A COMPUTER SYSTEM FOR DESIGNING NOISE RESISTING BUILDINGS

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Abstract. This paper proposes a computer aided system that will allow the design to respond to the predicted traffic noises associated with the given site. This system is a part of a comprehensive interactive system for Environmental Impact Assessment called IOTA. Designers can have real-time feedback on their designs with respect to the environmental impact from the IOTA. Traffic flow, traffic speed, percentage of heavy vehicles, gradient, site layout, etc. are implemented in this system. The noise level at the facade is computed in real-time. The designers can see the distribution of the noise level at the facade of the buildings in a 3D virtual environment while the buildings or the infrastructures are still evolving. It is envisaged that this system is not only good for the design of buildings but also good for the design of new infrastructures and town planning.

1. Introduction

People in the urban areas are constantly surrounded by many different kinds of noise in our living and working environment, such as road traffic, rail traffic, aircraft, pump houses, cooling towers, etc. Noise not only can cause annoyance to humans but also can induce more serious adverse psychological effects like hypertension and other mental illnesses. Noise can also cause physical damage to human hearing ability. Research in the UK has shown that noise of road traffic is the most bothersome among many kinds of noise sources (Langdon and Buller). From a designer's point of view, traffic noise is the most problematic of noise sources because noise is

CAADRIA '98 : Proceedings of The Third Conference on Computer Aided Architectural Design Research in Asia.
eds. T. Sasada, S. Yamaguchi, M. Morozumi, A. Kaga, and R. Homma
April 22-24, 1998. Osaka University, Osaka, Japan. Pp. 153-162

difficult to measure and predict. Its intensity varies with the distance between the source and the receptor as well as other environmental conditions.

In order to tackle the problem of noise, different measurement methods and prediction methods are developed. Measurement methods are only relevant for existing situations, whereas prediction methods can be used for both existing and planning situations. As a result prediction methods are more suitable for decision making process. A variety of prediction methods have been developed in various countries because of different environmental contexts, different standard requirements and many other reasons. Most of these prediction methods are employed by the planning bureaus or the environmental protection bureaus for evaluating the expected impact of the new structures on the surrounding environments. They do not play any active role in the design process. Consequently prevention and noise protection mechanisms, being the remedial measures, may not be able to be incorporated into the original design concepts. It is envisaged that these mechanisms can be embedded in the design as integral parts of the structures if the designers can know the influence of the traffic and other noise sources on the building whilst in the planning stages.

As a result this paper proposes a computer aided system that will allow the design to respond to the predicted traffic noises associated with the given site. This system is a part of a comprehensive interactive system for Environmental Impact Assessment called Interactive Optimization Tools for Architects system (IOTA) (Li and Will, 1997, Will and Li, 1997). Designers can have real-time feedback on their designs with respect to the environmental impact from this EIA system. Due to the interactive nature of the system and its ability to respond in real-time to the changes in the design plans, the system can be used at the early design stages and thus good designs with thorough consideration of noise reduction can be produced. Traffic flow, traffic speed, percentage of heavy vehicles, gradient of roads, noise shielding devices and site layout are implemented in this system. Later developments will allow the incorporation of other adjacent noise sources to be taken into account in addition to traffic noise.

2. Theories

The objective of this paper is not to propose a new prediction model but to make use of one of the existing prediction models in the design process. The modeling philosophy and some mathematical formulae adopted in this system are based on the model established by the Department of Transport in the United Kingdom, the CRTN. Some amendments are made on the on the calculation procedures so that these procedures can be carried out by the use of computers efficiently. A brief summary of the CRTN methods is described in this section.

The reference noise level used in this system is L_{10}(hourly) which is the noise level exceeded for 10% of the one-hour period. It is good for indicating the road noise at peak traffic flow. All the noise levels mentioned in this paper are all in L_{10}(hourly).

In this model individual vehicles are considered as moving point sources emitting spherical waves in the half plane above the road surface (Nelson, 1987). Under normal traffic conditions, individual point sources can be assumed to form a continuous line source such that the total acoustic power radiated is evenly distributed along an equivalent source line representing the trajectory of the traffic stream. The wave front is cylindrical in the half space above the ground plane. The source line is taken to be a line 3.5 m from the nearside edge of the road and 0.5 m above the road surface. In practice, a road scheme is divided into small number of segments such that the noise level within each segment is less (Tobutt and Nelson, 1990). Each segment is treated as an individual road source and the noise contribution of each segment is then evaluated separately.

