3D Noise Modeling for Urban Environmental Planning and Management

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1 ABSTRACT

In this paper, we demonstrate an application of a 3D urban model derived from laser scanning data to improve the information base on how differently urban citizens are harmed by noise pollution. 3D models have a long tradition in the field of urban planning; mostly they are used for visualization purposes, but there is a lack of knowledge of spatial analyses that utilize 3D models.

An increasing awareness of negative effects of environmental pollution on human health is emergent in our densely built-up urban areas. European environmental standards have been introduced in the past years. The 'Environmental noise Directive 2002/49/EC' requires from the Member States to produce strategic noise maps in order to inform the public about noise exposure and its effects. Most of the noise maps that are available today and also the requested EU noise maps are in 2D indicating the noise level at a certain height e.g. 4m above ground. In reality, noise travels in all direction and is high at the source and decreases with distance to the source. Such 2D noise maps do not allow distinguishing different levels of noise pollution e.g. inhabitants of high rise buildings are affected. It is therefore the development of 3D noise maps that can show the influence of noise in all directions, which help in better understanding of how many inhabitants are threatened by noise levels hazardous to human health.

Within this study a methodology is developed to build 3D noise models showing the spread of noise pollution. The method is illustrated using a 3D city model derived from laser scanning data of a small part of Delft, the Netherland. In order to model the noise levels 3D observation points (that represent the virtual microphones) are generated. The noise calculation is using the Dutch standard noise calculation models. Spatial interpolation methods are used to develop a noise surface. The results are than used to estimate the number of inhabitants possibly threaten by high noise level as well as the effectiveness of noise barriers is tested. The results show that although the number of inhabitants affected by high noise levels is approximated, the 3D noise model provides much clearer indication where standards are exceeded and allows quantification of effected inhabitants. The incorporation of noise barriers show that the model can be useful in calculating the efficiency of noise barriers. This method has a potential to improve information for urban environmental planning and management as it helps to clearly indicate hot-spots of pollution and better assess noise mitigation measures.

2 INTRODUCTION

2.1 3D models for urban planning and management

The use of 3D models (e.g. marquets) has a long tradition in the field of urban planning and design. 3D models of buildings set into a landscape are employed to assist in the decision making process to better communicate or discuss urban design issues, e.g. the (re)development of an area. Traditional marquets have the advantage to be easily understood by the audience, however drawbacks are that they cannot be viewed from different viewing angles/perspectives as well as they are isolated from their surrounding environment. The implementation of digital 3D visualizations of urban plans (using CAD or GIS environments) where the user can navigate through the urban landscape has been increasing the degrees of user interaction (Hanzel, 2007). These developments have a great potential to improve and ease the communication process between planning professionals and the community as they help in bridging the frequently observed communication friction between experts and public. Such developments are gaining importance in the context of collaborative planning in which planning professionals enable the community to come to a joined decision (Klosterman and Brail, 2002), essential here is to develop applications that are user-friendly and easily understood. The concept of collective design and planning has been joining several ideas towards a more context sensitive approach of participatory planning (Mantysalo, 2005).

Besides its potential to improve the communication process by assisting in a better understanding of the presented information, 3D models implemented within a GIS environment have a great potential to provide analysis of environmental phenomena that have vertical variations (e.g. environmental pollution). This enables planning professionals and the public to better discuss the implication e.g. of the (re)developed of an urban area as it is possible to model environmental impacts of the proposed plan (e.g. noise or air pollution levels). These developments eventually provide better basis for informed urban decision making (see fig. 1).

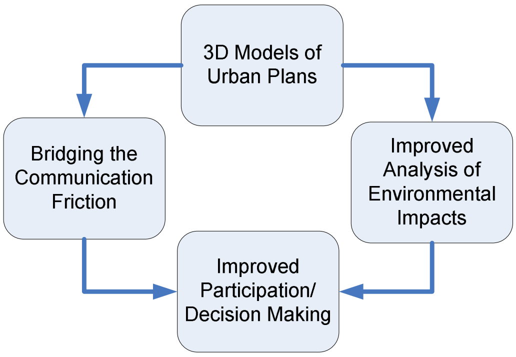

Fig.1: 3D models in urban planning and management

2.2 Road Traffic Noise Mapping

Noise pollution of urban environments is a major concern for environmental planning and management within local authorities. Noise pollution is also addressed by the European Union as an important issue that led to the formulation of the Environmental Noise Directive' 2002/49/EC. The directive indicates that e.g. every member state needs to make strategic noise maps for agglomerations with more than 250,000 inhabitants (European Commission, 2002). Such noise maps can be derived from measurements or using noise prediction models that are believed to be more cost effective (Kluijver de and Stoter, 2003). In most cities measurement are used for calibrating the noise models producing conventionally 2D noise maps at a specific measurement height e.g. according to the EU directive at a level of 4 meters from the ground.

