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Attenuation of Road Traffic Noise by Vegetation in Urban Spaces

The last decades of the 20th century and the beginning of the 21st century have been characterized by rapid urban growth of cities, which resulted in overcrowding and the lack of land. The aftermath of such circumstances is the construction of many buildings near the main roads and the bus stations, which causes population exposure to significant levels of noise. In the cities aimed at maintaining sustainable urban environment, greenery is a key element that can be used to approach this issue successfully. Green facades, also known as vertical greenery systems, are becoming increasingly popular in urban areas. Vertical green systems on the facade walls, low belts of green vegetation and trees of different heights, widths and lengths contribute to reducing the level of traffic noise. The ability of greenery to attenuate noise is greater with the increasing frequency of traffic. This paper describes the effects of certain types of vegetation on traffic noise reduction, depending on the parameters such as: the type of vegetation, the dimensions of the green belt, the distance from the noise source, frequency range, etc.

Keywords: *urban spaces, vegetation, traffic noise, traffic noise reduction*

1. Introduction

The change in the world population makes the process of urbanization one of the most significant global trends of this century. Cities and urban places have become the centre stage in global development. Urban city growth in the last decades of the 20th century and the beginning of the 21st century ignored the advantages of sustainable urbanization. The results of such a short-sighted approach are present nowadays: noise, pollution, congestion and the serious erosion of the quality of city life. The scarcity of urban land is the reason why schools, hospitals, commercial business centers, and other community buildings are built close to the main roads of the municipality without buffer zones. The constructions are erected near expressways or bus terminals, usually without adequate sound proofing. Road traffic noise is one of the predominant sources of annoyance without any other noise of comparable importance. In the European Union, more than 44% of the population was exposed to road traffic noise levels over 55 dB in 2000 [1]. For these reasons, the growth of road traffic and the construction of new roads have led to an ever-increasing problem of traffic noise pollution, and the need for ameliorative measures.

To overcome the problems of noise pollution, caused by rapid urbanization, noise barriers such as walls, fences or earth mounds are often used to reduce traffic noise pollution. Also, many vertical green systems placed on the facade walls, low belts of green vegetation, and trees of different heights, widths and lengths contribute to traffic noise reduction. During the last decades several researches were conducted proving that systems for greening the buildings envelope are not just surfaces covered with vegetation. Their aesthetical function is undisputable, but the technology involved in these systems can maximize their functional benefits as well. Namely, green walls can contribute to enhance and restore the urban environment and improve buildings performance, and above all they can contribute to noise attenuation.

The reduction of sound by vegetation is commonly attributed to the processes of reflection, deflection and absorption. Vegetation can reduce sound levels in the following manners: firstly, sound can be scattered or reflected by elements of the plant - trunks, branches, leaves or twigs. Secondly, vegetation can absorb sounds and due to mechanical vibrations of plant elements caused by sound waves, which dissipate the sound by converting sound energy to heat.

The focus of this paper is the attenuation of noise by vegetation. The effect of sound insulation by vegetation is rather small in urban environments, with the reductions ranging from 5 to 10 dB [3]. Other factors that influence noise attenuation by vegetation are multiple: the species, the screen dimensions, the shape and location from the noise source. The vegetation itself can reduce noise levels by up to 8 dB, and occasionally more [3]. Study of special characteristics of traffic noise attenuation by vegetation belts showed a significantly higher relative attenuation of more than 24 dB characteristically at 3.15 kHz at all the vegetation sites [4].

Kragh J. (1979) found that the sound levels from passing trains were determined to be 8–9 dB lower behind a dense, 15-year-old, 50 m wide tree belt which is made up of beeches, conifers, birches and elms, compared to grass-covered ground. There have been many investigations and measurement of road traffic noises at various locations 1, 5, 8, 10]. In the majority, the attenuations were found to be significantly higher through belts of trees and bushes when the frequency of noise went beyond 2 kHz [5].

When talking about the sound insulation effects of vegetation which is incorporated in city buildings, the studies usually emphasize the contribution of green roofs to noise attenuation. The references to green walls in terms of noise insulation are rather rare to be found and only few studies address the noise reduction that is provided by vertical greenery systems for buildings. Therefore, we must be aware of the fact that these constructive greenery systems are very different and that consequently, their acoustic behaviour will be very different [9].

