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# Innovative Approaches to Noise Reduction

*Mia Suhanek and Sanja Grubesa*

## Abstract

Nowadays, each individual is exposed to noise on a daily basis, and noise is often referred as in literature as a plague of modern society. Noise pollution is often overlooked when compared to other environmental pollutions (e.g. air, water, soil pollution). However, same as the all aforementioned pollutions, noise exposure has an accumulating character, meaning that the harmful effect of noise is detected only after a long period of time. Long exposure to noise pollution can be displayed as a bad mood, fatigue, insomnia, headache and loss of concentration, which causes reduced work ability and ultimately permanent hearing impairment. The goal of this chapter is to present two different approaches (traditional and contemporary) in noise reductions. The aim of both approaches is to link objective and subjective acoustic parameters, in order to plan future urban infrastructures while keeping in mind the existing acoustic environments, and to create and implement new solutions that will design, preserve and improve acoustic environments. Thus, we can conclude this chapter will be oriented towards human health and overall quality of life in terms of noise reduction.

**Keywords:** noise, noise pollution, noise reduction, acoustic parameters, noise barriers, soundscape

## 1. Introduction

Noise pollution is defined as any disturbing or unwanted noise that affects or deteriorates human or wildlife. Although noise constantly surrounds us, noise pollution generally receives less attention than, for example, water quality and air quality concerns, because it cannot be seen, tasted or smelled. Nonetheless, it is an indisputable fact that noise has a negative impact on everyday life especially if we observe urban areas. This chapter presents two ways of dealing with noise pollution in terms of reducing its levels. One is a more traditional approach and the other a more modern and very popular today with many directions and ways of implementations. The first major section will describe noise barriers with all their advantages and disadvantages, while in the second major section, soundscape approach will be discussed. The common goal of both approaches and of this chapter is to address the problem of noise pollution while bearing in mind the overall quality of life especially in urban areas.

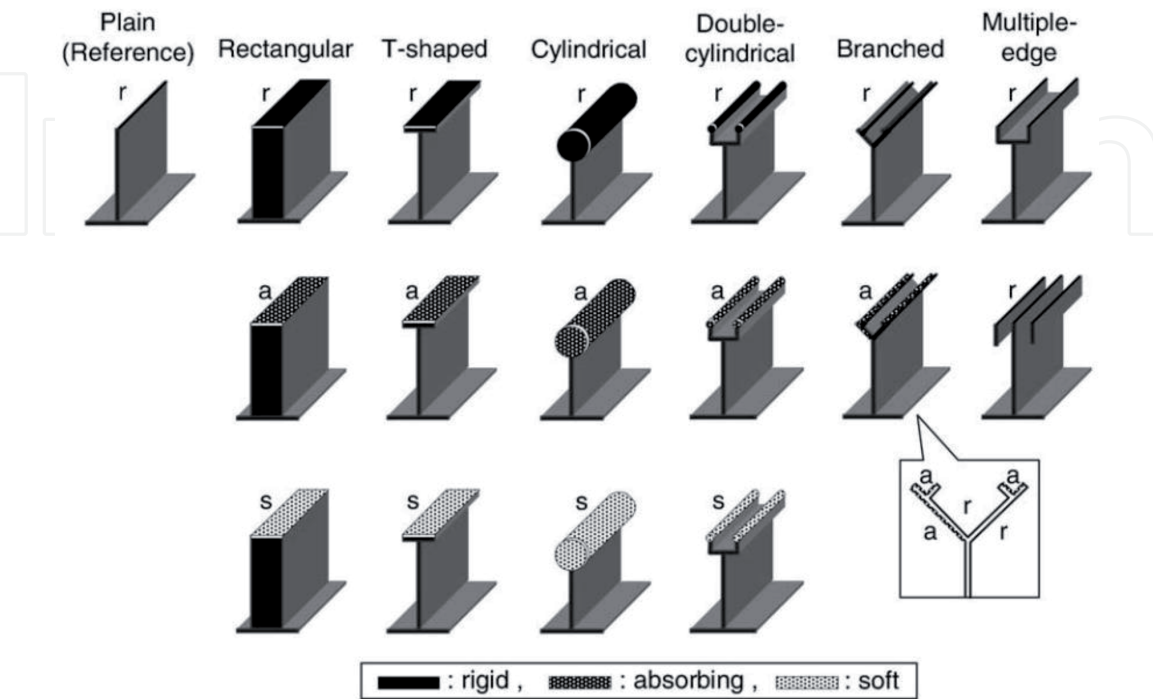
## 2. A traditional approach: noise barriers