In reality noise levels have a stark variation as a function of distance to the source of pollution. A major source of noise pollution in urban areas is traffic noise (Butler, 2004) therefore, the levels and consequently the effected number of inhabitants vary within a street canyon, e.g. inhabitants on lower floors are more affected than on upper floors. Road traffic noise is a major negative factor of residential environmental quality and can have serious impacts on human health (WHO, 1995). The location of hot spots of high noise levels that exceed a certain limit value has a vertical dimension which is neglected in conventional 2D noise maps. Noise is conventionally measured as dBA were the doubling of sound frequency is equal to an increase of 10dBA with the threshold of pain of approximately 120 dBA (National Road Authority, 2004).

The standard noise calculation methods in the Netherlands are based on extensive measurements done in the year 1970s and 1980s (VROM, 1999). The Dutch Ministry of Housing, Spatial Development and the Environment (VROM) has developed special noise calculation methods which are the Standard Calculation Methods 1 (SCM1) used for simple situations with few calculation parameters and the Standard Calculation Methods 2 (SCM2), using all the factors affecting noise levels including reflection and obstruction of sound between buildings. The equation used for SCM1 (also used for this study) is:

$$SCM1 = E + C_w + C_j + C_r - D_d - D_e \qquad \textit{Equation 1}$$

Where E is the emission level at source which is depended on the traffic factors, C_w the correction term due to the type of road surface, C_j the correction term for any traffic-light controlled junctions, C_r the correction term for any redound from vertical surface e.g. buildings and noise barriers, D_d the correction factor due to the distance attenuation from the source and D_e the correction factor due to air attenuation, soil attenuation and meteorological influences.

3 BACKGROUND OF THE CASE STUDY

The study area is one section of the central part of Delft, the Netherlands. The area (3ha) is covered by 185 buildings with an average height of 15 meters and a maximum of 20m (see fig. 2). The 3D city model was built using laser scanning data[1] of the year 2000 and is based on an interactive segmentation of the parcel boundaries using tools for splitting the polygon along height jumps edges (Vosselman et al., 2005). 3D city models extracted from laser altimetry produces reliable and detailed surface descriptions, it allows e.g. extraction of exact roof-shpaes (ibid).

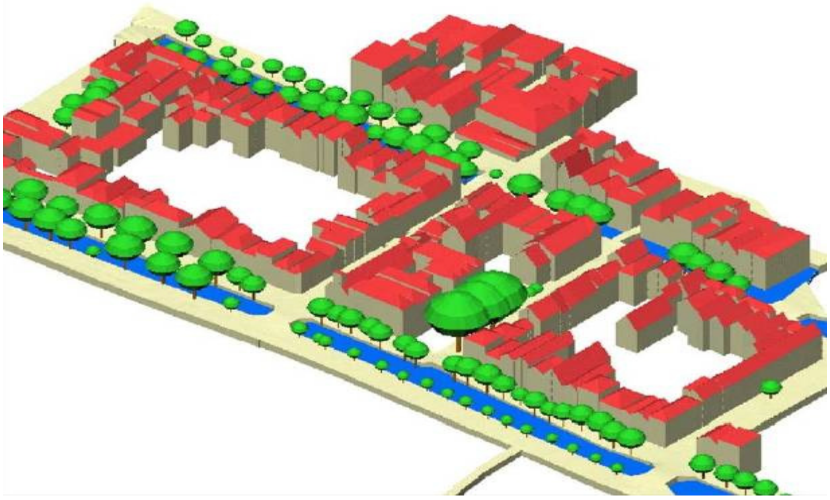

Fig.2: Central part of Delft, 3D city model of study area (Source: Vosselman et al., 2005)

The noise levels were extracted using the noise mapping model 'Standard Noise Mapping Method 1' (SMM1) which uses SCM1 (see equation 1) guided by an acoustic expert2 from dBvision. SMM1 is normally used for simple acoustic situations e.g. assessing the impact of plans on noise level variations. At the same time, the assumption of input data required for the noise calculation was discussed with the acoustic expert. This research experiments with fictitious data (e.g. estimates of traffic data) that means the results cannot be validated with actual field condition. The input data for noise calculation is assumed to be similar to that of field conditions. The factors such as meteorological conditions, air absorption, source strength variation, ground attenuation effect and barriers, and reflection are not considered for noise calculation.

