Towards “Natural” Noise Mitigation for Surface Transport

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Abstract

The importance of sustainability in all aspects of procurement is gaining momentum in many countries and recently the EC has awarded a contract (QUIESST) to develop not only improved evaluation techniques for acoustic performance of noise reducing devices but also to examine optimisation and sustainability issues. This paper examines some options for “natural” forms of screening surface transport noise that might on the face of it be considered sustainable but until a number of factors are fully considered it is not clear how they compare with manufactured noise barriers. It also considers the psychological benefits of using natural solutions based on the “tranquillity rating prediction tool” recently developed at the University of Bradford.

Introduction

It is likely that “natural” means of attenuating noise are among the most sustainable options though it is unclear how such options would rank on sustainability criteria. Such criteria will be developed as part of the work recently begun in the WP6 of QUIESST (QUIetening the Environment for a Sustainable Surface Transport - a project co-funded by the European Community's Seventh Framework Programme (FP7/2007-2013) that began on the 1st of November 2009). For example, sustainable design criteria might include not only the carbon footprint of the materials used but a consideration of sustainable design in terms of health and safety issues, effects on biodiversity, severance to communities and habitats but also transport of materials to site, maintenance issues, decommissioning and recyclability. There is a need to develop robust methods and criteria for assessing sustainability in terms of environment, society and economics. It is expected that QUIESST will provide useful practical guidance on assessing overall sustainability.

There is also the question of public acceptability of manufactured products such as noise barriers where anecdotal evidence suggests growing opposition to their use due to a number of factors including ugliness, visual intrusion, personal safety issues and increasingly their use as a “canvas” for graffiti artists. It is important to consider the extent to which more natural options such as belts of trees, earth mounds and “green” barriers are acceptable and this paper provides some insights using research on predicting perceived tranquillity. This paper begins by reviewing and reanalysing the results from some past studies of these natural means of noise control.

Tree Belts

Perhaps the most natural approach is to use belts of trees to screen transportation noise. There has been considerable work on the effects of woodland and forests of various sorts on attenuation of sound [1,2,3,4,5]. However, the most appropriate data for the controlling transport noise are some measurements in belts of English woodland of various types and densities using traffic noise as an effective line source [4]. The attenuation rates were compared with grassland from 5 m to 35 m. At each site the ground was flat and covered by vegetation in full summer foliage that was relatively homogeneous. Grassland was used as a control in order to gauge the benefits of open and dense vegetation. Figure 1 gives the additional attenuation over grassland for 2 different vegetation types i.e. open woodland and

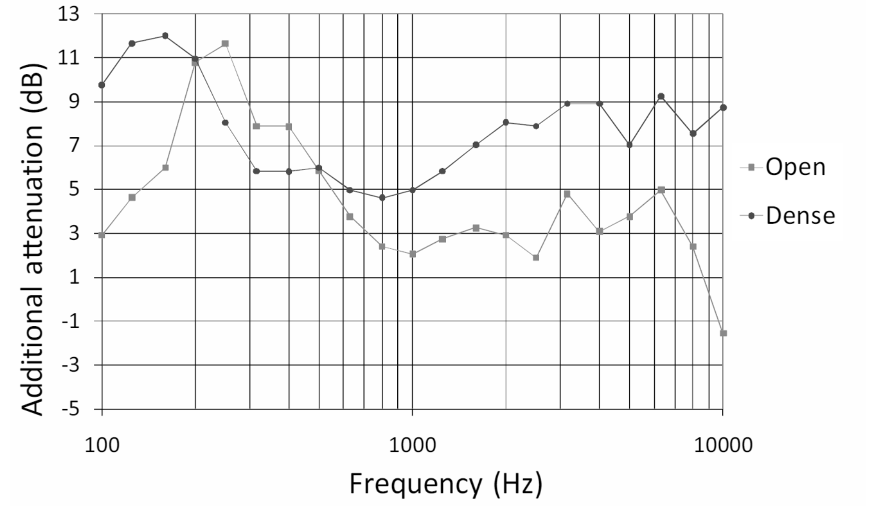


Figure 1: Additional attenuation through 30m belt of woodland compared with grassland

dense spruce and for a roadside noise barrier. Figure 2 shows views of the two extremes of vegetation.