2. Vertical greenery systems

Green walls comprise the vegetation growing on or against vertical surfaces. They can be divided in two main categories: green facades and living walls [6, 7]. In green facades, climbing plants grow along the wall and cover it, whereas in living walls, a wider variety of plants uniformly grow on the building surface.

Green walls may also involve stone walls, urban hedges, green screens, live curtains Green façades are made of climbing plants growing on a wall either independently, or with the help of stainless steel, wooden trellis or even cabling that would support plants. Figure 1 shows the classification of green walls, depending on their construction characteristics.

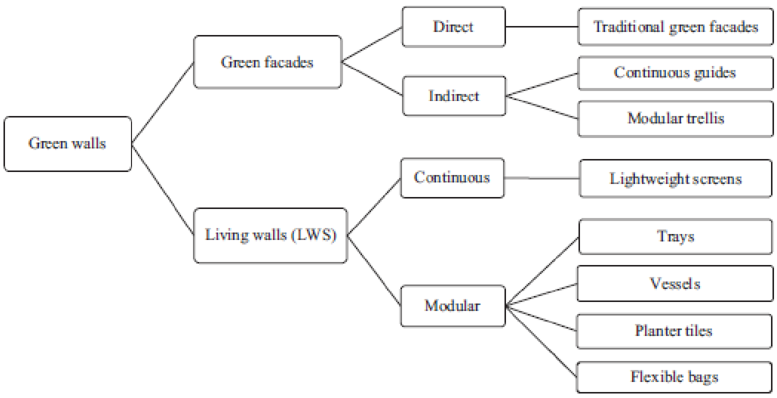

Figure 1. Classification of green walls, according to their construction characteristics [8]

Green facades can be classified as direct or indirect. Direct green facades are the ones where plants are attached directly to the wall. Indirect green facades usually include a supporting structure for vegetation, usually a vertical support structure for the development of climbing plants. Indirect green facades include continuous and modular solutions. Modular trellises have vessels for plants rooting and an individual support structure for guiding plants development.

The other type of green walls - living walls- enable a rapid coverage of large surfaces. The greenery that grows along the vertical surface is uniform, it reaches higher areas and adapts to all kinds of buildings. Living walls are completely artificial systems and they comprise of continuous or modular planted-up units. Continuous living wall systems can be made of felt-layers or be a block of concrete. Modular panels use modules of sphagnum, gabions, substrate filled metallic cage, plastic modules or rockwool units. Plants can be rooted directly in the structure (felt layers or sphagnum units) and in several kinds of growth media, before being added to the structure (concrete block, rockwool, plastic preformed module or gabion panel). Figures 2-5 show various forms of vertical greenery.

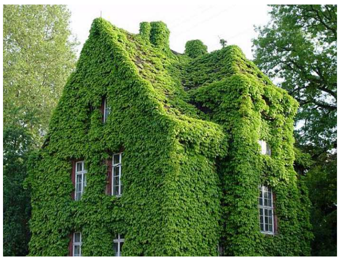

Figure 2. Direct green facade, private house

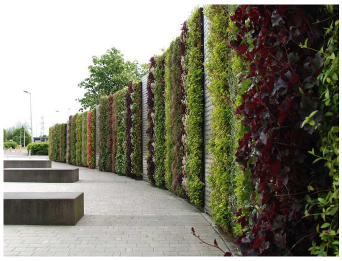

Figure 3. Indirect green facade

Figure 4. Continuous living wall system

Figure 5. Modular living wall system

1.1. Investigation of noise attenuation by vertical greenery systems

Road traffic noise is the most important and widespread environmental noise source in the urban environment.The research about the potential of building envelope greenery to achieve quietness in urban areas is rather limited; however, some references to the findings about acoustic benefits of greenery will be given in the lines to follow.