4 METHODOLOGY

The data required for the noise calculation are observation points, buildings and roads; the latter two data was extracted from the 3D city model. An important step was the generation of 3D observation points, representing virtual microphones where the noise levels were calculated. The scale and density of the observation points was designed to show high level of details in noise levels variation. In vertical direction the points are distributed evenly (see fig. 3) on straight lines with 2m interval. The points in horizontal direction are spaced to best model the noise phenomena that reduces logarithmically with distance to the source of pollution. Thus higher point density was selected near the noise sources and lower further away (lowest is 2m). Vertical points are arranged with an offset of 10cm leaning towards the buildings in order to ease the interpolation. Observation points are also selected on the backsides and the top of the building in order to extract noise behaviour at these locations.

1 The data was acquired with TopoSys-I scanner from an altitude of 1000m. The point density of laser scanning data is 10cm in flight direction and 2m in scan line direction (Vosselman et al., 2005).

2 Henk de Kluijver member of dBvision office Utrecht (The Netherlands).

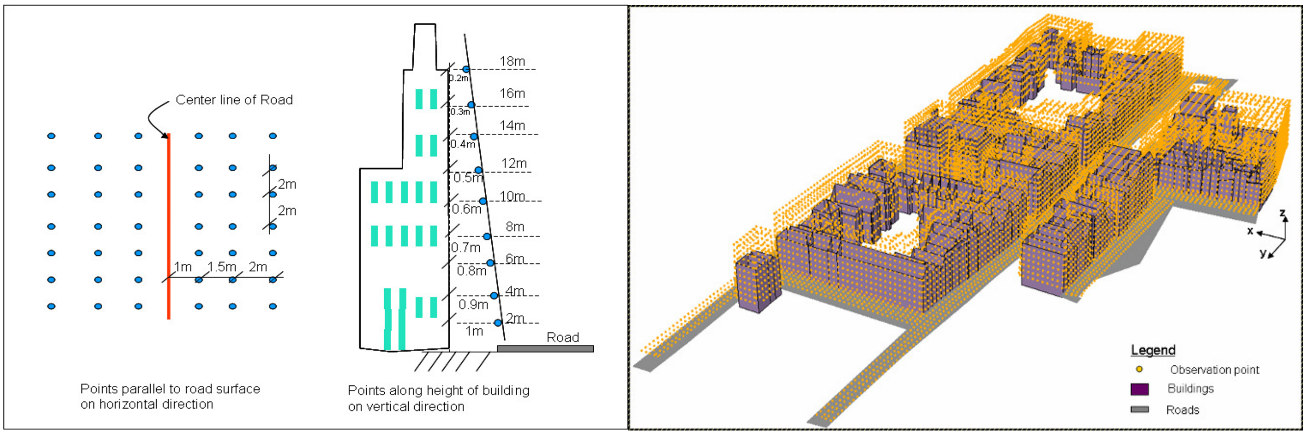

Fig. 3: Spacing of points in horizontal and vertical direction

The noise levels of observation points were computed using Standard Noise Mapping Method 1 (SMM1), integrating the SMM1 model within ArcGIS software. The calculation of the noise levels is starting from the centreline of the road. Noise was calculated at each observation point and TIN interpolation technique (showing the lowest RSME after experimenting with several interpolation techniques) was used for building the 3D noise model (see result in fig. 4)[3].

