

THE URBAN SOUNDSCAPE A DIFFERENT PERSPECTIVE

Dick BOTTELDOOREN¹, Bert DE COENSEL¹, Timothy VAN RENTERGHEM¹, Luc DEKONINCK¹ en Dominique GILLIS²

¹ *Ghent University
Department of Information Technology
Acoustics Group
Sint-Pietersnieuwstraat 41
9000 Gent
tel: +32 9 264 99 68
fax: +32 9 264 99 69
e-mail: dirk.botteldooren@ugent.be*

² *Ghent University
Civil Engineering Department
Institute for Sustainable Mobility
Vrijdagmarkt 10/301
9000 Gent
tel: +32 9 331 32 59
fax: +32 9 331 32 69
e-mail: dominique.gillis@ugent.be*

Abstract

Sound is an integrated part of the urban society. Overexposure to unwanted sound - often from mechanical or electronic origin - is often tackled after it occurs and in a remediating fashion. An integrated approach to land use planning, urban development, urban traffic management and quality of life - at least the noise related part of it - opens interesting new perspectives. This chapter discusses these opportunities and points at indicators and numerical simulation that can be advantageous when applying the ideas presented.

1. Introduction

Classical urban noise management mainly aims at reducing the level of unwanted noise - of mechanical or electronic origin - in the city by source mitigation and by obstructing the propagation path. Remediation after the problem arises or during planning in a more ideal situation using technical measures, is by far the most common approach to noise control. No doubt this approach is a very good one provided that it leads to significant noise reduction. However, this is certainly not the case in many of our modern cities and therefore more creative approaches are necessary. This chapter reports on some recent developments in this area and puts the urban soundscape (Schafer, 1977) and its design in a slightly different perspective.

For the reader less familiar with traffic noise management we summarize the most relevant technological possibilities (VMM, 2007a) for urban noise control before tackling the problem in detail. Road traffic noise is caused by the drive train at the one hand and by the wheel-road interaction (*rolling noise*) at the other. As driving speed increases and driving is more regular, the latter contribution start to dominate. Drive train noise is constrained by European noise emission regulations which have progressively become more restrictive over the years. Manufacturers have modified many technical details of cars to comply with these regulations, but they did not necessarily do much more than just that. Cars and buses powered by alternative fuel, in particular electric engines, can be significantly more quiet. Although the European noise regulation can not be circumvented by member states, they have opportunities to stimulate citizens and enterprises (including public transport companies) to buy more environmentally friendly vehicles or to introduce noise testing for vehicles in use. Rolling noise involves tires and road surface. Tire requirements, including noise, are also a European matter. A good choice of road surfaces can significantly reduce rolling noise, but road surface maintenance is at least as important, in particular in the urban context. In (VMM, 2007a) it is shown that there is some potential for reducing rolling noise in Flanders both through modifying road surfaces and through modifying tires, but the number of dBs to be gained is small.

The picture for railway noise is not all that different. Many rail vehicles are electrically powered and thus engine noise is often limited. Rolling of

metal wheels on metal rails produces a level of sound that depends on the smoothness of both the rail and the wheel. The opportunities for noise reduction at the source are probably more significant than for road traffic, in particular when considering freight. Important European advances can be expected in near future. Amongst all noise reducing measures, noise barriers placed close to the source are probably best known. Unfortunately, it is often difficult to apply them in urban areas due to space restrictions and visual impact.

2. The ideal urban sonic environment

A naive view of urban soundscape design may aim at making the sonic environment as quiet as possible. In a more modern view, absolute quietness is believed not to be a necessity and in some circumstances may even be unwanted. The ideal urban sonic environment depends on the context.

2.1. Dwellings: home environment

At home, extensive environmental mechanical or electronic noise is perceived as intruding the observers private space. As such it will be perceived as disturbing and annoying as soon as it is noticed. This immediately implies that different types of traffic noise will result in different annoyance for the same energetically averaged exposure. Today, the relationships between façade exposure measured in L_{den} and self reported long term annoyance have been well established for different types of traffic noise and are quite generally accepted (Miedema, 1998). These curves show that for the same average exposure, annoyance seems to be greatest for aircraft noise and lowest for train noise. For industrial noise, characteristics of the sound may differ significantly between sites and these characteristics (tonality, impulse) may increase noticeability and thus annoyance. This has been taken into account in regulation such as Vlare 2 that are applicable for industrial noise.

Assessing environmental noise levels at the façade is much easier than measuring noise at the actual ear of the urban dweller and hence most scientific advances in relating exposure to effects have been made in that area as stated above. It should nevertheless be remembered that what

matters is the sound that reaches the ear. The dwelling itself acts as a shield for the intruding noise - and in some particular cases as an amplifier for low frequency sound (Pedersen *et al.*, 2007). At the one hand the dwelling may (over)amplify low frequency problems, at the other hand it creates opportunities for indoor noise reduction. Noise reduction by increased building insulation requires closing all windows and doors at any time and thus may limit the sense of control and freedom of the inhabitants which in turn has a negative effect on perceived annoyance. This has led to the observation that insulation requirements should be relaxed at least on one façade and this in turn led to the introduction of the concept: quiet side (Ohrstrom *et al.*, 2006). Availability of a silent or highly shielded façade relaxes annoyance by an equivalent of a reduction of most exposed façade level by 5 to 10 dBA as long as the level at the quiet side does not exceed 55 dBA, and the difference between the loudest and quiet side is at least 10 dB. Furthermore, the noise levels at the most-exposed façade may not be excessively high. There is however also growing evidence that the sonic environment in the wider neighborhood of the house contributes to the annoyance (Klaeboe, 2007) in particular for people living in apartments.