Wong et al. (2010) conducted a study to evaluate the acoustic impacts of different vertical greenery systems on the insertion loss of building walls. The results of this study show that the insertion loss shows a stronger attenuation to middle frequencies due to the absorbing effect of the substrate. A smaller attenuation is observed at high frequencies due to scattering from greenery. Taking into account that not all of the examined vertical greenery system exhibit good noise reduction, low to middle frequency range reductions (approximately 5–10 dB), were chosen to be measured. For the high frequencies, the insertion loss reductions ranged from 2 to 3.9 dB, except for one, which reached the maximum value of 8.8 dB.

The second objective of the Wong et al. (2010) study was to determine the sound absorption coefficient of a green wall in a reverberation chamber. This experiment confirmed that the sound absorption coefficient of the studied greenery system has higher values than those of other building materials and furnishings. Moreover, it can be confirmed that the absorption coefficient increases with increasing frequencies as well as with larger greenery coverage [10].

Van Renterghem et al (2013) also performed a numerical study of road traffic noise. Three types of theoretical measures were considered, including the measurement of green roofs, green walls and vegetated low-height noise barriers positioned near roof hedges. The conclusions of this study stated that the effects of wall vegetation strongly depend on the assumptions of the material parameters in the reference case [11]. If acoustically softer bricks were assumed, i.e., the use of a reflection coefficient of 0.82, the effectiveness of green walls is moderate since the maximum effect remains below 2 dB. Furthermore, there are some inconsistencies at very low frequencies since the absorption coefficients of the wall vegetation could be smaller than the measured absorption coefficients of the bricks. However, calculations using a reflection coefficient of 0.95 could be considered as providing the maximum possible effects - an insertion loss of 4.4 dB in the case of fully vegetative source canyon façades. This study indicates that the substrates used for green walls have a high porosity and low density; consequently they reveal a complex acoustic behaviour. Therefore, high absorption values at lower frequencies and strong variations in the absorption coefficient at frequencies above 0.500 (kHz) are not well-measured by the used model. It was also noted that the presence of water inside the substrate could strongly affect its absorption properties, and similar effects can be expected both for rigid material and for fully water-saturated porous medium.

According to Yang et al. ground media and vegetation play different roles in absorbing and scattering sound. With increasing vegetation coverage, the absorption coefficient increased by approximately 0.2 at low and middle frequencies. On the other hand, at frequencies greater than approximately 2 000 (Hz), the absorption coefficient slightly decreased by approximately 0.1. A stronger effect on the sound absorption and scattering by aboveground vegetation components (excluding the roots and soil) was found at higher frequencies, with increasing vegetation coverage. The maximum absorption and scattering coefficients of the studied aboveground vegetation were 0.49 at 5 000 (Hz) and 0.43 at 2 500 (Hz), respectively. In addition, a green wall with a highly porous substrate maintained a relatively high absorption coefficient (approximately 0.6) even though it was nearly saturated [12].

2. Noise attenuation by grass and trees

Research on sound propagation through trees and grass has shown that benefits from grass and trees in urban areas are not only aesthetic, but also acoustic. Grass-covered surfaces help noise reduction on railway lines. Traffic noise can certainly be attenuated by belts of trees. For this reason, numerous acoustical measurements have been conducted to prove that grass, trees and shrubs can absorb environmental noise. Trees usually reduce perception of noise by creating a visual barrier between the source and the hearer since people are less conscious of noise if they cannot see the source.

Michael [4] studied noise attenuation by grass and trees. The research shows that frequency and distance mainly influence excess noise attenuation by grass and trees (or forest) (Table 1). Measurement results obtained by Michael [4] can be used to make the following conclusions:

- Excess noise attenuation by grass shows rapid decrease at octave band centre frequencies of 31.5-8 000 (Hz), gradual decrease at 8 000-16 000 (Hz) and constant decrease above 16 000 (Hz).
- The difference in excess noise attenuation by grass, $\boldsymbol{\Delta L_g}$, between 100m and 50m; 150m and 100m; 200m and 150m increases from 3.5 to 5.8 dB at 1 000 (Hz) until a constant value of 5 to 7 dB at 16 000 (Hz) (Table 1).
- Excess noise attenuation by grass is more pronounced or highest at low frequencies and, as should be expected, increases with distance from the source.
- Excess noise attenuation by trees increases from 1.3 dB at 1 000 (Hz) to a constant value of about 4.0 dB at 16 000 (Hz) per same distance difference of 50m. From these measurements, it can be concluded that grass barriers are more effective that trees or forests noise barriers.