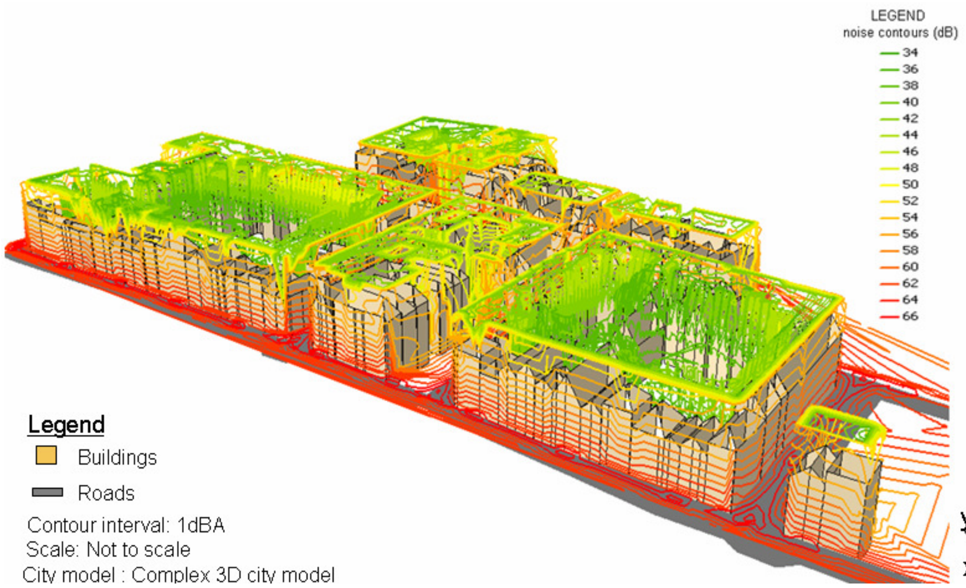

Fig. 4: Noise contour lines in combination with 3D city model

The main focus of building a 3D noise model was firstly to provide an easily understood visualization of a complex environmental phenomenon that could have a potential in bridging to communication friction between professionals and the pubic and secondly to extract more detailed analytical information about noise impact in a complex urban street canyon. Two possible analytical applications have been developed to show the potential of a 3D noise model within a GIS environment:

- to estimate the population affected by a certain noise levels more precisely than by a conventional 2D noise maps,
- and to study the effects of noise barriers.

3 For more details on the employed interpolation techniques refer to Kurakula et al. 2007.

5 DISCUSSION OF RESULTS

5.1 Visualization of 3D noise levels compared with conventional 2D noise maps

Conventional 2D noise map (see example in fig. 5) used by planning professionals are difficult to be understood by the public. The information is presented with a too high level of abstraction as well as most people have difficulties to recognising familiar objects and orient them in such maps.

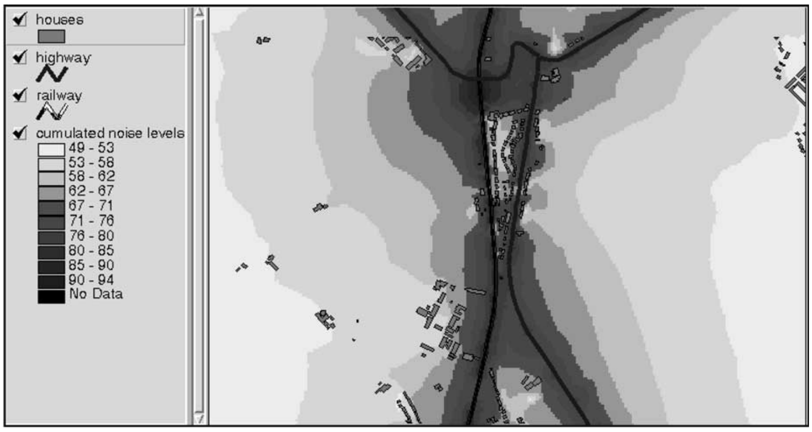

Fig. 5: Example of a 2D noise map (Source: Kluijver de and Stoter 2003)

As mentioned above one drive for developing 3D noise model was to ease the understanding of noise maps for the public. This motivated the decision to use a complex 3D city model extracted from laser scanning data that e.g. also give the roof shapes for visual orientation. Objects that would disturb the readability of the noise contours (e.g. trees) have been removed. Moreover, noise contours have been selected to ease its interpretability compared with another common method to projects the noise levels on the building façades (see example of fig. 6). The colour range of the noise contours was selected to reflect common threshold values of well-being of citizens that is exceeded at values of around 50 and 55 dBA according to Dutch and international standards (WHO 1999).