Disturbance of activity and in particular sleep disturbance are important as a first stage negative effect of intruding environmental noise. Subjective evaluation of sleep quality and fatigue correlate well with energetically averaged nightly noise levels, $L_{Aeq,night}$, but other sleep indicators (changes in heart rate, sleep stage, etc.) show a more complicated relationship with number and level of noise events (Griefahn *et al.*, 2006). There is some evidence that habituation to traffic noise events during the night does not occur (Griefahn *et al.*, 2008a). It has also been established that noise events occurring during the end of sleep have a stronger effect on overall sleep quality and thus traffic curfews are most effective in the morning (Griefahn *et al.*, 2008b). Disturbances occurring during the beginning of the night seem to be compensated. Concerning sleep disturbance, no clear difference between different types of traffic could be established indicating that the meaning of sound (within the scope of traffic noises) may not be as important during sleep as could be expected.

Health effects occur at much longer time scales and thus the analyses and design of the acoustic environment may need less temporal detail. Today the best proven effect of long exposure to environmental noise in the home

environment is ischemic heart disease, which may in turn be related to blood pressure (Babisch *et al.*, 2005). The effect threshold seems to lie around 65 dBA (daytime equivalent noise level in front of the façade) but odds ratios are small, even 10 dBA above that threshold. Since it is estimated that the causal path between exposure and health effects of environmental noise involves the cognitive / emotional path for 75% (Heimann *et al.*, 2007), urban noise management aiming at reducing annoyance can be expected also to reduce health effects.

2.2. Urban public space

City dwellers perceive and evaluate the soundscape of the urban public space in a rather different way than they perceive the intruding sounds in their home environment. Thus, modern urban soundscape planning is evolving new ideas and concepts to accommodate this difference. The soundscape is seen as an integral part of the urban environment, contributing to the identity and specificity of this environment. The quality of a soundscape is assessed within the particular context and use imposed by the urban space. The physical characteristics of the sonic environment needed to evaluate this quality go far beyond the overall noise level and include spectral (Raimbault, 2003) and temporal (Botteldooren, 2006) structure. Today the quest for appropriate physical indicators is continuing but one could argue that physical indicators will never be sufficient and the meaning that the listener associates to the sound is most important (Dubois, 2006).

The urban public space has different uses: shopping, moving between functions, recreation, The soundscape of parks and squares mainly used for recreation has often been in focus. An important reason for this is that the availability of high quality (green, quiet) urban space within reach was proven to benefit the health of urban dwellers. In particular, the potential for psychological restoration of natural quiet areas has been suggested (van den Bergh, 2007). Thus the goal for urban planning in relation to traffic noise is clearly broadened.

3. Quality of life and the urban sonic environment

How important is a suitable urban sonic environment in the overall assessment of the quality of life of the inhabitants? The answer to this question depends on the degree of urbanization and development of the region under study (Luz, 2008). Therefore we will focus on the Flemish context and base the answer on the above question on the SLO ('*schriftelijk leefbaarheidsonderzoek*') surveys conducted periodically by the Flemish government (SLO, 2004). The leading question in this 5000 person survey refers to the overall contentment with the quality of life in the neighborhood. A companion questions polls for reasons to encourage or discourage friends to come and live in this neighborhood. Inspired by a conceptual model such as the one shown in Figure 1, the answers to this open question were recoded to the 16 basic components shown in Figure 1. The correlation between the frequency of mentioning each of these factors and overall contentment is shown in Figure 2. It becomes clear that noise is most often mentioned at the same time as high contentment or discontentment. Bustle and subjective (traffic) safety also score quite high. Health effects related to noise, air quality or accidents numbers are not associated to the neighborhood by lay people. Moreover availability of shopping, schools, (easy access to) work and recreation does not rate very high, probably because these needs are taken for granted in our society. The relative importance of environmental noise in overall rating of quality of life was also observed in French research (Moser & Robin, 2006) where noise was found to be as important as a cause of stress as serious illness of a family member.

Figure 1: A conceptual model unraveling quality of life in the context of traffic

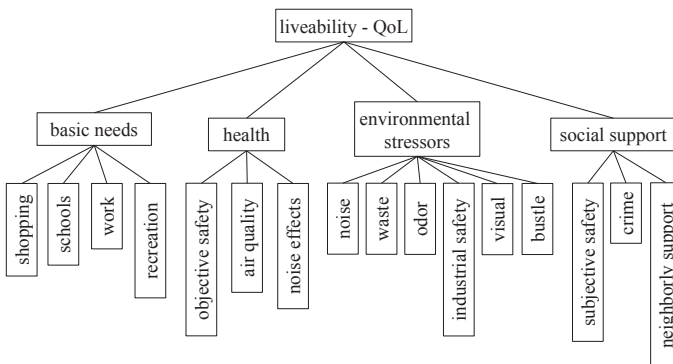
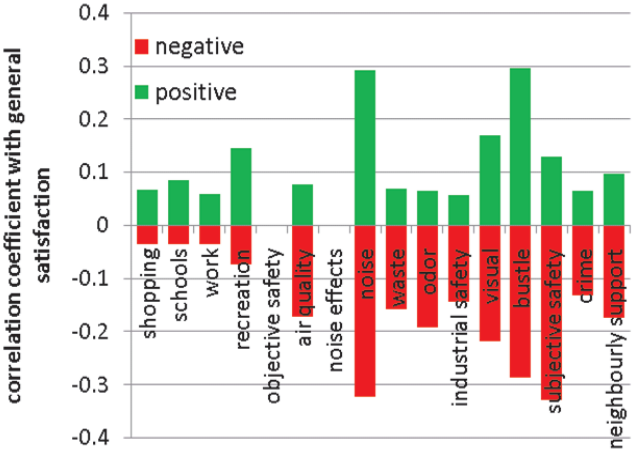
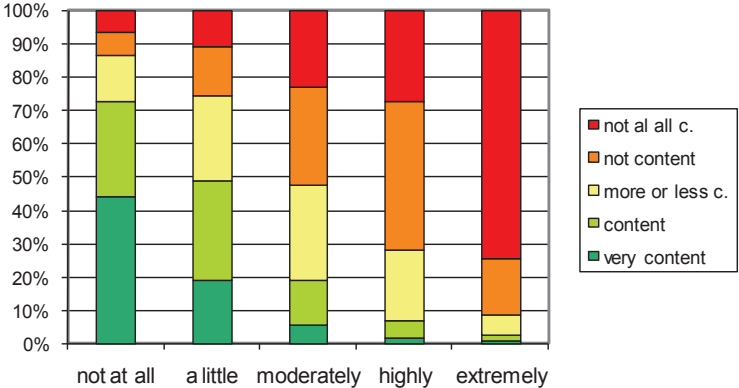