In order to reduce noise pollution, different protection measures can be applied. In terms of traffic noise pollution, reducing the impact of traffic noise on both

people and the environments can be achieved by planning and integrating the traffic routes outside the residential areas. In case of existing traffic routes within the residential areas, a good solution for reducing the noise levels is noise barriers [1–3]. Here we note that the noise barrier efficiency depends principally on their design. In the field of noise barriers, it is already established that the most favourable noise barriers are those which have a diffuse element on the top. In addition, the diffuse element can be circular, is Y or T shaped and is usually added on the top of the plain barrier. In particular, the Y and T shapes have proven to be a very good choice for the shape of the diffuse elements [4–7]. Ishizuka and Fujiware [4] gave an extensive overview of the acoustic efficiency for several typical diffuse element forms placed at the top of the noise barrier. **Figure 1** shows a plane (reference) noise barrier and several other noise barrier types obtained by adding capes at the top of noise barriers bearing in mind that the caps are made of different materials [4]. The optimization of T-shape noise barriers was more thoroughly studied by Baulac et al. [5] and Monazam and Lam [6], while Grainer et al. [7] explored the Y-shape noise barrier optimization.

In Toledo et al. [8] a procedure was proposed for improving the acoustic efficiency of noise barriers using top-edge devices. Furthermore, in Toledo et al. [9] a procedure was developed for the optimization of well-based designs on the top of road barriers with both thick and very thin bodies by coupling a genetic algorithm with a 2D Dual BEM code. In addition, when placing a noise barrier in residential areas, studies have shown that it is also essential to keep in mind the “visual pleasantness” of the noise barrier which is the parameter introduced in Maffei et al. [10, 11].

Grubeša et al. [12, 13] have addressed the problem of economic feasibility of building noise barriers of various shapes and materials. Research and calculations done in this paper suggest a new specific noise barrier cost parameter ( $Ke$ ) that must be taken into account during the optimization process of noise barrier shapes and materials while using computational calculations and optimization methods.



**Figure 1.**  
Different types of noise barriers [4].

## 2.1 Noise level reduction with noise barriers

There are three basic parameters which describe noise barriers: insertion loss (IL), transmission losses (TL) and barrier absorption coefficient. Noise barriers can be defined as a certain sound “obstacle” between the sound source and the observer, i.e. the sound propagates around and over noise barriers. However, in real-case scenarios, the sound propagates also through the noise barrier, which is usually neglected, i.e. the sound proportion passing through the barrier is substantially smaller than the sound proportion which will cross over and around the noise barrier. The noise level reduction achieved by the installation of noise barriers is often called an additional noise level reduction, since the noise level will be primarily reduced due to the distance from the source and the air absorption and furthermore because the noise barrier itself. When quantifying noise reduction, a parameter, entered losses, is also often used and is defined as the noise level reduction arisen from the installation of noise barrier (insertion loss). It represents the difference between the sound pressures  $p_p$  and  $p_n$ , which are measured at the observer location before and after the noise barrier is placed, with the same ground configuration and position of the source and receiver, calculated according to the expression in Eq. (1). This parameter is usually used for comparison of different noise barrier performances:

$$IL = -20 \log \log \left( \frac{p_p}{p_n} \right) \quad (1)$$

The noise reduction parameter which arises from the installation of the noise barrier depends on the shape and material of the noise barrier, the frequency and type of sound source, the position of the noise barrier with respect to the source and the observer and the absorption properties of the soil on both sides of the noise barrier. The noise barrier effectiveness directly depends on the frequency of the sound propagating over it, and therefore the parameter insertion loss (IL) is also frequency dependent.

