Northern Ireland Assembly

Queen's University Belfast · The Open University · Ulster University

Knowledge Exchange Seminar Series (KESS)

Environmental Methods for Reducing Surface Transport Noise

Introduction

Noisy neighbours account for half the complaints received by local authorities in the UK[1]. In Northern Ireland 'domestic noise' accounted for 79% of 11000 complaints made to local authorities in 2016, whereas traffic noise accounted for only 1.7% of these complaints [2]. But complaints are not necessarily a good indicator of the impact of noise. According to the 2012 National Noise Attitude Survey[3], over the UK as a whole, 5 million people (8%) are extremely disturbed by traffic noise and 55% are disturbed by traffic noise to some extent. The main adverse consequences of traffic noise are annoyance and sleep disturbance but it interferes with rest, concentration, and speech communication and is detrimental to children's learning and school performance. There is increasingly strong evidence for a causal link between long-term exposure to road-traffic noise and cardiovascular disease, including hypertension and myocardial infarction. but these have associated costs. The World Health Organization (WHO) has estimated that the yearly burden of transport noise-related disease in the EU corresponds to a loss per inhabitant of two days per year and, of environmental factors, only air pollution is estimated to have a larger disease burden[4]. Effective traffic noise reduction is likely to mean substantial economic gains and positive effects on public health and well-being.

The most effective way of reducing traffic noise is to reduce noise emissions at the source, for example, by greater use of electric vehicles, by introducing regulations demanding quieter engines, tires, or road surfaces, or by limiting traffic flow volumes and introducing stricter speed limits. However, such methods are often difficult to implement for economic, city planning, or political reasons. Consequently noise reduction at source must be complemented with methods that act on the noise as it travels to the receiver. Noise barriers are a standard way of reducing traffic noise between roads or railways and dwellings. A 3 m high noise barrier placed close to a road should give at least 10 dB reduction in noise levels over a wide area on the other side of the barrier. A reduction of 10 dB is substantial since it corresponds to a halving of loudness. But noise barriers may be visually intrusive and, because any gaps render them ineffective, they may divide communities.

In this presentation we outline some alternatives to noise barriers for reducing noise as it travels from source to receiver based on Open University contributions to a project funded by the European Union Seventh Framework Programme (FP7/2007–2013) under grant agreement n° 234306. Collaborative project HOSANNA[5]. It was coordinated by Jens Forssén of Chalmers University of

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[1] ***The Noise Climate Post-Brexit*** ***http://hacan.org.uk/wp-content/uploads/2017/02/The-Noise-Climate-Post-Brexit-1-1.pdf***

[2] https://www.daera-ni.gov.uk/publications/noise-complaint-statistics-northern-ireland-2015-2016

[3] *http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0ahUKEwia1Ynphv7SAhXKJcAKHRcXDmQQFggmMAE&url=http%3A%2F%2Frandd.defra.gov.uk%2FDocument.aspx%3FDocument%3D12378_SummaryReportV1.0.pdf&usg=AFQjCNGCtHnyJ9KeJWUWF5qghUxcfelJOg&bvm=bv.151325232,d.ZGg|*

[4] WHO Burden of Disease from Environmental Noise http://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf

[5] http://www.greener-cities.eu/

Technology and involved 13 partners from seven countries. Each of the methods on its own will not achieve 10 dB reduction. However it is possible to combine the methods to increase reductions and, in any case, even 5 dB reduction would be clearly noticeable and worthwhile. A reduction of 3 dB, although only just noticeable, represents a halving of sound energy. First we note evidence that 'greening' cities helps to reduce overall noise levels.

Noise levels are lower in 'greener' cities

A recent comparative study of noise levels in eight UK and six EU cities[6] has shown that overall noise levels depend on the proportions and distributions of green areas and porous ground. Figure 1(a) illustrates this point for the EU cities. Figure 1(b) shows that sound levels tend to be higher in UK cities with higher building densities (smaller average nearest neighbour index (ANN)) and potentially fewer green areas within 30 km^2 of the city centre. The balance and dispersion between green space surfaces and built-up surfaces turns out to be a more meaningful indicator than green space coverage alone. Noise levels will tend to be lower where there are more 'green' spaces involving naturally porous ground and where housing developments and road networks have lower densities because of the larger distances between noise sources and dwellings. The usual decrease of noise levels with distance is augmented by extra reductions from 'soft' ground effect, tree belts, bushes and hedges. The reasons for these extra reductions and their potential exploitation are the subject of this presentation.

