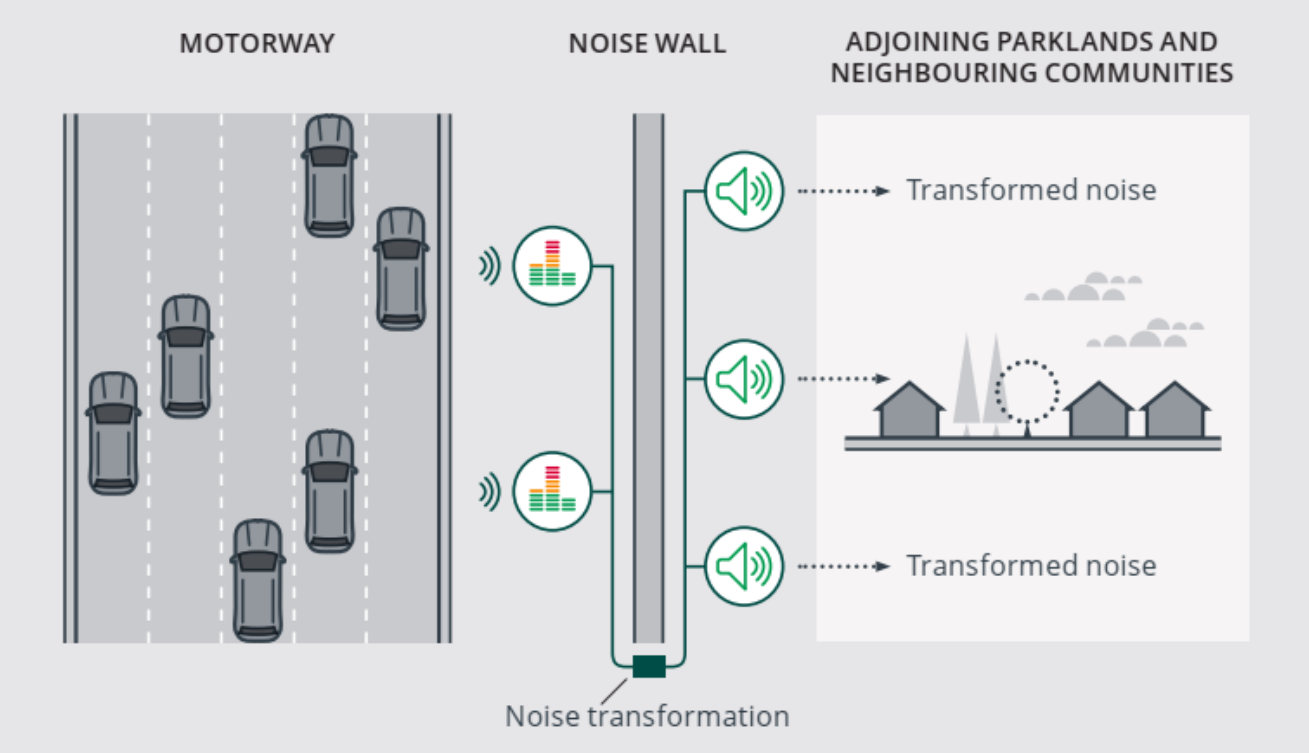
could be an efficient mean to divert attention of individual from the unwanted sounds by providing a pleasant sound.
Auditory experiments, based on listening to water sounds and road traffic noise reveals that favourable subjective perception are attained when water sound is not less than 3 dB lower than the traffic sound. As shown in Figure 4, in Sheffield, UK water features and a noise barrier (water wall) were integrated in urban design near a central train station to enhance the soundscape perception at the area which used to be significantly affected by the adjacent major road. Different water features provided spectral variety and different frequency ranges resulting in an effective masking of the traffic noise (Kang et al, 2016).