The noise barrier sound-absorbing properties are qualified according to EN 1793-1 [14], while the airborne sound insulation index which corresponds to the transmitted noise barrier losses is defined in EN 1793-2 [15].

## 2.2 Noise barrier types

There are three basic types of noise barriers. These are ground-mounted noise barriers, structure-mounted noise barriers and a combination of the first two types. Ground-mounted noise barriers are constructed of natural earth materials such as earth, stone, rocks or gravel. This type of noise barriers is typically constructed from excess materials in a noise-protected location, and source and availability of such natural materials are factors that can significantly affect the cost of such noise protection. Ground-mounted noise barriers take up more space than structure-mounted noise barriers. The reason for this is the slope of the embankment, which must gradually increase in order to maintain the stability of the whole structure. The increase is defined by the ratio  $m:n$ , where  $m$  is growth in the horizontal direction and  $n$  is growth in the vertical direction. For most embankments, the ratio is 2:1 or 1.5:1, while for stone embankments, the increase is usually 1:1.

Structure-mounted noise barriers or commonly called just noise barriers can be:

- Panel, shown in **Figure 2**.
- Brick and masonry, shown in **Figure 3** [16].





**Figure 2.**  
*Panel noise barriers.*



**Figure 3.**  
*Brick and masonry noise barriers.*

- Freestanding which can be:
  - Cast concrete at the installation site, shown in **Figure 4** [16].
  - Concrete blocks manufactured under controlled conditions then delivered and positioned at the installation site, shown in **Figure 5**.
  - Green vertical gardens, shown in **Figure 6**.

### 2.2.1 Panel noise barriers

Panel noise barriers usually consist of a board or panel, which can be wooden, metal or concrete, and it can be constructed out of one piece, or it can be assembled at the place of noise barrier installation from several components. The panels are



**Figure 4.**  
*Cast-in place noise barriers.*



**Figure 5.**  
*Precast concrete noise barriers.*





**Figure 6.**  
*Green vertical noise barriers.*

mounted between the base posts. The basic elements of this noise barrier type are the post and the elements which attach it to the foundation, the panels and the elements which attach the panels to the posts.

There are several ways to set up or build a foundation for posts:

- Reinforced concrete foundation with a post anchored to the top of the foundation using anchor bolts.
- Reinforced concrete foundation where the post is partially embedded in the concrete mass during concreting.
- Continuous foundation wall.
- Unreinforced concrete foundation with post submerged to full depth of foundation.
- Wooden posts dug into drilled cylindrical holes with stone fill.

### 2.2.2 Brick and masonry noise barriers

Brick and masonry noise barrier units are constructed out of either finished brick or masonry made of precast concrete blocks. Both types of noise barriers can

be built at the installation site (by hand or machine), or they can be prefabricated in the form of blocks which will be assembled at the installation site. The construction of the noise barriers at the installation site allows greater flexibility and better adaptation to the terrain on which the noise barriers are placed, while the advantage of blocks or modules manufactured in advance in a controlled environment is greater uniformity, better durability and regularly lower costs. A disadvantage of such blocks or modules is the need to allow access and space to work machines (e.g. cranes and transport vehicles) at the installation site area in order to enable the assembling of the whole noise barrier.

### *2.2.3 Free standing noise barriers*

Free standing noise barriers can be concrete noise barriers moulded at the installation site. The process of building them involves digging the ground for support, laying down a steel reinforcement, pouring concrete, surface treatment and concrete hardening. In this particular construction, the casting and later hardening of concrete are carried out in different weather conditions, which can affect the quality of the final product. The advantage of these noise barriers is the fact that the shape and method of installation can be fully adapted to the terrain, which is the reason why these noise barriers are most commonly used on bridges and viaducts. An additional advantage of such noise barriers is their high structural strength and resistance to damage, which is why, alongside the noise protection and reduction function, they are very often used as retaining walls for separating traffic lanes for safety reasons.