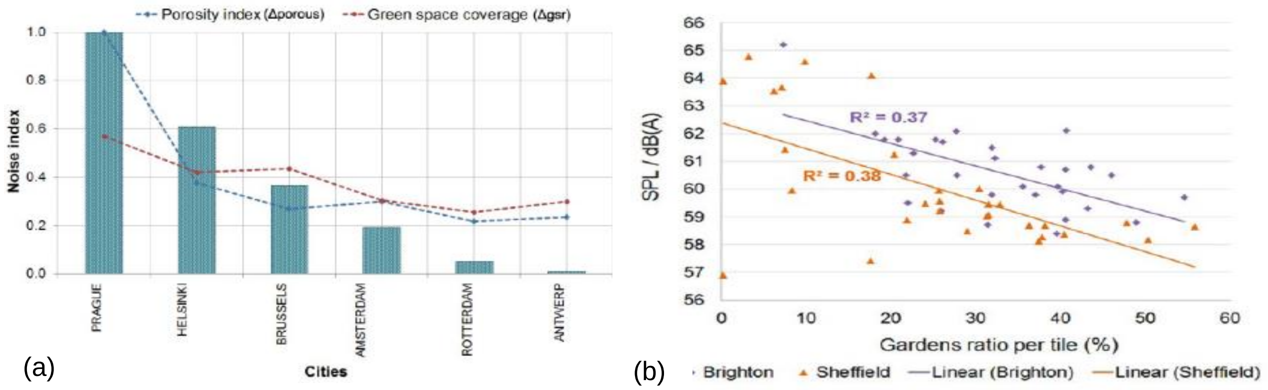

Figure 1 (a) Influence on noise levels of the ratio of porous to non-porous surfaces and the proportion of green spaces to total area in EU cities (b) influence on noise levels of the gardens ratio in two UK cities[6].

Noise reduction by 'soft' ground

Sound waves from single compact sources outdoors will tend to spread spherically so the sound level reduces by 6 dB for each doubling of distance from the source. Maximum sound levels of road traffic noise are predicted by considering each vehicle as a single compact noise source. On the other hand predictions of the average, or equivalent, sound level refer to L_{den} and $L_{Aeq,24h}$, which are measures of sound energy averaged over specified time periods used in many standards and guidance[7] assume that the whole length of the road is the source. So maximum noise levels due to individual vehicles reduce by 6 dB per doubling of distance from the road, whereas the equivalent continuous energy levels from a long straight road reduce by 3 dB per distance doubling (cylindrical spreading). A similar principle applies to energy equivalent average levels of railway noise. When making the noise mapping calculations required by the EU Environmental Noise Directive[8], the whole traffic network has to be considered along with the existing propagation conditions. As well decreases due to wavefront spreading the reduction of sound levels with distance is influenced by the state of the atmosphere near to the ground, particularly by wind- and temperature-gradients and turbulence which results in sound level fluctuations. Up to about 300 m from a noise source, the presence of the ground, or other surfaces, influences average levels significantly. At greater distances meteorological effects tend to be more important.

When the sound source is located above a ground surface, sound waves reflected from the ground combine with those travelling directly from the source. If the sound waves arriving along the two paths are in phase which is true at some frequencies, there are increased levels. When they are out of phase, which will happen at other frequencies, the total sound

[6] Efstathios MARGARITIS and Jian KANG, Relationship between green space-related variables and traffic noise distribution in the urban scale, an overall approach, Proc. InterNoise 2016, Hamburg pp 2882-2888; Relationship between urban green spaces and other features of urban morphology with traffic noise distribution, Urban Forestry & Urban Greening, 15 174 - 185 (2016)

[7] WHO Community Noise Guidelines http://www.who.int/docstore/peh/noise/ComnoiseExec.htm