Source: (Kang et al, 2016)
Figure 4 Soundscape Design Process

5.2 Passive, Active and Virtual Noise Barrier

Role of a traditional solid noise barrier in reducing traffic noise is not unknown to acoustician. It provides a noise reduction of at least 10 to 12 dB to the outdoor space, particularly effective in high frequency range. However, with the use of the noise barrier, a positive soundscape might still be lacking in an outdoor urban environment where the space might require distraction from traffic noise for the users to be involved into the outdoor space and interact with it. Active Noise Cancellation (ANC) techniques have been found promising in controlling low frequency noise of the traffic when loudspeakers are installed on the edge of a solid noise barrier to cancel low frequency traffic noise component and thus improving the insertion loss (Ohnishi et al, 2004, Chen et al, 2013, Won-Pyoung et al, 2014). This is known as an Active Noise Barrier (ANB). Virtual Sound Barrier (VSB) is a system where an array of acoustic sources and sensors are used to form a virtual barrier entirely using noise active noise cancellation to block direct propagation of noise without affecting ventilation and light. Researchers have found that the VSB system can be applied along motorways or the windows of residential housing to reduce traffic noise transmission (Chen et al, 2014).
A recent research local study by Transurban and RMIT University uses Cancellation, Transformation and Ethnography techniques in managing traffic noise to provide a positive soundscape in the urban environment. Transformation is the process in which the environmental sounds recorded in the microphones are analyzed for its amplitude envelope and spectral content to generate new sounds in response to the analysis results. Ethnography is an approach to evaluate people's experience and perception of a sound environment.

Using this approach, motorway noise is transformed to a musical or aesthetic experience that is pleasing to the human ear. This system has been already tested on CityLink (Victoria) and Hills M2 (New South Wales) motorways and a positive community response have been received on the pleasing outcome of the soundscape (Transurban et al, 2017, Lacey et al, 2017).

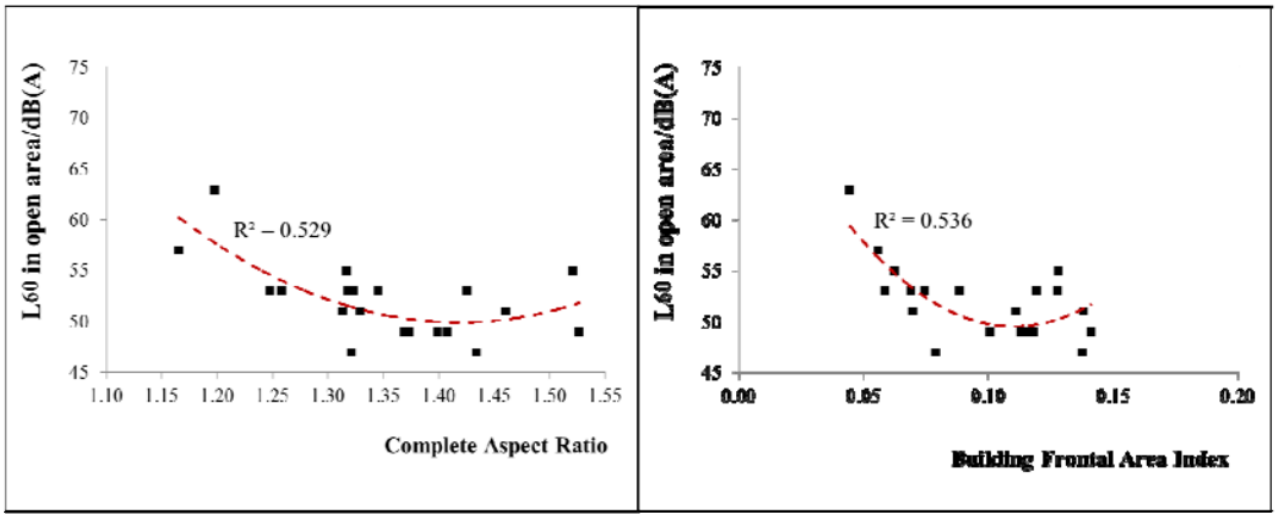


Source (Transurban, RMIT 2017)

Figure 5 Soundscape design using cancellation and transformation technique

5.3 Urban Morphology

Urban morphology has been extensively investigated for the different aspects of urban environment including energy and bioclimatic analysis, ventilation analysis and thermodynamic analysis of an urban environment. Though there has been limited research on the effect of urban morphology on sound perception in outdoor urban spaces, urban morphology is increasingly observed as a potential factor in shaping the urban soundscape. Commonly used parameters used in urban morphology are mean building height, standard deviation of building height, building plan area density, building volume ratio, building frontal area index, complete aspect ratio, building surface area to plan area ratio and height to width ratio. Soundscape research by Kang, 2007 has revealed that different street patterns, with particular references to detached houses, semi-detached houses and terraced houses have influence on the attenuation of broadband traffic noise. Hao, 2014 has demonstrated that the total building and ground surface area (i.e., 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}. It is noted that Complete Aspect Ratio (CAR) is defined as the ratio of the combined surface area of the building and exposed ground to total surface area of the study region. Building Frontal Area Index (BFAI) is defined as the ratio of the total area of the façade parallel to the road to the total surface area of the study region.