The efficiency of individual trunks and branches to scatter sound is related to the characteristic diameter of the scatterer. Scattering is significant when the frequency of sound is well above the scattering limit frequency f', given by:

$$f' = \frac{c}{\pi D_{chr}}$$

where D_{chr} is a characteristic cross dimension (in m) of the scattering object [5] and *c* is the velocity of sound in m/s.

Figure 3 hows the scattering limit frequency as a function of tree trunk/branch diameter. The density of the scattering trunks will be important and clearly the density of small branches is considerably greater than for trunks ensuring significant attenuation at several kHz.

From Figure 1 it is clear that there is a dip in the additional attenuation from approximately 800 Hz to 1.2 kHz where there is a little additional attenuation which perversely corresponds to the A-weighted peak in the traffic and railway noise spectra. To improve attenuation efficiency of vegetation over grassland the focus of attention should therefore be in this band. From Figure 3 a diameter of 0.14 m would equate to a scattering limit frequency of 800 Hz. Therefore introducing a high density of scatterers with a diameter of around 0.14 m should improve attenuation above 800 Hz. An approximation to this situation was found in the spruce forest.

This forest gave the greatest attenuation at mid frequencies and this is because the trunks were approximately 0.12 m diameter (critical scattering frequency 900 Hz) and were thickly planted (just 1 m apart). In addition from Figure 2 it can be seen there was a high density of interlocking branches down to ground level which ensure good high frequency performance as well, although pine needles were largely absent due to the lack of light.

In contrast the deciduous woodland shown in Figure 2 had few branches near ground level and the trunks although thicker (0.2 m) were relatively widely separated (2.5 m) giving poorer overall performance at mid and high frequencies. The attenuation data provided in reference [4] was used to determine the LA10 values expected at a range of distances from 9m from the road edge to over 100m. This was calculated for grassland, open woodland and dense spruce forest.

In addition using CRTN (Calculation of Road Traffic Noise) predicted levels were determine over similar distances with a 3m reflective barrier placed 4m

(a) Open deciduous woodland

(b) Dense spruce forest

Figure 2: Range of vegetation measured

from the roadside. Figure 4 shows the additional attenuation over grassland for these options.

Close to the barrier it is clear that the barrier provides superior screening but as distance increases the curves converge. At 70m from the source the dense spruce forest is predicted to produce similar screening to the noise barrier while at the largest distance of 110m the open woodland gives similar results to the noise barrier. Clearly where space is available, dense vegetation such as closely planted spruce is a useful alternative to a manufactured noise barrier, especially at the larger distances. However, such a belt does not reach the efficiency of a purpose built noise barrier close to the noise source. Further study is required to optimise the attenuating properties of woodland by careful selection of trees, shrubs and ground cover. Some guidance has been obtained by noting the apparent "pass band" in conventional woodland and forest at around 1 kHz and by a consideration of scattering theory. This would suggest that closely spaced branches and tree trunks of approximately 0.14m should be a guide. Another option is to plant trees in geometric patterns to obtain stop bands at critical frequencies using sonic crystal theory [6]. However, with a distributed broadband noise sources it would be a challenge to obtain meaningful attenuation rates.

Earth Bunds

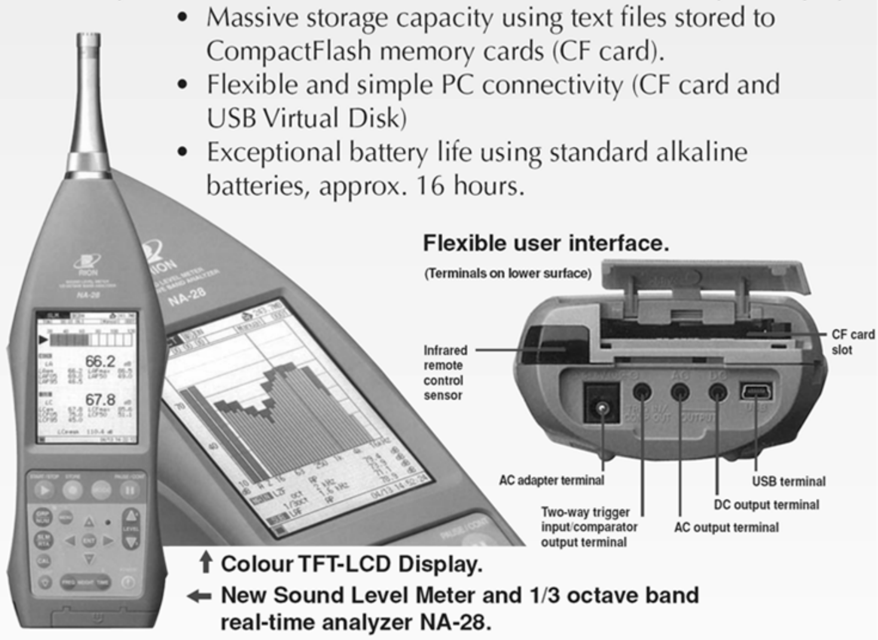
For the control of highway noise the use of earth bunds, banks or berms have long been used as an attractive option due to their ease of construction where spare soil is available from levelling operations and their natural appearance. In addition they often support a considerable range of flora and fauna.