[8] http://ec.europa.eu/environment/noise/directive_en.htm

is less. These interactions are known as *ground effect*. The reduction in sound levels is sometimes called ground absorption and is important for surface transport noise. It depends on the type of ground surface and the locations of the sources and receivers. The Calculation of Road Traffic Noise (CRTN) scheme[9], used for assessing eligibility for sound insulation of dwellings near new or improved roads in the UK, includes an allowance for the extra reduction in levels *" If the ground surface between the edge of the nearside carriageway of the road or road segment and the reception point is totally or partially of an absorbent nature, (e.g. grassland, cultivated fields or plantations)*". The extra reduction depends on the mean height of the sound travelling from the road source to the locations of interest and distance travelled over soft ground and it can be calculated using the chart shown in Figure 2(a). It is noted that " *To avoid the difficulty of defining adequately the many other more absorbent types of ground cover, the correction shown ... is to be used for all predominantly absorbent surfaces. Thus the calculations will **slightly** underestimate attenuation effects, particularly where the intervening ground is intensively cultivated or planted*." A similar correction and the same statement appears in Calculation of Railway Noise[10] (CRN Fig.2(b)).

For a mean path height of 1.5 m and a distance of 50 m from the nearest side of a road or railway, CRTN and CRN predict soft ground reductions of 4 dB and 1 dB respectively. The lower reduction for railway noise is consistent with wheel/rail sources (on the tops of tracks above sleepers and ballast) being higher than tyre/road sources (assumed to be at heights of 0.4 m and 0.01 m respectively in HOSANNA).

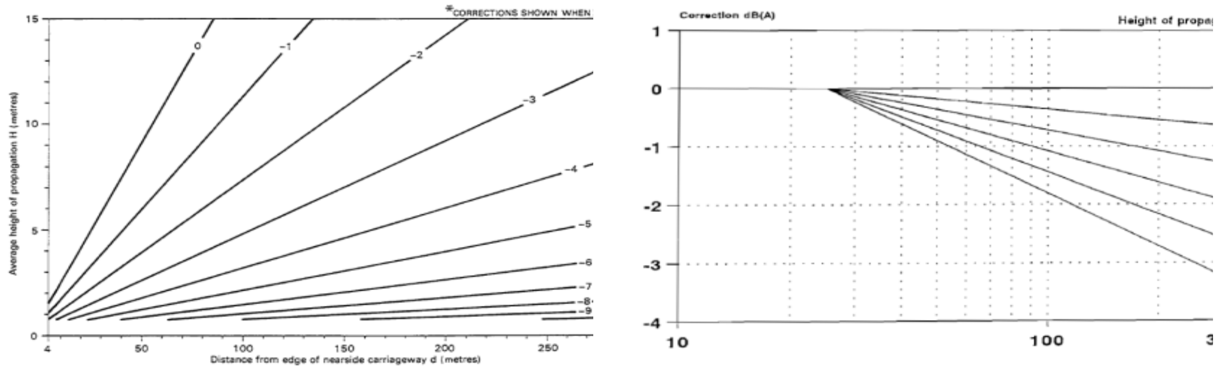

Figure 2 Corrections for 'soft' ground effect according to (a) CRTN and (b) CRN

CRN includes an additional reduction of 1.5 dB as a result of the porous (sound absorbing) nature of ballast. For a similar reason the use of porous rather than non-porous slab track is to be preferred when constructing high speed rail links and porous road surfaces are to be preferred to non-porous hot-rolled asphalt[11].

The introduction of grassy areas between and alongside tramways has been found to give perceptible noise reduction[12]. Measurements of the acoustical properties of ground surfaces and numerical calculations of noise levels due to a 2-lane urban road (5% heavy vehicles, 95 % light vehicles, travelling at 50 km/h), make it possible to identify less compacted (i.e. less mowed and rolled) grassland which will achieve the highest 'soft' ground reduction. A soft ground reduction of 5 dB, similar to the 4 dB predicted by CRTN, is predicted if a 1.5 m high receiver is located 50 m from the road over compacted grassland (Figure 3(a)). But for the same receiver location, 8 dB reduction is predicted i.e. twice that predicted by CRTN, if there is less compacted grassland such as the meadow shown in Fig.3(b). Typical urban road traffic noise spectra in the presence of hard ground and two types of soft ground are shown in Fig. 3(c)[12]. Some 'ground cover' reductions are predicted to increase with distance faster than would be predicted by CRTN.[13]