Source: (Hao, 2014)

Figure 6 Relationship between L_{60} in open areas and urban morphological parameters.

5.4 Greenspace and Landscape Architecture

Green space is becoming an important consideration in urban soundscape design as it plays an important role in reducing noise-induced stress and is often associated with good mental health. Green space is considered as cost-effective, affordable and of pleasing characteristics providing for natural sounds and allowing residents to relax and withdraw from their stressful and noisy lives (Van-Kempen et al,2014). Recent research by Angel et al, 2015 shows that interaction with green spaces have significant effects on people's noise sensitivity, which implies that people living closer to green spaces and in a greener environment were less sensitive to noise.

An association between appreciation of landscape and acoustic environment has been observed in research findings, which is argued due to the pleasing surrounding environment (i.e. greenspace, vegetation) that acts as a relaxation element to reduce the negative perception caused by the noise (Weber, 2012, Szeremeta et al, 2009). Therefore, integration of green spaces to the urban environment is considered a key factor in reducing noise induced stress, resulting in a more pleasing outdoor environment. In addition, spatial distribution of the green space pattern is often found more effective in reducing noise level compared to clustered green space (Kropp et al, 2016). Research in eight UK cities about green space pattern reveals that small and dispersed green spaces lead to lower average noise levels (Kropp et al, 2016).

5.5 Placemaking

Placemaking is a multi-faceted approach to the planning, design and management of spaces. Placemaking focuses on the physical, cultural and social characteristics of a place that encourage people to collectively appreciate the public places as platform for social gathering and interaction. Soundscape should be adopted as an integrated design strategy as part of the placemaking approach. Integration of soundscape into the placemaking will not only enhance the aural environment but will enhance people's positive soundscape experience. In addition to water features, some soundscape approaches that have been used for urban placemaking includes tuning platforms (tunes sound and vibration to music), sound installations (recorded sound played by hidden loudspeaker) and sonic art. A tuning platform can be used to experience the noise of passing cars and buses as physical vibration transformed and musically tuned. For this installation a resonance tube is used, which picks up the surrounding sound, tunes it and transmits it to became musically perceptible (Auinger, 2017). Sound installations with loudspeakers hidden in the architectural art or garden is another approach in enhancing positive soundscape experience specially in the urban parks or children playground. Sound-art installations are also implemented in some European cities which are used in soundscape design as an approach for active engagement of the human and the environment.

6 CONCLUSION

With rapid urban growth and compact city development, outdoor public spaces and recreation areas are often getting noisier. Traditional noise control approaches reduce overall noise levels, however, the enjoyment of an urban place is often offset by the presence of background transportation noise and noise from mechanical equipment associated with the nearby building. Noise control measures by the planner, architects and designers are often aimed in reducing the noise level which not necessarily will enhance the aural perception. The dynamic sound perception in the urban environment are still very much neglected aspects in planning and architectural design. A positive soundscape is therefore needed to enhance the quality of outdoor recreational areas and to create restorative urban spaces for the public. Research shows that a positive soundscape can create opportunities to focus one's attention away from everyday thoughts and creating places for social gathering and interactions and thereby improves health and wellbeing through the provision of restorative urban spaces (Van-Kempen et al,2014). This paper has discussed the factors that are relevant for designing a positive soundscape in an outdoor urban environment. Several soundscape design approaches have also been discussed in this paper which can be considered in re-vitalisation of an urban outdoor space. Living in the age of sustainable design, livability and smart city, it is important that we do not just design a "space" by reducing noise alone, rather we create a place by taking a "placemaking" approach and incorporating positive soundscaping to enhance the aural comfort and contribute towards the health, wellbeing and restoration of the community.

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