Figure 2: Correlation coefficient between mentioning each factor in a negative or positive sense and overall contentment



Close to all studies in post-industrial countries such as Belgium confirm that traffic is the most important contributor to environmental noise (Miedema, 1998). Thus it comes as no surprise that the SLO studies (SLO, 2004) confirm that 14.1% of the Flemish population is highly or extremely annoyed by traffic; neighbors are responsible for highly annoying 5.9% of the population; recreation and tourism follows with 4.5%, industry and SME with 4.3% and finally agriculture with 1.4%. Figure 3 confirms that there is a strong relationship between reported traffic noise annoyance (rated on a five point scale: not at all, a little, moderately, highly, extremely) and reported overall contentment with the living environment (reported on a five point scale: not at all content, not content, more or less content, content, very content). This is to be expected given the dominance of traffic noise amongst environmental noise categories.

Figure 3: Percentage of the population reporting different degrees of overall contentment with the living environment as a function of the reported annoyance by road traffic noise



Is environmental noise an urban problem? Due to the concentration of functions, traffic intensities are generally high near cities. This could potentially lead to higher noise exposure levels in the urban area where population density is often rather high as well. The chapter on the urban area in MIRA (MIRA 2007c) compares high annoyance in the 13 large Flemish cities with noise annoyance in the countryside and concludes that the percentage of the population highly annoyed by noise is indeed significantly higher in those 13 cities. A more detailed analysis (Botteldooren *et al.*, 2008) revealed that the current situation in Flanders is slightly more complex. The percentage of the population living in highly or very highly populated areas very close (less than 50m) to important roads that is highly annoyed by road traffic noise is extremely high, over 32%. However, at slightly larger distances from the road this percentage drops considerably, to 11%. This drop is less pronounced outside densely populated areas with 30% highly annoyed close to the important road and 14% further away. The typical urban building structure discussed in the next paragraphs is responsible for this. Thus one might conclude that the influence of road traffic noise on quality of life is not in particular a problem of the urban area, but it might indeed be different in urban areas than in the open country.

4. Urban planning and development

Urban planning and development has long discarded noise as a point of concern. It was believed that environmental noise issues could best be tackled after all geographic and visual planning of the city had been finished or in the best case at the very end of the planning stage. Most technical measures at the source are indeed still applicable then, but they rarely are efficient in urban context. In the new perspective, sound is an integral part of the urban setting and thus should be considered at the same level of importance as visual esthetics.

4.1. Living areas with low exposure

Noise levels in general decrease quite rapidly as the distance to the source is increased. In open area, near the source, noise levels drop by 6 dBA with doubling of distance when the source is a well localized point and by 3 dBA with doubling of distance for a line source (a straight road for example). In natural areas and parks, the ground acts as an acoustical porous material. Sound propagating above such a material is strongly attenuated over a certain frequency range. This so called *ground effect* can result in a significant additional noise reduction. It does however require that sound shears the ground and thus the positive effect vanishes under several conditions: when strong temperature inversion or a wind gradient bend the sound waves downward; when the sound propagates over a valley; when the sound source is elevated for example on a bridge; when the observer is elevated, for example living in a high rise building. In the urban context, *screening* by buildings can reduce sound levels considerably thus leading to a decrease with distance that is well above the 3 or 6 dBA rule mentioned above. This is why it is so important to increase the distance between urban dwellings or recreational areas and the source of noise: traffic. To take advantage of the additional ground effect and screening by buildings, traffic routes are best planned as low as possible within the 3-dimensional city.

In many Flemish cities and villages, road traffic is at the level of the surrounding terrain and houses form a continuous screen along this sound source. This explains why - as mentioned above - the percentage of highly noise annoyed people drops considerably for houses somewhat further away from the main roads. In the areal photograph of part of a city and the

corresponding noise map in Figure 4 it can be seen that some zoning occurs naturally because of commerce and SME moving to the arterial road but also that it is far from perfect.