The basic noise level hourly L_{10} in dB(A) for a given hourly traffic flow (q) at a mean speed of 75 km/h, with zero percentage of heavy vehicles (p), and zero gradient (G) at a reference point of 10 m away from the nearside edge of the road is given by Formula 1:

$$L_{10}(\text{hourly}) = 42.2 + 10\log_{10} q \ \text{dB(A)} \qquad \text{...... (1)}$$

where q is the hourly flow of all light and heavy vehicles.

Firstly, A series of corrections is then made on this basic noise level. The correction for percentage heavy vehicles (p) and traffic speed (V) is determined by the Formula 2:

$$\text{Correction} = 33\log_{10}(V + 40 + \frac{500}{V}) + 10\log_{10}(1 + \frac{5p}{V}) - 68.8 \ \text{dB(A)} \qquad \text{...... (2)}$$

The value of p is given by

$$p = \frac{100f}{q} \qquad \text{...... (3)}$$

where f is the hourly flows of heavy vehicles that is all vehicles with an unladen weight exceeding 1525 kg and q is the hourly traffic flow of all light and heavy vehicles.

The value of V depends upon whether the road is level or on a gradient. Some typical traffic speeds for different kinds of roads can be found from the CRTN. For the roads with a gradient a reduction (ΔV) which is given by Formula 4 will be applied to the traffic speed. This reduction is only necessary for roadways that are treated separately or for one way traffic schemes. This adjustment is only applied for upward flows. In the case where an actual estimate or measurement of speed of a road is obtainable from the highway authority, this estimate or measurement should be used instead.

$$\Delta V = [0.73 + (2.3 - \frac{1.15p}{100})\frac{p}{100}] \times G \text{ km/h} \qquad \ldots\ldots(4)$$

Secondly, adjustments accounting for the effect of propagation are then made on the basic noise level computed using the procedures described above. The distance correction given in Formula 5 is applied on the basic noise level.

$$\text{Correction} = 10\log_{10}(\frac{d}{13.5}) \text{ dB(A)} \qquad \ldots\ldots (5)$$

where d = shortest slant distance from the reception to the road source line

Having applied the distance correction it is necessary to consider the attenuation due to ground absorption or obstruction of barriers. For unobstructed road segments, a correction for ground absorption is applied; for obstructed segments, the screening effect of the barriers is considered. In the case where the source line is partially obscured by noise barriers or other buildings the noise levels assuming both obstructed and unobstructed propagation have to be calculated. The lower of the two resulting levels is taken. Formula 6 is the correction for the ground absorption effect in terms of the mean height of propagation (H), the shortest horizontal distance (d) and the proportion of absorbing ground (I).

$$\text{Correction} = \begin{cases} 5.2I\log_{10}\left(\dfrac{6H-1.5}{d+3.5}\right) \text{ dB(A)} & \text{for } 0.75 \le H < \dfrac{d+5}{6} \\ 5.2I\log_{10}\left(\dfrac{3}{d+3.5}\right) \text{ dB(A)} & \text{for } H < 0.75 \\ 0 \text{ dB(A)} & \text{for } H \, ? \, \dfrac{d+5}{6} \end{cases}$$

Valid for $d \, ? \, 4\,\text{m}$ …… (6)

The method used in CRTN for determining the attenuation due to screening by barriers is based on the functions developed by Fisk (1975) upon the semi-empirical relation established initially by Maekawa (1969). The degree of screening is calculated from the path difference (δ) of the diffracted ray path **STR** and the direct ray path **SR**, i.e. δ = a + b – c, as illustrated in Figure 1.

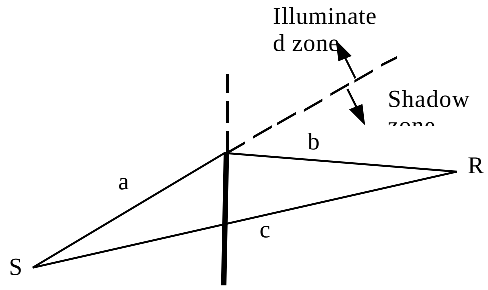

Figure 1. Geometry for determining path difference (after Fisk 1975)