Developments in more efficient boundary element method (BEM) codes have enabled noise level predictions to be made behind large and complex shaped earth mounds in order to identify acoustically efficient yet practical designs. The effects of detailed modifications to the top surface and slopes of sides can also be examined e.g. the use of multiple edge diffracting edges 0.5m tall placed on the top surface of the bund [7].

It can be seen in Figure 5 that the increasing the side slopes of bunds placed adjacent to the road moves the top diffracting edge closer to the source of noise.

With the standard slope of 20 degree the diffracting edge is 8.2m from the verge edge while for the steep sided bund (80 deg) the diffracting edge is only 0.5m from the verge. This gives additional attenuation compared with the standard bund at 8.2m as can be seen in Figure 6. The greatest gain is for the steep sided bund (80 deg) where insertion loss gain is approximately 3dB(A). A further benefit will be the sound absorptive qualities of the grass covered slopes when compared with standard reflective noise barriers. In addition a much smaller volume of earth is employed in the narrower bund and of course the space required is considerably less. In order to produce such steep-sided bunds some interventions are necessary for soil stability. Various methods can be used, for example the use of woven willow baskets to retain the soil with evergreen creepers growing over the barrier. Once the creepers have been established there should be no requirements to irrigate.

A further method is to use gabions (wire mesh boxes to retain soil and stones).



These can be shaped in various ways or rectangular boxes can be stepped. Figure 7 shows a possible structure for free standing trapezoidal shaped gabions filled with irregular shaped rocks. Such a fill will have the effect of scattering and absorbing sound. However attention has to be given to sound transmission and it may be necessary to carefully grade the stone fill to achieve a satisfactory balance between sound absorption and sound transmission. The challenge for this design is to achieve an acceptable surface finish. The use of evergreen ivy may be an option as a cover or a stepped design may encourage the establishment of grasses and creepers.

A further design which takes even less space is a woven willow fence with ivy growing on the outside (Figure 8). Fibrous sound absorbing panels are incorporated into the panels. The willow is dried so no irrigation is required.

A living willow barrier is shown in Figure 9. This design requires irrigation and is likely to be less robust than the ivy equivalent. Because these barriers are made of natural materials withgrowing creepers or willow the barrier has the potential to enhance the urban environment by providing an attractive

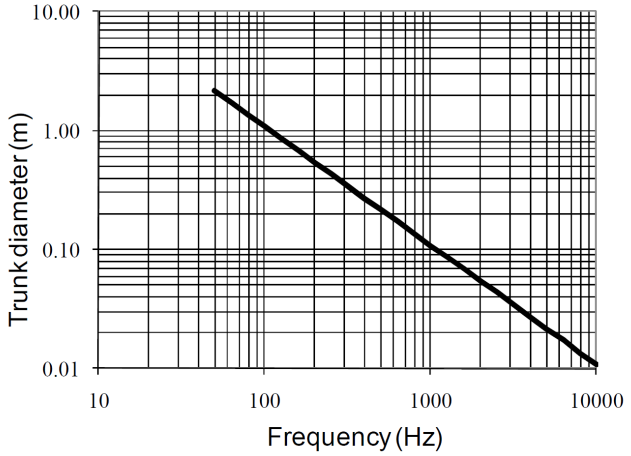


Figure 3: Scattering limit frequency by trunk diameter.