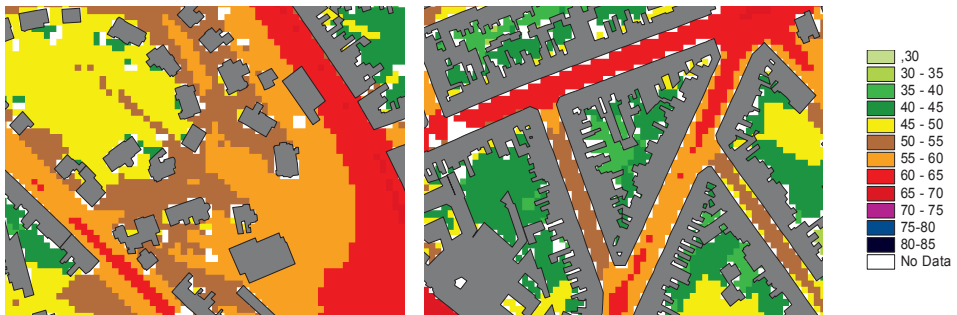
Figure 4: Areal photograph (left) and corresponding noise map (right) for part of a city



4.2. Noise barrier buildings and quiet sides

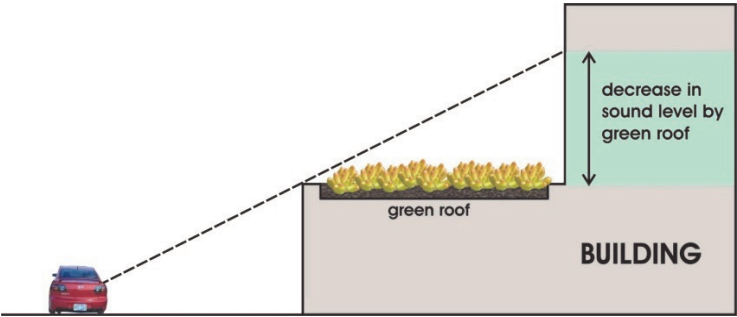
The importance of a quiet side for perceived noise annoyance has been mentioned in Section 2.1 Silent façades can be achieved in various ways. A cluster of buildings, with a central courtyard is an interesting configuration (Figure 5), and provides a large number of buildings with a quiet side. A “noise barrier building” has both a quiet side and moderate noise levels behind the most-exposed façade. Such a façade only has a limited number of (acoustically highly insulated) windows. The silent (or noise-sensitive) side on the other hand contains the necessary windows and doors, balconies and gardens. Very efficient noise barrier buildings could make use of a climbing earth berm against the most exposed-side. When noise barrier buildings are connected together, their efficiency is largely increases because side diffraction is prevented.

Figure 5: Two excerpts from a city noise map (L_{den}) showing building structure with pronounced quiet side (left) and buildings where a quiet side is almost absent (right)



Vegetated roofs tops (green roofs) can help in achieving quiet façades. The substrates used for both extensive (mostly granular material) and intensive (uncompacted earth) green roofs have sound absorbing properties. Sound diffracting over the roof will be attenuated more than when it propagates over classical, acoustical hard roof coverage. Numerical simulations (Van Renterghem & Botteldooren, 2008; Van Renterghem & Botteldooren, 2009) showed the potential of using green roofs to reduce the noise impact near buildings for example in the situation shown in Figure 6. Important parameters in this respect are the sound frequency, the layer thickness of the substrate, the building geometry, and traffic related parameters like vehicle speed and vehicle type. Besides reducing sound waves shearing over the building, a reduction in the transmission of sound through the roof construction is obtained. More generally, roof type and roof slope angle should be considered when the sound pressure levels at non-directly exposed façades are of interest (Van Renterghem & Botteldooren, 2009).

Figure 6: Example of a building geometry leading to a decrease in sound level at part of the facade caused by the presence of a green roof



4.3. Street reverberation

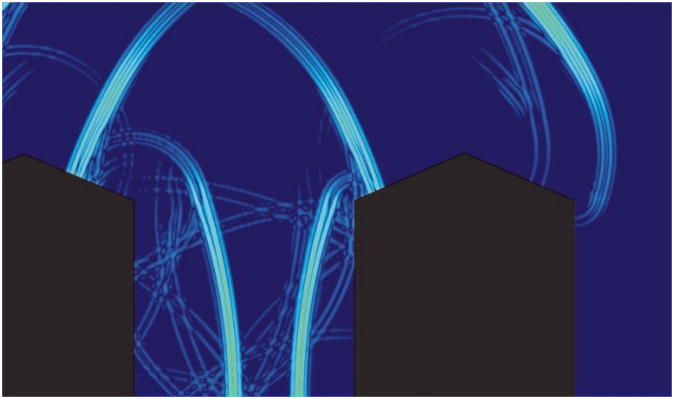
Environmental noise heard in an environment with a long reverberation time is often perceived as very annoying (Kang, 2000). A so-called street canyon, i.e. a narrow street, enclosed by tall and connected buildings, induces such long reverberation times. Such street geometries are typically observed in the centers of (historically grown) European cities. Due to the confinement of the sound in the street, the sound decay by geometrical spreading is low (Figure 7). The road surface, the footway, and façades of buildings mainly consist of acoustically rigid materials. This absence of absorbing materials further increases the reverberation.

Besides specular reflection (also called mirror source reflection), a non-flat surface also induces (to some degree) diffuse reflection. As a result, the incident acoustical energy is spread over a range of directions, while sound reflection from a fully flat surface is very directive. Architectural ornaments, window sills, and protrusions and recessions by windows increase diffuse reflection in a street. Large surfaces of glass are known as specular elements. In case of diffuse reflection, part of the acoustical energy is also reflected in upward and sideward direction. This allows sound to leave the street canyon already after a limited number of diffuse reflections which causes noise levels to drop and reverberation time to shorten.

Increasing the absorption of façades largely reduces sound pressure levels in the street (Van Renterghem *et al.*, 2006). The (classical) porous

absorbing materials are often not suited for application near the façades because they are not weather-resistant. A possible application of such materials, however, is at the underside of balconies (Hothersall *et al.*, 1996). Vegetation near facades is another interesting option. By means of new techniques it is possible to fix the necessary substrates at a few centimeters from the walls. Given the large number of reflections between the façades in a street canyon, and since such substrate are highly porous, strong reductions of noise levels and street reverberation may be achieved. Reducing extensive reflections in the street canyon also reduces noise levels at the least exposed façade.