[9] https://www.scribd.com/document/252065568/D49-Calculation-of-Road-Traffic-Noise
[10] Department of Transport. (1995). Calculation of railway noise
[11] *Environmental Methods for Transport Noise Reduction* ed Nilsson *et al* Cat/ISBN:Y119572 /9780415675239 CRC Press an imprint of Taylor and Francis New York (2014)
[12] *Novel solutions for quieter and greener cities*, HOSANNA brochure, 2013; downloadable from www.greener-cities.eu
[13] K. Attenborough, I. Bashir, S. Taherzadeh, Exploiting ground effects for surface transport noise abatement, Noise Mapping Journal, **3** 1- 25 (2016)

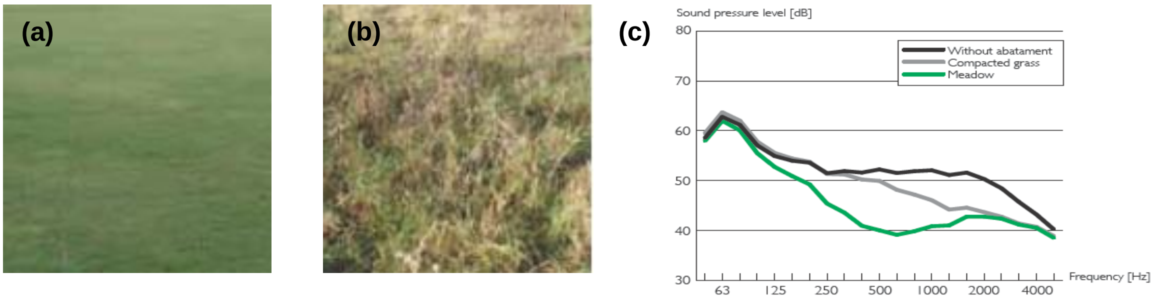

Figure 3 (a) compacted grass (b) meadow (c) Typical traffic noise spectra at a 1.5 m high receiver in the presence of hard ground and these two types of grassland.

Noise reduction by trees, hedges and crops

Although there is little or no allowance for noise reduction by trees in predictions schemes, many measurements show that tree belts reduce noise[14] as well as helping to reduce air pollution[15]. Some of the ways in which trees influence the way sound travels are illustrated in Figure 4(a) which compares numerical simulations of the sound fields developing from a sound pulse over open grassland and through a tree belt. Tree trunks and branches and the stems of vegetation redirect incoming sound. Regularly (or nearly regularly) planted trunks can act as 'sonic crystals'. Friction at foliage surfaces and leaf vibrations absorb sound and the ground beneath trees, hedges and crops is made 'softer' for sound reflections by the fallen and decaying leaves. Different mechanisms are important in different frequency ranges but in combination, as illustrated in Figure 4(b), they can reduce traffic noise at a 1.5 m high receiver 15 m behind the centre of a 75 m long and 25 m wide belt of trees (slightly irregular planting of 16 cm diameter trees with mean spacings of 1 m parallel to the road, and 2 m at right angles to it: the stem cover fraction is 1 %) starting at the edge of a 2-lane urban road (5% heavy vehicles, 95 % light vehicles, driving at 50 km/h) by nearly 8 dB.

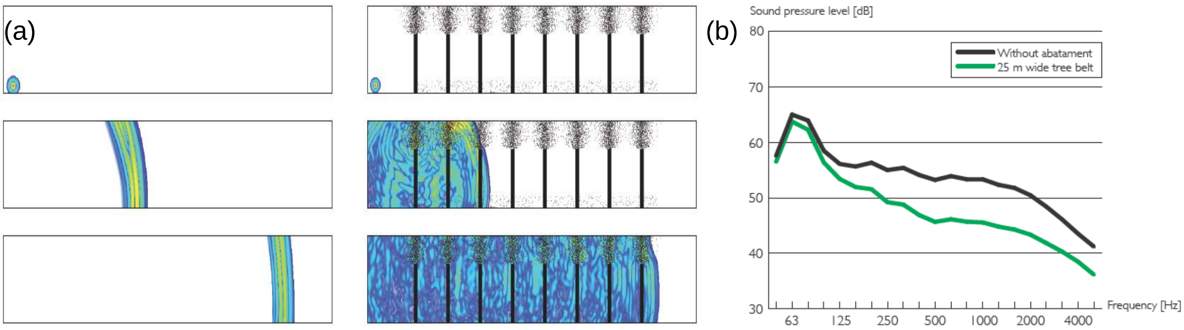

Figure 4 (a) snapshots of the sound fields due to an acoustic pulse starting at the same time on an open field or next to a tree belt and at two subsequent identical instants predicted using a numerical method (b) Predicted sound spectra at 15 m behind the centre of a 25-m wide, 75-m long tree belt near a 2-lane urban road.