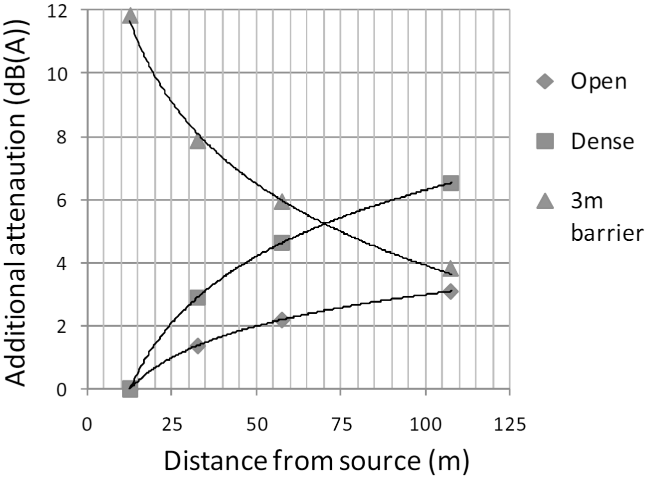


Figure 4: Additional attenuation compared with grassland.

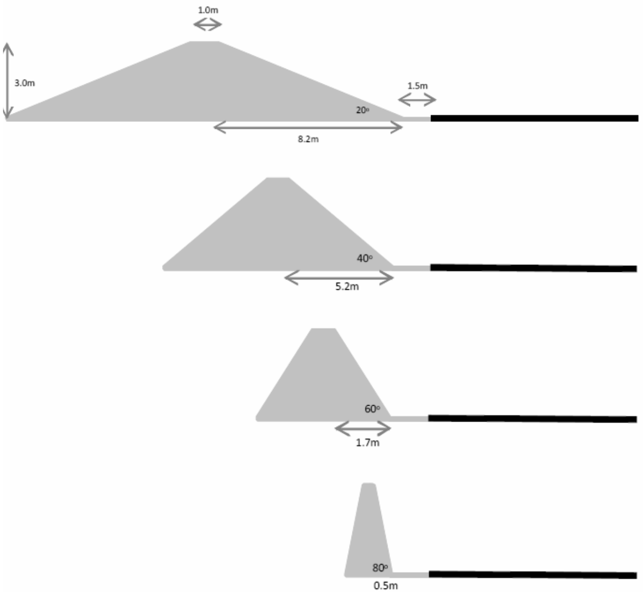


Figure 5: Earth bunds with different side slopes

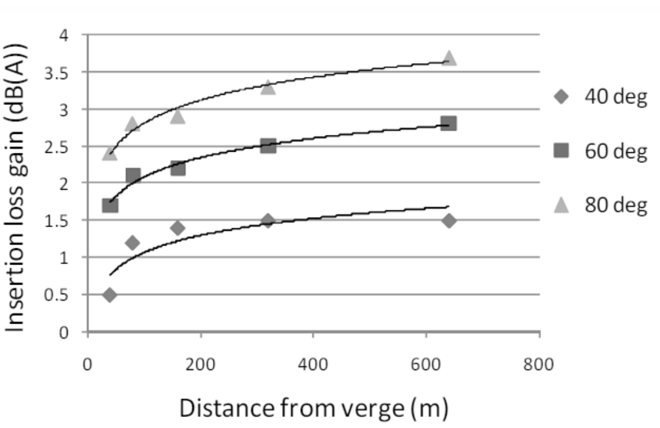


Figure 6(a): Insertion loss gain compared to standard bund with 20 degree slopes.

Figure 6(b): Retained soil bank with well established evergreen creeper (Weavewall Ltd).

contrast with hard man-made surfaces such as brick, concrete, glass and steel. They will also be less attractive to graffiti artists. For the barriers using growing willow it will be necessay to irrigate and regular pruning will be essential to maintain a tidy appearance and prevent excessive windloading.

Effects On Human Perception

The human perception system is multisensory and so that auditory perception is influenced by what is seen. Some recent research using functional magnetic resonance imaging (fMRI) has demonstrated that connections in the brain are strengthened when the scene is considered tranquil rather than non-tranquil [8]. In fact this study showed a greater connection between the auditory cortex and medial prefrontal cortex indicating a greater engagement with the tranquil scenes and an apparent rejection of non-tranquil scenes. This was despite the fact that the same audio input (a constant “roar”) was replayed at the same level under both conditions. Quiet and natural environments are key feature of such tranquil environments and it is quite likely that for a noise screen to be fully acceptable to residents, both auditory and visual factors should be considered of similar importance to gauge overall perception.