Figure 7: Wavefronts travelling back and fort in a street canyon after a short acoustic pulse is emitted in the center of the canyon



5. Urban open space

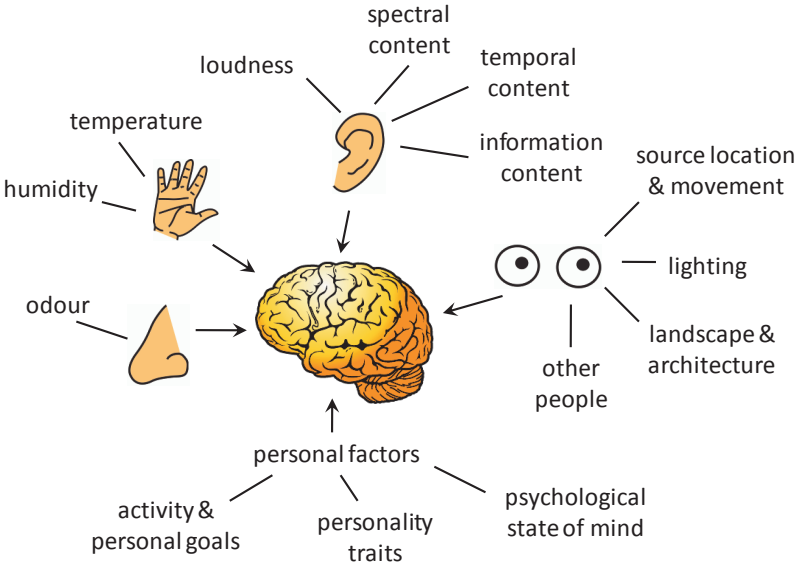
Traditional noise control engineering has two main disadvantages when it is solely applied in order to mitigate noise at more quiet urban areas with recreational purposes, such as urban squares and parks. Firstly, the traditional approach may result in a greying of the sonic environment, because often black spots are targeted, at a disadvantage of the sound pressure level at other places (Schafer, 1977). Secondly and more importantly, noise control engineering is a negative approach: not all sounds are noise, some sounds do fit well in some environments, and we should strive to preserve these sounds rather than to eliminate them. A

more positive and holistic approach is needed, aimed at designing entire environments that are pleasing to the ear.

5.1. Soundscape description

A high quality sonic environment can be defined as a sonic environment in which there is a good match between the sounds that can be heard (commonly referred to as the *soundscape*, as an analogy to the term *landscape*), and the sounds that are expected. In other words, a high quality soundscape contains lots of fitting sounds that can be clearly heard, and less non-fitting sounds. Unfortunately, defining which sounds fit in a given environment is a complex and interdisciplinary problem. Understanding the factors which influence the perception of environmental sounds forms the main subject of *acoustic ecology*, which is the study of the interactions, mediated through sound, between humans and their environment (Truax, 1978; Wrightson, 2000). Whereas traditional noise control engineering solely involves physical measures, acoustic ecology departs from a human-centered viewpoint.

Figure 8: Various factors in the perception of environmental sounds



The perception of sounds, and as such their perceived degree of fit to the environment, is determined by both sensory and personal factors (Job *et al.*, 1999). Sensory factors include auditory aspects, such as the loudness, spectral, temporal and information content of the sound, visual aspects such as the location and movement of the source (if it is visible), the landscape and architecture, lightning, activities of other people, tactile aspects such as temperature and humidity, and olfactory aspects. Personal factors include traits such as noise sensitivity and attitude towards different types of sources, the current activity and personal goals, and the current emotional state. These various factors are visualized in Figure 8.

5.2. Planning and acoustic design

The visual aspect has been, up to now, the most important factor in the design of urban parks and open spaces. However, including auditory aspects and knowledge on perception of soundscapes in urban planning and design, an approach often referred to as *acoustic design*, has great potential (Brown & Muhar, 2004).

Urban public spaces can be designed to encourage activities which generate unique sounds or *soundmarks*, that attract attention and reflect traditional or cultural elements. A first example is music. Studies suggest that the low frequency content in live music is often not loud enough to mask traffic sound (Kang, 2007). High frequency components, on the other hand, can make the music stand out from the background, making the soundscape more pleasant. Another example is the sound from water fountains. Altering flow methods and fountain design has proven to provide great potential in shaping the spectrum of water features (Kang, 2007), making it an ideal instrument for attracting attention and masking traffic noise. Adding greenery in well arranged spaces may enhance the natural feeling of the environment and alter the sound pressure level distribution, but may also attract songbirds. As a more drastic measure, (camouflaged) loudspeakers can be introduced into the design, which could play back fitting environmental sounds, such as singing birds in an urban park (Lee *et al.*, 2004).

Auralisation forms an important tool in acoustic design (Kleiner *et al.*, 1993; Fürjes *et al.*, 2004). This technique aims at a realistic, artificial simulation and reproduction of the various sound sources that can be heard

in a given environment, such as traffic, fountains, street music, human voices etc., The full path that sounds travel, from emission at the source to reception at the ear, is hereby modeled. Reflections and diffractions of sound on objects has to be taken into account, as well as the Doppler effect for moving sources or listeners. In order to achieve a realistic representation, the auralisation should be accompanied with a (3D) visual representation of the virtual environment.

Artificial soundscapes produced with the auralisation technique have still to be listened to by human listeners in order to be able to assess their quality, which limits the applicability of this approach. In the future, models for automatic acoustic evaluation could replace the human listener. Several approaches have already been suggested, such as artificial neural network based models (Prante, 2001), or approaches that try to model the human perception of sound in a bottom-up fashion, starting from basic psychoacoustic and psychological principles (De Coensel & Botteldooren, 2007).