5.2 Estimate the population affected with a noise levels beyond the noise threshold

A possible application that reveals the analytical capability of a 3D noise model is its usage for estimating the number of inhabitants affected by critical noise levels. For demonstration purposes a simplified approach was developed that uses noise observation points at building façades. The following assumptions are made to estimate the affected population:

- The height of each storey of the buildings is assumed to be 3 m.
- All apartments inside buildings are of the same size. The front side of each apartment facing towards the road is assumed to be of 10m width (and 3m height).
- Number of people living in each apartment is assumed to 3.

The threshold of annoyance is set to 55 dBA using the WHO guidelines (1999). The number of points that have noise levels greater than 55 dBA is obtained by query operation. Similarly, the estimation of population was also carried out in the case of 2D noise maps. Table 1 shows the comparison of estimated number of affected inhabitants using the 3D noise model and 2D noise maps.

Noise models	Population Number (round)
2D noise maps	1650
3D noise model	1100

Tab.1: Estimated number of affected inhabitants (by noise levels of more than 55 dBA) in the study area

The results in table 1 show that the estimated number of population affected by high noise levels using the 3D noise model is lesser than based on the 2D noise maps. This is caused by the fact that with the 3D model only the stories affected by noise levels of more than 55 dBA have been taken into account. Whereas in the case of the 2D map the affected population number is estimated by including the total number of people living within a building if the limit value is exceeded at the standard measurement height. With these results it can be concluded that the 3D noise model has the potential to provide a more accurate estimation of affected inhabitants compared to traditional 2D noise maps.

5.3 Effects of noise barriers

As second application of 3D noise models the assessment of the effectiveness of noise measures was selected, in particular the design of a barrier in terms of its size (height, width) and position. The demonstration of the effectiveness of a noise barrier is very useful especially in cases where noise barriers have to be provided near to sensitive buildings such as hospitals and schools.

In this example, the effects of barriers are studied by building a 3D noise model of a small part of the study area, the noise levels are here for study purposes projected on the façades. Figure 6 shows the effects of seven different barriers on the noise variation on the building façades. The first three barriers (a – c) are of 3m height and are located at a distance of 3m, 6m, 9m from the edge of the road. The next three barriers (d – f) are of different height ranging from 2m, 3m and 4m and are located at a equal distance of 5m from the edge of road. The last barrier g is located in front of an open terrain. Comparing the first three barriers (a, b, c), the barrier a is found to be most effective in reducing noise levels both in horizontal and vertical direction, thus it can be concluded that the barriers located close to the road are more effective than the barriers located far from roads. Comparing the second three barriers (d, e, f) it is found that the barrier f which is of 4m height is lightly more effective than the other barriers of 2m and 3m height. It implies that, as the height of the barrier is increased, the effect of barrier in vertical direction also increases.