A single row of trees has little effect on sound levels from a road but if it is behind a noise barrier (i.e. on the receiver side), a row of trees assists the reduction due to the barrier particularly in downwind conditions which would otherwise make the barrier less effective. To have the biggest influence, the trees should have dense canopies and so coniferous trees are well-suited for the purpose. Close to the barrier, the shielding that was lost by the action of the wind can be partly recovered when the bottom edge of the canopy is close to the barrier top. But leaving a gap between the lower edge of the canopy and the top of a barrier is predicted to lead to better barrier noise reductions at larger distances downwind[11,12]. Typically hedges are shorter and narrower than tree belts so they offer only 2 to 3 dB reduction at a 1.5 m high receiver behind them. On the other hand a 50 m wide area of 1 m high dense crops next to a road is predicted to offer about 5 dB extra reduction compared with grassland[13].

Noise reduction by parallel low walls and lattices

Introducing parallel low walls, no more than 0.3 m high, on smooth acoustically-hard surfaces changes the sound reflection from the surface so as to lower the frequencies at which there is cancellation between direct and ground reflected sound and

[14] K. Attenborough, K.M. Li, K. Horoshenkov, *Predicting Outdoor Sound*, Taylor and Francis, London, 2007, Chapter 10.
[15] R. Kessler, Green walls could cut street canyon air pollution, Environmental Health Perspectives, **121** A14 (2013)

this results in a reduction in traffic noise levels. The reduction due to an array of low walls depends on their mean height, total array width, mean spacing, cross-sectional shape and whether the spacing is random or regular. An 3 m wide array of 16×0.05 m wide 0.3 m high parallel walls (such as shown in Fig.5(a)) starting 2.5 m from the road edge is predicted to reduce traffic noise from a 2-lane urban road (5% heavy vehicles, 70 km/h average speed) by 7 dB, compared with smooth, acoustically hard ground, at a 1.5 m high receiver, 50 m from the road. A 1.5 m wide lattice configuration (such as shown in Figure 5(b)) of the same height (0.3 m) is predicted to reduce traffic noise by a similar amount. For a given height and spacing, a lattice gives a larger reduction for each metre width than an array of low parallel walls because the angle at which the sound arrives has less influence.

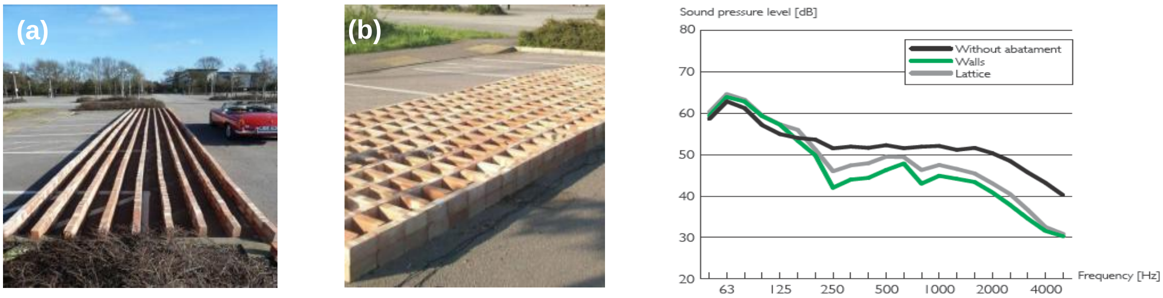

Figure 5 (a) Array of 0.2 m high parallel low walls and (b) a lattice arrangement of the same height made from loose bricks for vehicle pass by experiments in a car park (c) predicted sound levels as a function of frequency at a 1.5 m high receiver 50 m from a 2-lane urban road over a hard smooth surface, with a 3.05 m wide 0.3 m high array of 16×0.05 m wide parallel walls or a 1.5 m wide lattice of the same height starting 2.5 m from the road.