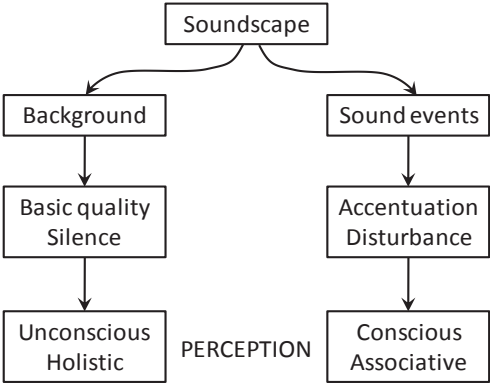
5.3. Assessment of quiet areas

Generally, a quiet area is defined as an area that is more quiet than the surrounding region, and which has a psychological restoring effect on people visiting it. There is a growing awareness that quiet areas deserve special attention and preservation, and this goal has therefore been subscribed in the Environmental Noise Directive of the European Commission and in policy intentions of many countries. In line with the ideas described above, an (urban) quiet area such as a park or open space, does not imply the absence of sound (which would be silence). Rather, its soundscape should be *experienced as quiet* by the average visitor. Quality assessment methods for urban quiet areas have to reflect this principle; the average sound pressure level is therefore less suited as the only indicator to characterize quiet areas. Moreover, one should go beyond the use of only quantitative approaches.

A starting point could be to consider the soundscape of urban quiet areas as the superposition of an always present background and sound events (Schafer, 1977). This subdivision is illustrated in Figure 9. The background largely determines the overall feeling of quietness, and thus the basic quality of the soundscape. It can be heard, but it does not trigger

much meaning because it is not listened to consciously. Events can disturb the soundscape, but it is also possible that they, being fitting sounds, accentuate the basic quality. It is known that the perception of sound events involves source recognition and association (Maffiolo, 1999). The background, on the other hand, may not lead to any source recognition; it may be experienced in a more holistic way.

Figure 9: Various aspects related to the urban soundscape



A multicriteria approach to the quality assessment of urban quiet areas has to address the quality of both background and sound events, and has to include the different perceptual factors described in paragraph 5.1. Based on a meta-analysis of several studies on soundscape perception, the authors have proposed a quality assessment methodology consisting of the following subjective and objective criteria (De Coensel & Botteldooren, 2006): pleasantness and the presence and number of non-fitting sound events, determined using a questionnaire survey; quality of the background, measured using indicators for loudness, temporal and spectral content; congruence of the area; biological, natural and landscape value of the environment. The proposed set of indicators forms a balance between scientific validity, applicability and comprehensibility.

6. Orchestrating traffic noise

Reducing road traffic noise at the source is more than reducing engine noise and improving tire-road interaction. By modifying the traffic stream

itself, through careful traffic planning, many aspects of the urban sonic environment can be tuned. Dynamics and temporal structure depend on the pass by of individual cars, trucks, and motorcycles. Microscopic management can help designing this detail of the soundscape. On a wider spatial horizon, reorganizing traffic streams can be very useful.

6.1. Dynamics and temporal structure: microscopic management

Strategic, large scale traffic management decisions, for example on the scale of a city, are most often based on estimates of average traffic flow through main roads. However, over the past decades, the awareness has grown among traffic researchers that small-scale changes in infrastructure, and even in driving behavior of individual vehicles, can have a large influence on (macroscopic) traffic flow. A good example is the green wave induced by the coordinated use of traffic lights at several successive signalized intersections along a driving direction of a road. Also stimulated by the growing availability of computing power, traffic researchers and engineers are therefore more and more considering the use of microscopic simulation models in their study of urban mobility problems.

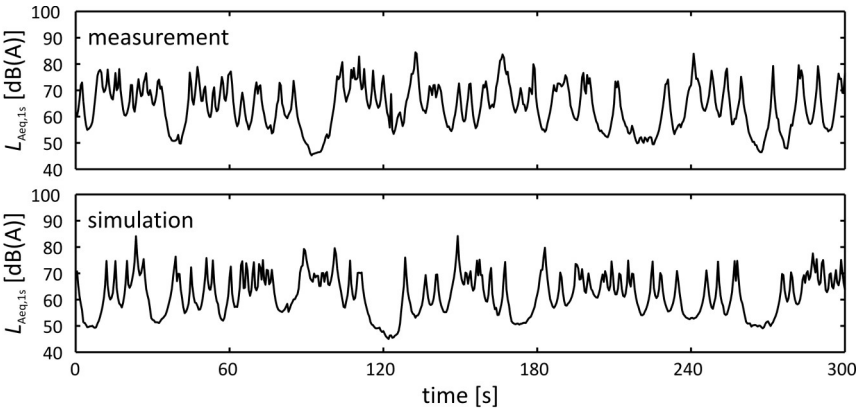
Microscopic models (micromodels in short) consider the exact location and movement of individual vehicles over time, within an (urban) environment that is modeled in high detail (locations of kerbs and stop lines, exact size of intersections etc.). Behavior rules, such as the distance to keep to the vehicle in front or when to change lanes, form the core of the model. Micromodels allow traffic engineers to gain insight in the course of complex phenomena such as the formation of jams or the propagation of traffic density waves.

Micromodels have great potential as a tool in acoustic design of the urban soundscape. When coupled with a noise emission model for single vehicles and a detailed propagation model, micromodels allow to estimate the (temporal structure of) peaks in the sound pressure level caused by vehicle pass-bys (see De Coensel *et al.* (2005) for an example of this approach). Figure 10 shows an example of the measured time-varying sound pressure level at the kerbside of the Frederik Burvenichstraat in Gentbrugge, Belgium, together with a simulated time series at the same

spot within a micromodel of the city of Gentbrugge. Note that there is only a statistical similarity, not an exact one, because of the stochastic nature of microsimulation models. Nevertheless, this approach allows to estimate peak levels and statistical levels such as the median sound pressure level with good accuracy. As such, the influence of detailed traffic management measures, such as speed bumps, roundabouts or speed control (Bendtsen & Larsen, 2006; Desarnaulds *et al.*, 2004) and of sound propagation measures such as inserting noise barriers, on the temporal structure of the urban soundscape can be assessed.