At the University of Bradford research has been carried out in the laboratory using the playback of video cuts that contained binaural recordings taken with an artificial head in a variety of landscapes from open moors through beach scenes and residential areas to city centres. The background to this research [9] and the final form of the formula relating auditory and visual factors has

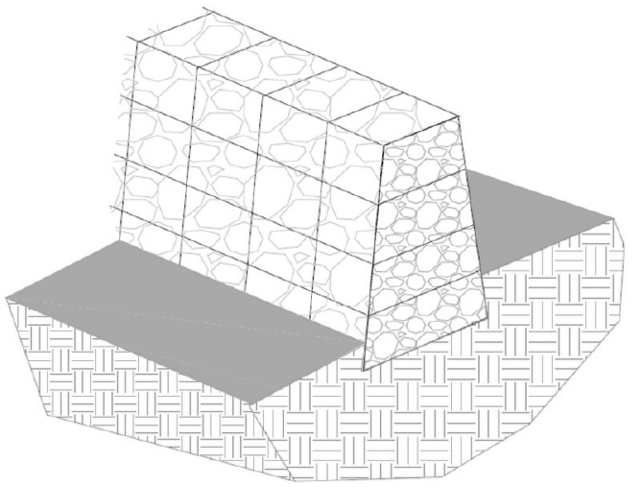


Figure 7: Gabion system for noise control (Enviromesh Ltd).

recently been reported [10].

$$TR = 9.68 + 0.041\ CF - 0.146\ L_{Aeq} + MF$$

Where TR is the tranquillity rating on a 0 to 10 rating scales. CF is the percentage of natural and contextual features in the landscape (average over 360 degrees). Contextual features include listed buildings, religious and historic buildings, landmarks, monuments and elements of the landscape, such as traditional farm buildings, that directly contribute to the visual context of the natural environment. L_{Aeq} is the equivalent constant A-weighted sound pressure level, which for practical application should be the level of man-made noise over the day time period. MF is an adjustment due to moderating factors which are not expected to be large and include the presence of water and associated sounds and litter and graffiti. The following classification of the tranquillity rating is suggested to guide assessments for planning purposes [10]:

<5	unacceptable
5.0 – 5.9	just acceptable
6.0 – 6.9	fairly good
7.0 – 7.9	good
≥ 8.0	excellent

With a constant noise level, increasing CF will improve the rated tranquillity. If this can be applied to noise barriers it will be seen that this may have a relatively large effect. To model the effects it is assumed that a busy road (1300 vehicles/hr with 10% heavy vehicles) is subject to a 50km/hr speed limit and is screened by a 3m high barrier 4m from the kerb. It is also assumed that the barrier subtends essentially 180 degrees in the horizontal plane and that the receiver is surrounded by grassland with uninterrupted views of the barrier.The angle of view at the receiver position in the vertical plane is ±20.4 deg and the area of sky above the barrier is not used in the calculation of CF. Hence the view of the barrier will critically influence the perceived tranquillity at close distances. Further away the barrier subtends a smaller angle and its visual influence will consequently diminish.Noise levels will also reduce with distance due to geometric spreading. If the barrier is perceived as a natural feature then CF=100%. However, if the barrier is not perceived as natural or contextual e.g. an obviously manufactured product such as a concrete or metal barrier, then CF will be lowered depending on the area the barrier subtends when compared with the rest of the scene (which is assumed will be natural grassland).

Figure 10 shows that at 5m distance behind the natural barrier the perceived tranquillity is expected to be 5.0 which is "just acceptable" on the above scale. However for the manufactured barrier the expected rating would reduce to 3.2 which on the scale is clearly unacceptable. The difference is a result of the visual aspect alone as noise levels are identical in these two cases. At greater distances the predicted tranquillity for the two barrier types converge as can be seen in Figure 10. For taller barriers differences will be greater and the convergence will be less rapid due to the larger angles subtended by the screen at the receiver. Further research is required to confirm these predictions but the implications, if correct, are potentially very important for predicting residents' reactions. Note that it should be possible to further refine predictions by a consideration of the moderating factors (MF). For example it has been shown that the presence of litter causes a reduction of one scale point [11] so it is likely that the presence of graffiti on the barrier surface

Figure 8: Woven willow panels with recent ivy plantings (ETS Ltd).

would have an even greater deleterious effect due to the fact it will tend to be more obvious and is more permanent. This should be considered a possibility especially for manufactured products that present a suitable surface for spray paints.

Figure 9: Growing woven willow fence with absorptive panel cores (ETS Ltd).