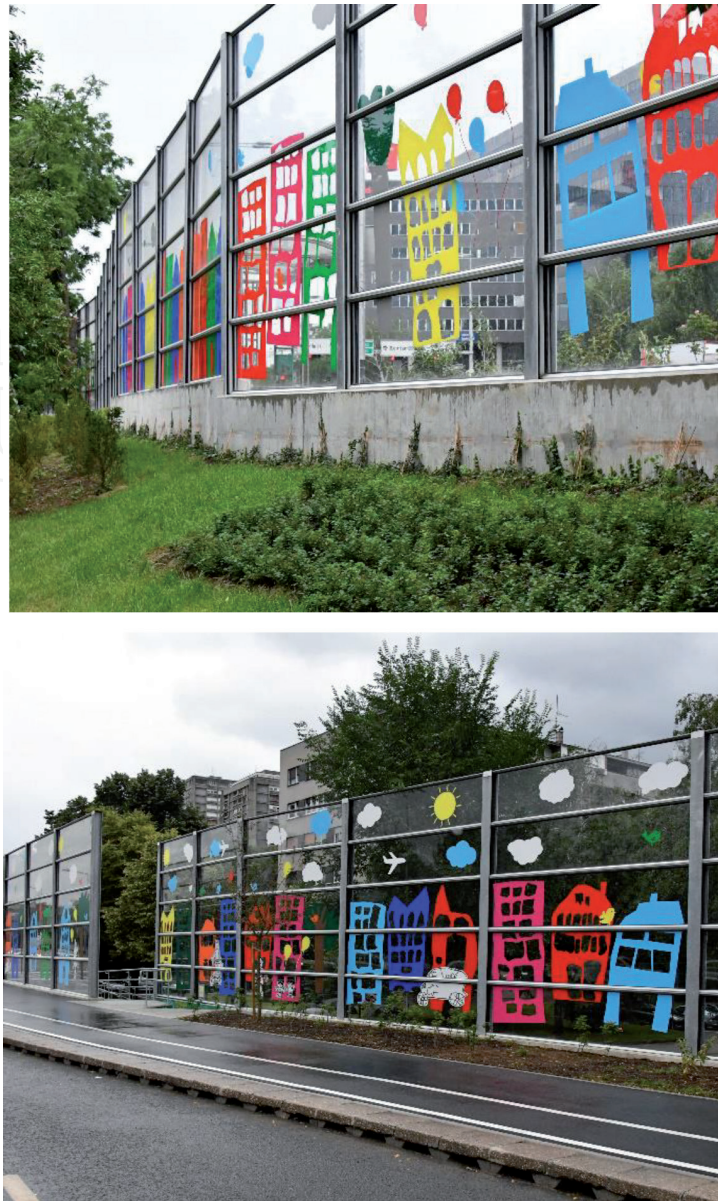
Free standing noise barriers can also be precast or premanufactured, i.e. concrete panels are factory-made under controlled conditions and then delivered to the installation site where they are installed (please see **Figure 6**). Furthermore, free standing noise barriers can be designed as green vertical noise barriers which are shown in **Figure 7**. Currently green vertical noise barriers are becoming more and more popular in cities because, in addition to reducing noise, they also reduce air pollution and they do not take up additional space, i.e. they are built into existing freestanding walls or facades.

To conclude, all of the aforementioned types of noise barriers are used as a measure of protection against traffic noise, while the choice of the noise barrier itself depends on the noise level at the location where the noise barrier is installed (i.e. acoustic properties of the sound source). In addition, the selection depends on the position of the noise barrier itself (distance of the noise barrier from the sound source and the receiver) and the allowed noise barrier height.