More detailed study of auditory perception of car and truck passages allowed to estimate the subjective annoyance (used as an opposite to sound quality in this study) on the basis of specialized sound quality measures (Rossberg, 2006): relative approach, peak loudness (5 percentile), and peak sharpness (5 percentile). Relative approach measures abrupt changes in time of frequency. This sound quality approach is now being extended to traffic streams as a whole. Micromodels create an unsurpassed potential for tuning this sound quality using different traffic measures.

Figure 10: Measured and simulated 5-minute time series of the sound pressure level caused by traffic noise at the kerbside of the Frederik Burvenichstraat in Gentbrugge during rush hour



Next to their use in modeling the time-varying sound pressure level in urban environment, micromodels can also be applied in the assessment of the impact of dynamic vehicle parameters, such as acceleration, on the

average sound pressure level. Urban intersections are an obvious point of interest, because of the typical acceleration and deceleration pattern of traffic near intersections. Classical traffic noise estimation models based on average flows do not allow to take into account the acceleration or deceleration of vehicles correctly, but they can be corrected based on more detailed microsimulation results of traffic at and near intersections (De Coensel *et al.*, 2006, 2007).

6.2. Calming urban traffic: macroscopic management

Calming urban traffic in certain parts of the city is an alternative for optimally locating dwellings: if you cannot move people away from traffic, move traffic away from the living areas. This is not always as straight forward as it seems at first sight. A drastic halving of traffic intensity theoretically reduces overall noise levels by 3 dBA, but when taking into account that the traffic will move more freely, hence faster, one may end up with virtually no noise reduction. Depending on the strategy for implementing the reduction of traffic intensity, local fleet composition may change (e.g. more public busses due to private traffic charging). If traffic calming measures are applied to particular road segments and / or particular parts of the day (night ban, congestion charging) this may lead to traffic increases on alternative roads and at alternative times of the day. Careful traffic modeling with additional focus on day, evening and night periods is needed to distinguish between noise reduction and noise redistribution (Sundbergh and Algiers, 2007). Unfortunately, current traffic modeling exercises often neglect nightly traffic or only make rough assumptions about it.

To quantify these observations, we present a few examples of simulated traffic noise emission in this section. Three prototype roads are considered: a highway (HW) of three lanes, a 2 by 2 lanes major road (MR) with divided directions and a local road (LR) with 1 lane for each direction. In addition, the three fleet compositions shown in Table 1 are considered: Fleet 1 corresponds to the current situation in Belgium, Fleet 2 strongly promotes alternative fuels and Fleet 3 bans petrol and diesel from cars all together. These alternative fleet may seem rather unrealistic, but one should consider that they could correspond to the local situation in parts of a city. Fleet 3 for example could correspond to part of a city where

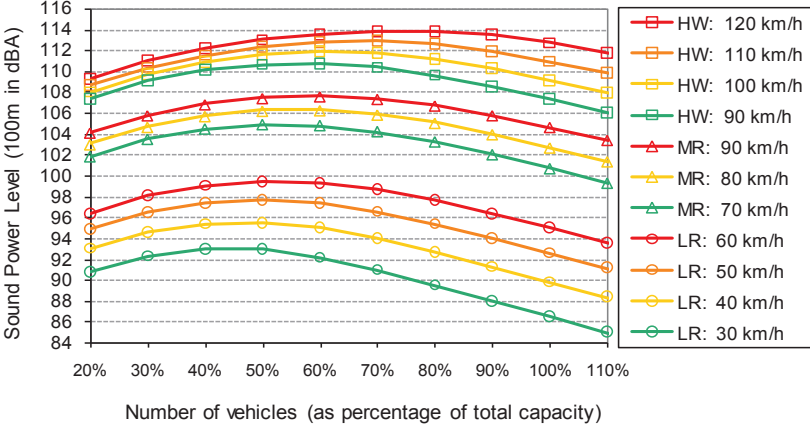
classical fuel cars are strongly discouraged. Still, implementing such drastic scenarios would take several decades.

Table 1: Fleet compositions used in the model

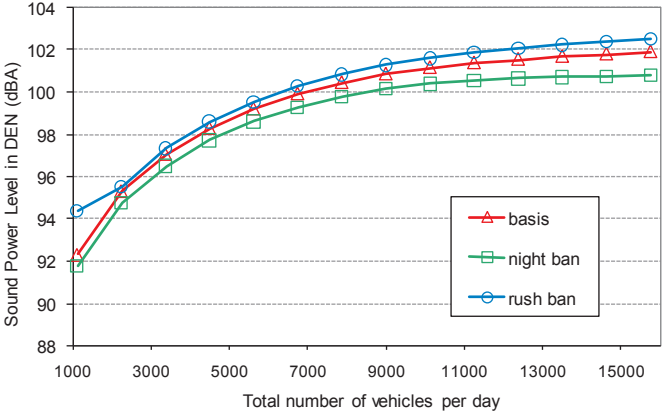
	Fuel type	petrol	Diesel	LPG	CNG	Hybrid	Electric
Fleet 1	Cars	44.2%	54.5%	0.9%	0	0.4%	0
	Light	44.2%	54.5%	0.9%	0	0.4%	0
	Heavy	0	100%	0	0	0	0
Fleet 2	Cars	20.0%	20.0%	0	10.0%	25.0%	25.0%
	Light	20.0%	20.0%	0	10.0%	25.0%	25.0%
	Heavy	0	80.0%	0	0	20.0%	0
Fleet 3	Cars	0	0	0	25.0%	25.0%	50.0%
	Light	0	0	0	25.0%	25.0%	50.0%
	Heavy	0	50.0%	0	0	50.0%	0