For reducing noise from traffic, there is no predicted advantage from spacing low parallel walls regularly rather than randomly but the appearance of uniform arrangements may be preferred. In contrast to a conventional barrier (which has to be air-tight) the reduction offered by low parallel walls or lattice arrangements is not much affected by creating a path through them. Also to improve their appearance, plants can be placed between low walls or in lattice cells without affecting the noise reduction significantly as long as the depth of the gaps between the walls or the lattice cells are not filled by more than about 30%[16].

Noise reduction by combining effects

Methods of traffic noise reduction that have been introduced here (tree belts and low lattice structures on the ground), and others considered in the HOSANNA project[9] such as vegetated low (1 m high) barriers and berms, can be combined when designing an urban area. Figure 6 (a) shows a housing estate and a park that are protected from noise created by a busy road by a vegetated berm and a low vegetated barrier respectively. Pedestrian access across the road between the housing area and the park, requires that the berm is interrupted near where the road passes beneath a railway but noise reduction is provided by areas of low walls or lattice wall arrangements on both sides of the road which include pathways to a pedestrian crossing. The housing estate is protected from railway noise by a low barrier along the bridge and by a belt of trees. Figure 6(b) shows dwellings organised into blocks creating 'quiet courtyards', railway noise reduced by a low vegetated barrier and a dense tree belt and noise reducing green façades, roofs and a lattice structure near to a square.

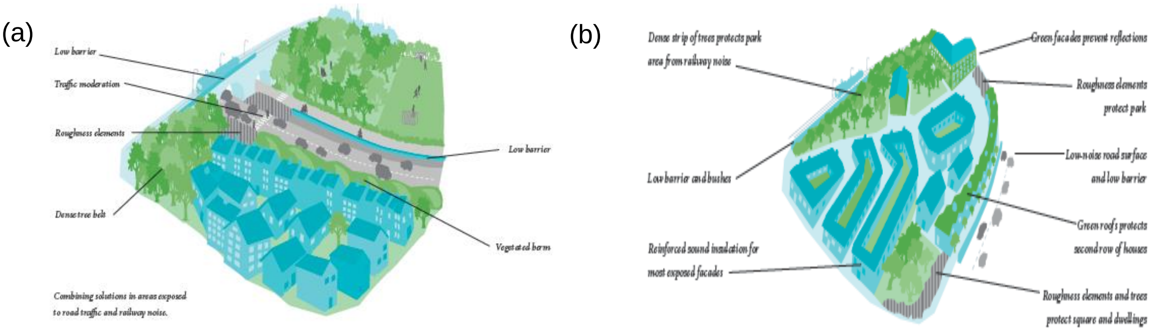

Figure 6 (a) and (b) designs of areas including various methods of surface transport noise reduction

[16] I. Bashir, Acoustical *Exploitation of Rough, Mixed Impedance and Porous Surfaces Outdoors*, Ph.D. Thesis, Open University, 2013

Other environmental methods for noise reduction, perceptual aspects and cost-benefit analyses

Other methods of traffic noise reduction in urban areas considered in the HOSANNA project include vegetated façades, green roofs, 'gabion' barriers made from piles of stones, vegetated low barriers, special designs of barrier tops, sonic crystal barriers (regular arrays of vertical cylinders), sonic-crystal-assisted barriers and artificial 'refraction' of sound using horizontal cylinder arrays, corrugating the surfaces of berms and enhanced porous road surfaces including buried resonators.

Adding evergreen vegetation to the urban spaces can contribute 'positive' sounds as well as reducing undesirable ones. It will increase wind sounds and attract wild life adding its typical vocalisations. Use of vegetation on façades can improve the visual quality of environments. The extent to which such visual changes also influence auditory perception of noise is debatable. However, the effect on the overall environment is more important, and noise-mitigation methods that, in addition to reducing noise, also improve aesthetic values are obviously better than methods that do not. For instance, the noise reduction associated with a low vegetated barrier may lead to an increase in visible bird activity especially in the summer. The HOSANNA project looked also into the costs and benefits of the various methods for noise reduction. The most robustly cost-efficient of the environmentally-friendly methods, taking into account non-acoustical benefits such as air pollution reduction and bio-fuel generation, was found to be the provision of dense tree belts alongside surface transport corridors.

Apart from the noise reduction and subjective benefits of replacing hard ground by grassland near tram tracks[11,12], noise reductions by the methods outlined have yet to be demonstrated in practice. Nevertheless the methods are based on 'sound' science and it is to be hoped that this presentation will encourage their use.