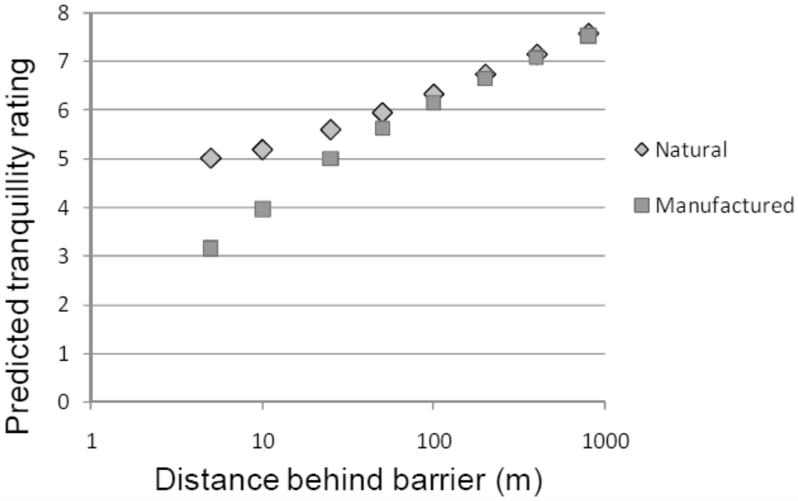


Figure 10: Predicted effects of barrier type on perceived tranquillity.

Conclusions

The following conclusions can be drawn from this analysis of “natural“ means of controlling surface transport noise.

- Both woodland and planted forests produce significantly greater attenuation than grassland. The greatest effect was produced by dense spruce forest. With such a dense forest extending from close to the roadside it was predited that at approximately 70m from the source the attenuating effect on a traffic noise would be similar to that of a 3m high barrier placed near the roadside.
- Earth bunds can achieve significant screening though it has been shown that for the greatest benefit the bund should be placed close to the noise source. This implies a requirement for steep sided bunds and various solutions are described.
- The perceived benefit of noise screening has been examined using a novel tranquillity prediction tool. This indicates that natural barriers have advantages over barriers made from man-made materials if they are perceived as natural features in the landscape.

References

1. K. Attenborough, “Acoustical impedance models for outdoor ground surfaces”, Journal of Sound and Vibration 99, 521-544 (1985).

2. K. Attenborough, “Natural noise control”, Proceedings of Internoise 96, 51-73. Liverpool (1996).

3. R. Hendriks,“Traffic noise attenuation as a function of ground and vegetation (interim report)”, Report number FHWA/CA/TL-89/09, California Department of Transportation, Sacramento, California (1989).

4. L. Huddart, “The use of vegetation for traffic noise screening”,Research Report 238, Transport and Road Research Laboratory, Crowthorne, Berkshire (1990). 5 I. M. Noordhoek, “Sound propagation through urban areas and vegetation”, TNO-report HAG-RPT-010001, TNO TPD. 2600 AD Delft, The Netherlands (2001).

6. P. A. Morgan and G. R. Watts, “Application of the Boundary Element Method to the design of transport noise mitigation measures”, TRL Annual Review 2005, TRL Ltd, Wokingham, Berkshire UK (2005).

7. G. R.Watts, “Effectiveness of novel shaped bunds in reducing traffic noise”, Proceedings of the Institute of Acoustics 21 (2), 41-50 (1999).

8. G. R. Watts, M. D. Hunter, M. Douglas, R. J. Pheasant, T. F. D. Farrow, I. D. Wilkinson., J. Kang, K. V.Horoshenkov and P. W. Woodruff ,”The use of fMRI techniques to investigate the perception of tranquillity”, CD-ROM, Proceedings of Internoise 2009, Ottawa, (August 2009).

9. R. J. Pheasant, K. V. Horoshenkov, G. R. Watts, B. T. Barrett, “The acoustic and visual factors influencing the construction of tranquil space in urban and rural environments: – Quiet Places?” Journal of the Acoustical Society of America, 123, 1446 – 1457 (2008).

10. G. R. Watts, R. J. Pheasant, K. V. Horoshenkov, Tranquil spaces in a metropolitan area CD-ROM, Proceedings of International Congress on Acoustics, Sydney (August 2010).

11. G. R. Watts, R. J. Pheasant, K. V. Horoshenkov, Validation of tranquillity rating method, Proceedings of the Institute of Acoustics, Ghent, 29-30 (April 2010). ¶