Noise emission per vehicle is calculated based on the Harmonoise/Imagine road traffic source model using traffic volume and speed as the main parameters. The emission data are tuned to account for quieter propulsion and corresponding lowering of rolling noise in hybrid and electric cars. The latter is a positive side effect: it was observed that car manufacturers opt for quiet tires on their hybrid cars. Capacity is estimated at HW:4590 veh/h, MR:2430 veh/h, and LR:1125 veh/h and average speed is deducted from speed-capacity relationships counting one heavy vehicle as two cars (Janssens, 1996). Average speed reduction due to congestion is entered in the emission model rather than a more realistic speed distribution and acceleration or deceleration that can be obtained from micro-simulation. Simulation results are shown in Figure 11.

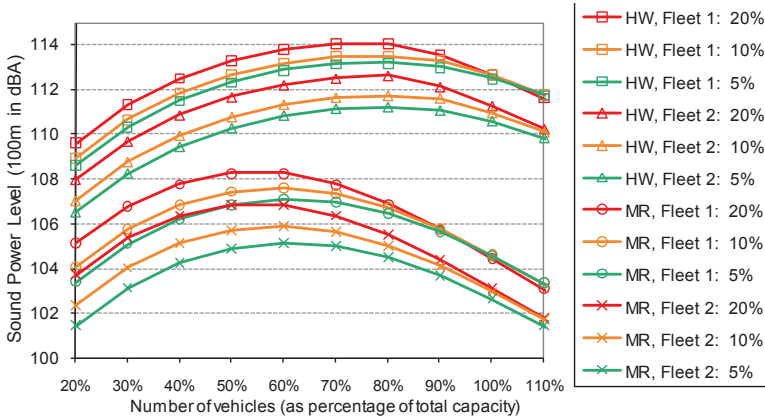
Figure 11: Sound power level emitted by 100m of road (one driving direction) as a function of traffic volume: for different driving speed (a), for different fleets on highway and main road (c) and on local road (d), and for two scenarios of heavy traffic ban (b), including day-evening-night weighting



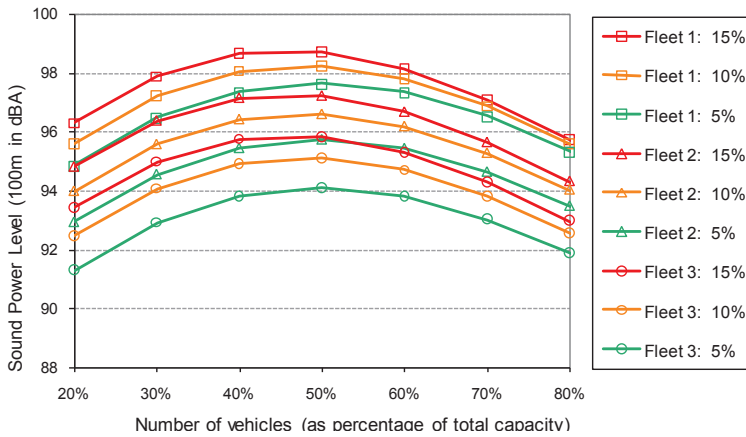
(a)



(b)



(c)



(d)

From Figure 12a the significant effect of speed limit on noise emission can be recognized. Note that the traffic volume is expressed relative to the capacity of the different road prototypes and that the percentage of heavy traffic differs amongst road types (HW: 15%, MR: 10%, LR: 5%). Road saturation and corresponding lowering of traffic speed reduces noise emission. This saturation effect was validated against long term measurements along a Flemish highway in (VMM, 2007b). The rather flat top of the curves explains why reducing traffic volumes not always leads to expected sound level reduction.

The influence of fleet composition on noise emission is shown in Figure 12c for highway (speed limit 120km/h) and major road (speed limit 90km/h) and in Figure 12d for local roads (speed limit 50km/h). As the

percentage of heavy traffic increases, noise emission increases since trucks produce significantly more noise than cars. Closer to saturation, trucks tend to slow down traffic and thus the overall noise emission depends less on percentage of heavy traffic. The influence of rather drastic fleet changes is significant, but comparable to effects of speed limit and percentage of heavy goods traffic.

Figure 12b illustrates the positive effect of night (23:00 till 7:00) ban for heavy vehicles on a local road (speed limit 50km/h, a realistic diurnal pattern, and 10% of heavy traffic) on $L_{W,den}$, the sound power penalized with 10 dBA during the night and with 5 dBA during the evening. $L_{W,den}$ is chosen because it relates directly to L_{den} , the noise immission indicator that is used for quantifying noise annoyance in Europe. A night ban reduces this emission parameter by a few dBA only when the overall number of trucks per day remains unaffected by the ban. In contrast, a rush hour (7:00 till 9:00) heavy traffic ban increases this emission indicator due to shifting of part of the truck traffic to the night hours. As explained in Section 2.1 increased noise levels at the end of the night may even have a much stronger effect on sleep. This quantifies our concern expressed at the beginning of this section.

7. Conclusions

Listening to the urban soundscape from a different perspective opens new opportunities for improving the quality of life of urban dwellers. This many faceted problem was touched upon in this contribution. Fine tuning the goals of soundscape design may improve the real effect of our endeavors observed in the population. Helped by modern computer simulation, more aspects of traffic noise production and propagation can be taken into account. This could lead to a more efficient use of traffic noise measures in urban context.

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