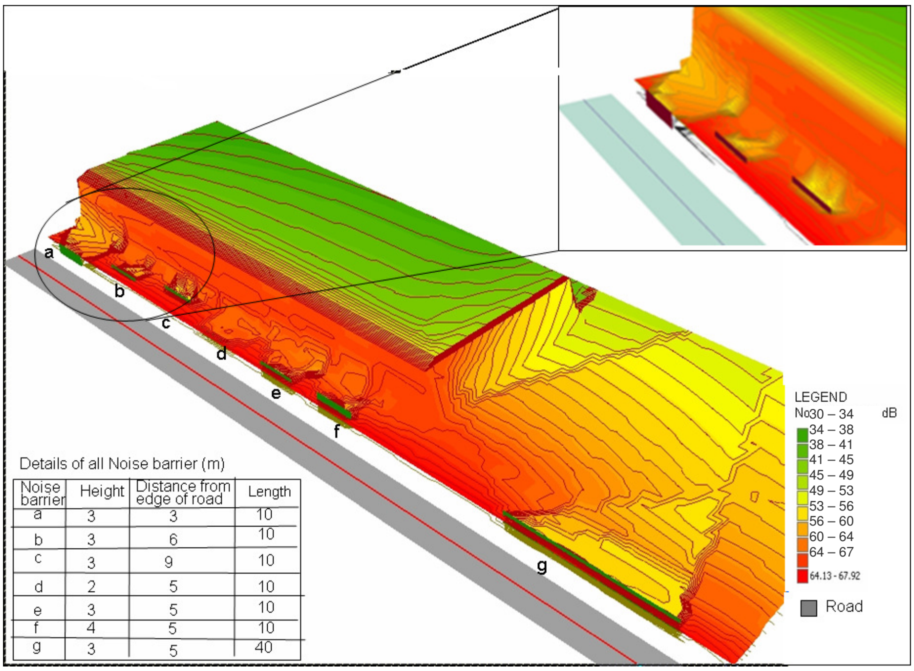

Fig. 6: 3D noise effects of noise barriers

The barrier g gives very clear effect of noise levels in 2D, but it cannot provide a vertical effect of the noise, this is the major disadvantage of projecting the noise levels on building façades. Combining this application with the previous on estimating the number of affected inhabitants an improved cost-benefit assessment of noise protection measures could be performed, as it easily allows relating the reduced number of affected inhabitants with the cost of a specific measure (e.g. a noise barrier of a specific height at a selected distance from the road).

6 CONCLUSION

This paper presented a 3D visualization of a noise map within an urban street canyon. The obtained visualization has the potential to be easier interpretable by the public using a more realistic visualization of the built-up environment using a complex 3D city model in combination with noise contours. The actual advantage of such 3D visualization over conventional 2D maps will need to be tested in real communication situations between planning professionals and the public. However, such visualization set for example in an easily accessibly environment as Google Earth that provide also information on the surrounding context could facilitate the communication process. Second within this paper two different analytical application of 3D noise models have been presented. Although the example of estimating the population affected by high noise levels used a simple approximation, it shows that the 3D noise model provides a more differentiated picture of the noise levels inhabitants are affected by as a function of the story they are living. In the second application the results show that such 3D noise models could be very useful in assessing the effectiveness of noise barriers. Here clearly the importance of distance to the road edge for improving the effectiveness of a barrier is illustrated. The distance shows a starker impact on the reduction of noise levels than the variations in height of the noise barrier. Combining these two applications could help in easily relating a certain protection measure e.g. its costs with its effectiveness of reducing the number of inhabitants affected by critical pollution levels within a cost-benefit analysis.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

BUTLER, D.: Noise management: Sound and vision. Nature, 427(6974): 480-482, 2004.

EUROPEAN COMMISSION: Directive 200249/EC of the European Parliament and of The Council, Luxembourg, http://www.imagine-project.org/bestanden/2002-49-EC.pdf (accessed, 30-08-2006), 2002.

HANZL, M.: Information technology as a tool for public participation in urban planning: a review of experiments and potentials, Design Studies, 28: 289-307, 2007.

KLOSTERMAN, R., and BRAIL, R. (eds.): Planning Support Systems: integrating geographic information systems, models, and visualisation tools, ESRI Press, California, 2002.

KLUIJVER, DE H. and STOTER, J.: Noise mapping and GIS: optimising quality and efficiency of noise effect studies, Computers, Environment and Urban Systems, 27(1): 85-102, 2003.

KURAKULA, V., STOTER, J.E. and KLUIJVER, DE H.: 3D noise models: a methodology to improve noise modelling and 3D visualisation of noise in urban areas, Coordinates, 3(12): 24-29, 2007.

MANTYSALO, R.: Approaches to Participation in Urban Planning Theories. In Zetti, Iacopo & Brand, Shira (eds.), Rehabilitation of Suburban Areas – Brozzi and Le Piagge Neighbourhoods, Dept. of Technology of Architecture and Design, University of Florence: 23-38, 2004.

NATIONAL ROAD AUTHORITY: Guidelines for the Treatment of Noise and Vibration in National Road Schemes. http://www.nra.ie/PublicationsResources/DownloadableDocumentation/Environment/file,1207,en.PDF (accessed 20-09-06), 2004.

VOSSELMAN, G., KESSELS, P. and GORTE, B.: The utilisation of airborne laser scanning for mapping, International Journal of Applied Earth Observation and Geoinformation, 6(3-4): 177-186, 2005.

VROM: Handleiding Meten en Rekenen Industrielawaai (calculation and measurement methods industry noise). Ministry of Housing, Spatial Development and the Environment, Den Haag, 1999.

WHO: Community Noise, http://www.nonoise.org/library/whonoise/whonoise.htm#introduction (accessed 20-09-06), 1995.

WHO: Guidelines for Community Noise, http://www.ruidos.org/Noise/WHO_Noise_guidelines_contents.html (accessed 15-11-06) 1999.