## **2.3 Material features**

The noise barrier construction can be made of different materials. It is possible to construct a noise barrier with only one material; however, more often the construction of noise barriers consists of several different materials. The choice of materials depends on several basic factors: acoustic properties, type and level of noise sources from which we are protecting a certain space, mechanical properties, aesthetic requirements on both sides of the noise barrier, regulations and the cost of an investment in noise protection for a certain space. In addition to the above-mentioned and described basic materials (concrete, metals, wood, etc.), sound-absorbing materials (e.g. stone wool) are often used in practical case scenarios. Such materials can be used as noise barriers' fill and with their sound absorption properties increase the noise barrier efficiency.





**Figure 7.**  
*An example of a transparent noise barrier on expressway.*

### 2.3.1 Concrete

Concrete is one of the most commonly used building materials. Concrete cast into blocks which are transported to the installation site or cast at the installation site is considered as one of the most durable construction. It is robust and can withstand high temperatures, strong sunlight, moisture, ice and salt. It is quite easy to shape and colour; thus, its appearance can vary. The versatility of concrete also relates to the shape and size of the slabs that can be produced (cast in place, prefabricated concrete blocks). In addition, concrete enables various installation techniques.

### 2.3.2 Metals

Three types of metal are most commonly used while constructing a noise barrier: steel, aluminium and stainless steel. Steel is the cheapest and most common of all metals used generally in construction. Thus, it is also generally used in the noise barrier construction, especially combined with concrete. Steel consists of a mixture of iron ore, coal and a small amount of other metals, while the ratio of the constituents varies depending on the desired physical properties.

For structures that require a slightly lower mass, aluminium is used, mainly as a light alloy with additives of manganese, silicon, copper and/or magnesium. Depending on the type of elements added to the aluminium in the alloy and their ratio, different mechanical, thermal, industrial and acoustic properties are obtained. Aluminium and its alloys are weatherproof and can be easily coated and anodized in different colours, making them suitable for installations with specific aesthetic requirements.

Stainless steel, which is a low carbon alloy with a minimum of 10.5% chromium, and is often mixed with nickel, molybdenum and titanium, is a very durable and resistant to corrosion due to its chromium alloy's ability to bind to oxygen atoms from the air, thus creating an invisible thin protective film on the metal surface that protects the metal from oxidation and damage. Since stainless steel is almost completely resistant to corrosion, its surface does not need to be coated or additionally protected and is often used in areas with high humidity, especially if the noise barrier is in contact with or near seawater.

Metal panels have a great advantage over concrete materials, which is their light weight. Their low weight makes them particularly useful for vertical extensions of existing walls, that is, for installation on existing retaining walls and for installation on bridges. Due to their simple manufacturing and easy assembly, either by attachment or welding, they are often used on bridges and viaducts attached to the existing load-bearing structural elements of the bridge itself.

### *2.3.3 Wood*

Different types of wood can be used in the production of noise barriers. The design range of constructions varies from simple, i.e. consisting of several wooden panels, to very complex structures made of multiple wooden pieces that can often be made of different types of wood. Wood is a natural, environmentally friendly material, which is very easy to process and has a low mass. Panels of wood that are creating a noise barrier parts can be installed piece by piece at the installation site or may be partially assembled on the ground prior to installation. Such noise barriers are easy to disassemble or remove, and the wood is from the aesthetic point of view, a very accepting and pleasing material to the environment. In addition, it does not conduct electricity. A significant problem with noise barriers made of wood is its flammability, and furthermore the smoke and gases resulting from its combustion are toxic. In addition to burning, the process of wood rotting in contact with moisture is very fast, which makes it necessary to protect it with a chemical preservative, which adds complexity to the process of producing the noise barriers and the need for more frequent maintenance. Wood products are not dimensionally stable and tend to change shape, which causes open cracks between joints, and the tendency to change shape increases with the dimensions of the wooden piece of the noise barrier itself.

### *2.3.4 Transparent panels*

Transparent panels can be made of glass or plastic materials, such as Plexiglas, Lexan, Acrylic, etc. which is shown in **Figure 7**.