The potential barrier correction is then calculated by the polynomial

$$\text{Correction} = A_0 + A_1x + A_2x^2 + \ldots + A_nx^n \quad \text{…… (7)}$$

where $x = \log_{10}\delta$

	Shadow zone	Illuminated zone
A_0	-15.4	0
A_1	-8.26	+0.109
A_2	-2.787	-0.815
A_3	-0.831	+0.479
A_4	-0.198	+0.3284
A_5	+0.1539	+0.04385
A_6	+0.12248	
A_7	+0.02175	
Range of validity	$-3 \le x \le +1.2$	$-4 \le x \le 0$

When x is out of the valid range, the potential barrier correction is defined as follows:

Shadow zone	Illuminated zone
For x < -3 Correction = -5.0	For x < -4 Correction = -5.0
For x > 1.2 Correction = -30	For x > 0 Correction = 0

Thirdly, the effects of certain site layout features, including reflection from opposite facades and size of segment, are considered. The correction for reflection from opposite facades is +1.5(θ’/θ) dB(A) where θ’ is the sum of the angles subtended by all the reflecting facades on the opposite side of the road, and θ is the total angle subtended by the source line at the reception point.

Before combining the contributions of noise levels from the source segments, the noise level for each segment is subjected to an adjustment, given by Formula 8, accounting for the size of the segment.

$$\text{Correction} = 10\log_{10}\left(\frac{\theta}{180}\right)\text{dB(A)} \qquad \ldots\ldots (8)$$

where θ is the angle of view subtended by the segment boundaries at the reception point.

Lastly, the contribution of noise levels from all the source segments is combined using Formula 9.

$$L = 10\log_{10}\sum_{i=1}^{n}\text{Antilog}_{10}\left(\frac{L_i}{10}\right)\ \text{dB(A)} \qquad \ldots\ldots (9)$$

where $L_1, L_2, \ldots, L_n$ are the n component noise levels contributed by n road segments

3. A computer system to calculate noise

The system is developed on the Silicon Graphics platform and is programmed with OpenInventor library and C++. The methodology of calculating the noise levels is primarily based on the methods summarized in the last section.

As all the computations are on a 3 dimensional basis, the user of the system must first of all input a 3D model of the site context. An interactive interface is provided for the user to input some parameters of the environment, such as traffic flow and traffic speed of the road segments and percentage of heavy vehicles and to define the site location. A maximum possible envelope of the building is then located at the site. Figure 1 shows a sample model of a site.

Figure 2

For each 3m x 3m area on the facade of the building a ray tracing technique is used to determine the direct noise sources, reflected noise sources and shielded noise sources. The basic noise levels, the corrections for the propagation effects and the corrections for the site layout are computed according to the results of the ray tracing. The expected noise level at that area of the facade is calculated by combining the basic noise levels and all the corrections for all road source segments. According to the expected noise level, the area will be filled with a color of red for noisy areas to a color of blue for quiet areas so that the user can observe the distribution of noise levels in a visual mode immediately from the monitor of the computer.

Unlike many other noise evaluation systems that can only evaluate one or a few reception points at a time, this system computes the noise levels on the facade of the building so that the designers can visualize the distribution of noise levels on the facade clearly, as shown in the Figure 3.