Table 1. Summary of excess noise attenuation by grass and trees (forest) at various octave band centre frequencies and distances [4]

Distance d (m)	Octave band centre Frequency f_c (kHz)	Excess noise attenuation, ΔL (dB)		Distance d (m)	Octave band centre Frequency f_c (kHz)	Excess noise attenuation, ΔL (dB)	
		Grass ΔL_g	Trees (forest) ΔL_t			Grass ΔL_g	Trees (forest) ΔL_t
50	1	2.0	1.0	150	1	9.0	3.8
	2	2.5	1.3		2	10.3	4.5
	4	3.0	1.5		4	12.5	6.0
	8	3.8	2.5		8	14.8	7.3
	16	4.3	3.0		16	17.0	9.5

100	1	5.5	2.3	200	1	11.3	5.0
	2	6.0	3.0		2	14.3	6.3
	4	8.3	3.8		4	16.0	7.8
	8	10.0	4.8		8	19.8	8.0
	16	10.3	5.8		16	22.0	12.5

Excess noise attenuation by grass, ΔL_g, and trees, ΔL_t were regressed on the octave band centre frequency, f_c, in order to establish the empirical relationships between them at various distances. These relationships can generally be expressed as follows [4]:

$$\Delta L_g = a_1(d) In\, f_c + a_o(d) \quad (1)$$

$$\Delta L_g = b_1(d) In\, f_c + a_o(d) \quad (2)$$

$$\therefore \Delta L_g = [2.31 b_1(d) I_n\ f_c + a_o(d)] \quad (3)$$

From equation (3), it is clear that equationa. (1) and (2) are similar. Also,

and $$\Delta L_t = m(d)\, f_c^n \quad (4)$$

$$\Delta L_g\ \Delta L_t = k \log f_c + k^1(d) \quad (5)$$

are functions of distance while **n** and **k** are constants having average value of 0.3333 or 1/3.
Equations (1) to (5) are the best relationships between the variables ΔL_g, $\Delta \boldsymbol{L_t}$ and $\boldsymbol{f}_c$.

Similar relationships have been found to exist between excess noise attenuation and frequency in Crocker and Kessler [13]:

$$(A^3)_{Shrubbery\ of\ grass} = (0.18 \log f\ 0.31) r \quad (6)$$

$$(A^4)_{Forest} = 0.01(f)^3\, r \quad (7)$$

where r is path length through shrubbery (or over grass) or forest in metres.

4. Conclusion

Noise pollution is becoming a significant environmental problem in rapidly developing cities. Traffic noise is the most rigorous type of noise pollution, being a consequence of inadequate urban planning of the city in the past. The problem has been emphasized by the alarming increases in traffic volumes and the number of heavy motor and other vehicles, which are far beyond the expectations of early urban planners.

To overcome environmental degradation, greenery on buildings is being consolidated as an interesting way to improve the quality of life in urban environments. Among the benefits that are associated with greenery systems for buildings, such as energy savings, aesthetic functions and biodiversity support, there is also noise attenuation. Applying building envelope greening aimed at mitigating noise pollution can, therefore, be considered as a highly sustainable goal. A question of main concern is what type of building envelope is most efficient to reduce noise.

Plants and trees have been used for years as barriers against traffic and other urban noise pollution. Green walls and green facades built on the exteriors of buildings insulate against noise, vibrations and reduce sound penetration in modern cities. Grass and trees are also considered a fairly good noise barrier. Grass introduces excess noise attenuation about twice that of forest at all frequencies, and they are used for noise control, especially at frequencies between 1 000 (Hz) and 4 000 (Hz) where the normal human ear is very sensitive. Excess noise attenuation by grass is more pronounced or highest at low frequencies. The findings from various studies confirm the contribution of increased greenery coverage to achieve noise abatement.

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