Glass panels are usually made of tempered or laminated tempered glass. Tempering the glass strengthens the glass, and therefore such product becomes more resistant to breakage. If broken, the shards are small and grainy, with pieces generally no larger than 12 mm, which is far safer than knife-like shards that result from breaking glass that has not been heat treated. In addition to tempering, the glass panel can also be laminated. This type of glass is manufactured by inserting a translucent, rubber and flexible interlayer between the two tempered glass panels.

When such glass breaks, small granular fragments are formed which remain glued to the interlayer.

Transparent panels are ideal for reducing or completely eliminating the visual impact of a noise barrier; however, their costs can be 20 times higher than those made of concrete or steel. The justification for their high cost can be found in improving safety in places where opaque noise barriers can have a negative effect on visibility. These types of panels are more sensitive to damage from flying debris and abrasive action as a consequence of the sandblasting effect that is inevitably due to the swirling dust that is always present on the pavement layer.

2.3.5 Plastic

There are several types of plastic materials available and often used in the construction of noise barriers: polyethylene, PVC (polyvinyl chloride) and fibre-glass. Plastic panels can be installed in almost any situation due to their extremely low mass, easiness to mould and weatherproof features. Bearing in mind all of the aforementioned, they are increasingly used for the construction of noise barriers, especially those of a more complex shape. The problem with plastic materials is a slightly lower structural strength and flammability, i.e. the smoke and gases produced by the combustion of plastics are very toxic.

2.3.6 Composite materials

Composite materials for noise barriers can be defined as any product composed of two or more “basic” materials, for example, wood mixed with concrete and then placed on a concrete foundation. By combining basic materials, the characteristics of the final product (noise barriers) and its durability, and even in some cases safety, are altered.

Material	Thickness (mm)	Weight (kg/m2)	Transmission loss (dBA)
Concrete Block, 200 mm × 200 mm × 405 mm	200	151	34
Dense Concrete	100	244	40
Steel	1,27	10	25
Steel	0,95	7,3	22
Steel	0,79	6,1	20
Iron	0,64	4,9	18
Aluminium	1,59	4,4	23
Aluminium	3,18	8,8	25
Aluminium	6,35	17,1	27
Wood (Fir)	12	8,3	18
Wood (Fir)	25	16,1	21
Wood (Fir)	50	32,7	24
Plywood	12	8,3	20
Plywood	25	16,1	23
Glass	3,18	7,8	22
Plexiglas	6	7,3	22

Table 1.  
Approximate values of transmission loss parameter for different types of materials.



## 2.4 Noise barriers transmission loss (TL)

Typical values of the noise barriers transmission loss (TL) parameter when looking at the A-weighted characteristic are from 10 dBA to 15 dBA. Noise barriers should be constructed of materials with a minimum density of  $20 \text{ kg m}^{-2}$ . A density of  $20 \text{ kg/m}^2$  can be achieved by lighter and thicker or heavier and thinner materials (i.e. higher material density enables a thinner material). **Table 1** gives the approximate TL values for some common materials, tested for a typical A-weighted highway traffic frequency spectrum [16]. These values can be used as a rough guideline in designing noise barriers. For more accurate values, one would need to find material testing reports from authorised laboratories.

## 3. A contemporary approach: soundscape

The soundscape concept has been introduced to modify and complement the assessment of noise and its effects on humans. From the beginning, soundscape research has questioned the limits of existing acoustic measurements and the cultural dimension which Schafer included in his research for the first time in the 1960s [17].

### 3.1 Soundscape definition

A particular soundscape includes all the sounds from a certain acoustic environment received by the human ear. The first idea of soundscape was introduced by Schafer, in his book *The New Soundscape* [17]. His primary idea was to record a soundscape of the world in a form of a map similar to geographical maps. However, extremely rapid changes in the soundscapes have made this idea impossible to implement. Soundscapes, among other things, change rapidly due to the growth of the human population, people's migration and traffic increase. On the other hand, it is possible and of great interest to record current soundscapes.

The soundscape of a certain environment consists of various sound groups and sound sources. They can be divided into three major groups, biophony, geophony and anthrophony [17], which is shown in **Figure 8**.