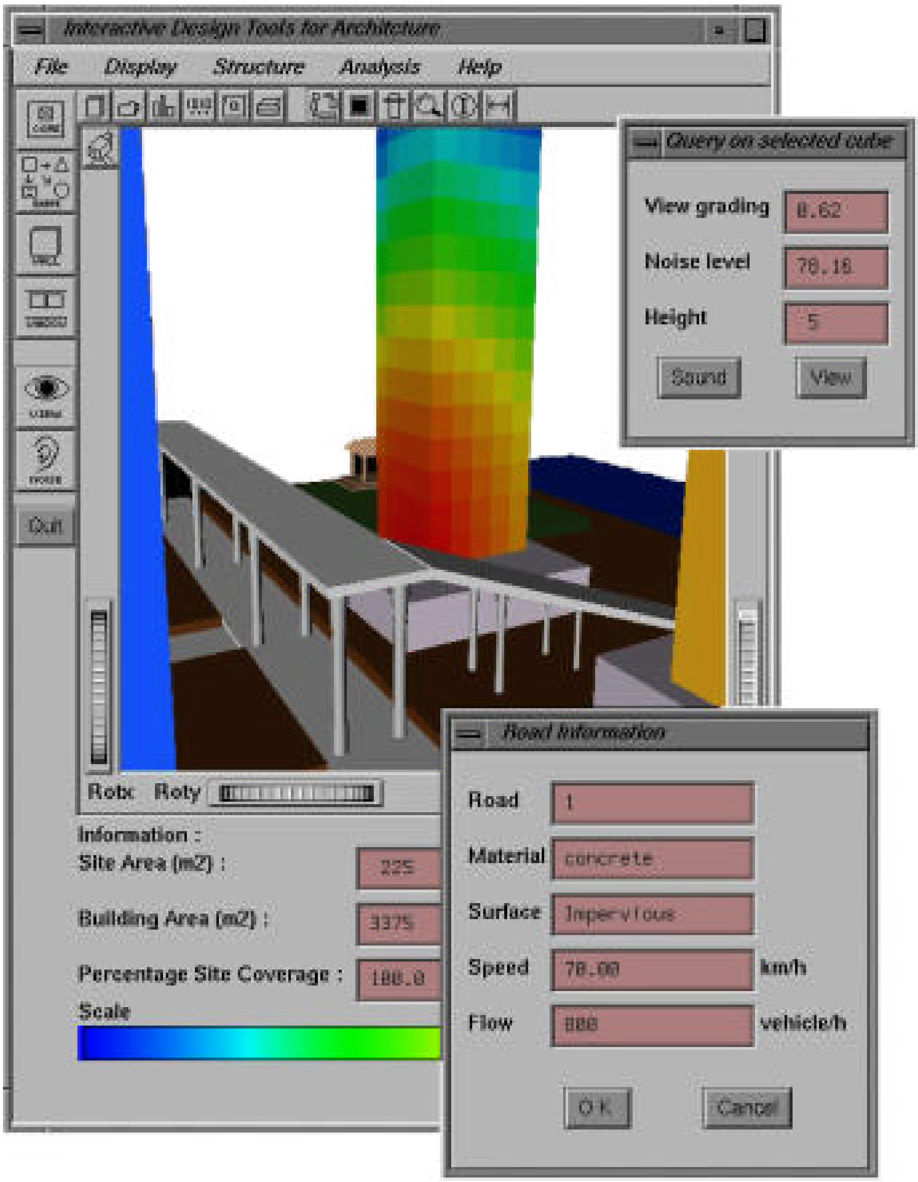

Figure 3

The interactivity property of the system allows the user to make amendments to the building under study. As a default a building of rectangular form is assembled as a stack of cubes. The user can remove unnecessary cubes from the rectangular block to form the shape that is required. When the basic 3D building form is established, the designer can then insert different elements such as slabs, windows, cores, internal partitions and noise barriers into the massing model. The result of the change can be seen immediately on the monitor whenever the user changes the design scheme. This feature promotes the use of evaluation procedures at the early design stages. It is thus envisaged that good designs with thorough considerations of traffic noise can be achieved.

Besides observing the colors on the building facade, the user can experience the virtual environment by walking-through the virtual environment. The audio functions of the system can provide the sense of noise. The user can also pick at any point on the facade to see a numeric readout for detailed calculations at that particular point.

4. Conclusions

Noise prediction methods have been developed in various countries for the assessment of traffic noise levels. In some countries, certain prediction methods are officially promoted or adopted by the public authorities responsible for land use planning and noise abatement design. The static forms these legislations invoke do not give an accurate picture of the complex problem of noise and its impact on buildings. This system is a positive steps in overcoming these problems and in allowing noise abatement measures to be integrated with other design aspects such as energy consideration, natural lighting, external facades and other important design parameters.

The main theme of this paper is to bring attention to the proper uses of evaluation systems as useful design aids during the design process. As a result the accuracy of the prediction model is not the major concern in this paper because no prediction model is absolutely correct. Using different prediction models may give different results, or applying the same prediction model to different situations may result in different answers. In most prediction models, changes will be made from time to time as collected data improves the accuracy. This system is readily able to adopt these evolutionary changes.

5. Further developments

As this is an ongoing project there are obvious areas for improvement. Firstly, a routine allowing the movement of elements in the site context will be implemented so that the system not only can be used for designing buildings but also can be used for urban design. Secondly, the system will provide a mechanism for changing the formulae of the prediction model such that the system can applied for the systems other than the British one and amendments on the prediction model can be updated easily. Lastly, the system will be ported to the PC platform.

Acknowledgements

This research kindly appreciates the help given by some student of Master of Architecture, 1997-98, from the Department of Architecture, the University of Hong Kong. Special thanks are addressed to Dr. Francis C. M. Lau, Department of Computer Science, The University of Hong Kong.

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