Biophony are all the sounds produced by living organisms in their natural habitat (**Table 2**). It is by far the most complex feature of soundscape because it combines all biological sound sources, from microscopic to large fauna that live in a given environment for a certain period of time. In environments that are rich with different voices of living beings, organisms produce acoustic signals in different spatial relationships which can sound as one or more sound signals. Geophony are all-natural sounds coming from non-biological sources in a certain environment (**Table 2**). Generally, they can be divided into four types: the sound effects of wind, water, climate and geophysical forces. Anthrophony are all sounds generated by humans in any natural environment. This group includes sounds coming from people, music and traffic noise.

Bearing in mind all of the aforementioned, it can be concluded that the concept of soundscape as a field of research is extremely broad and requires a multidisciplinary approach. In studies and researches, apart from acoustic engineers, psychologists, physicians, builders, architects and sociologists should be involved.

**Table 2** shows sound sources or acoustic components and direct acoustic effects of non-anthropogenic sound elements (biophony and geophony).

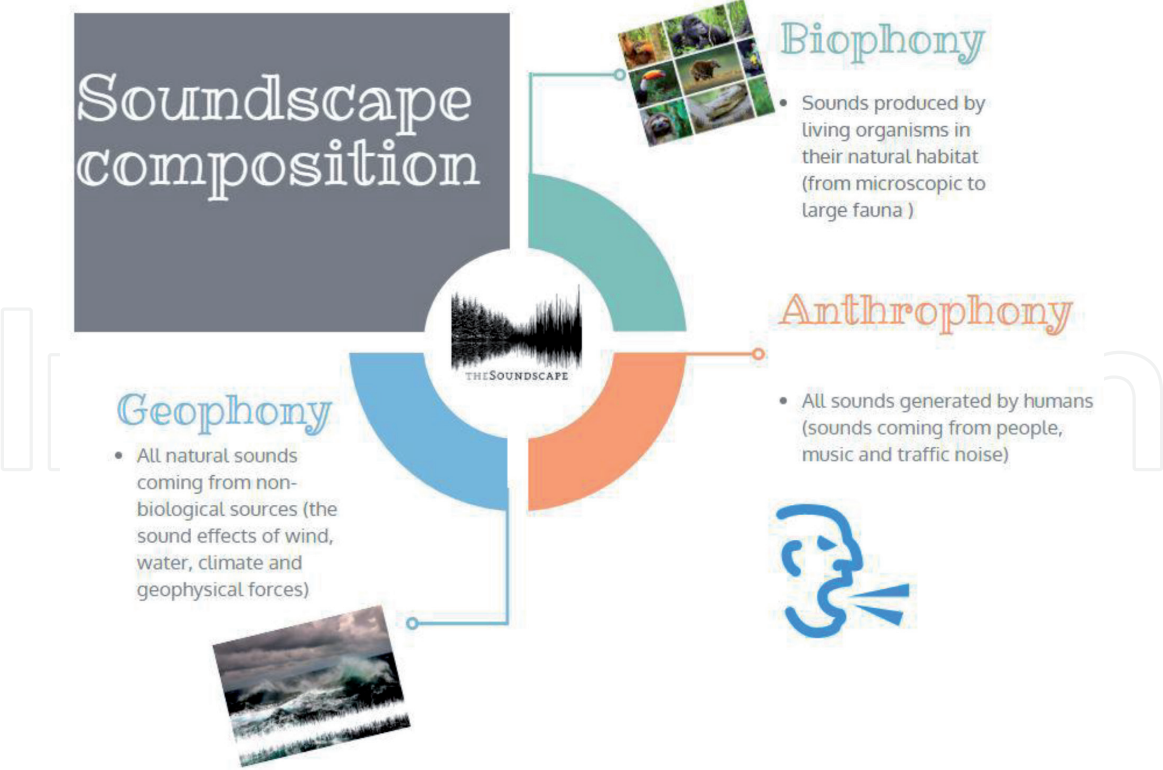


Figure 8. Soundscape composition.

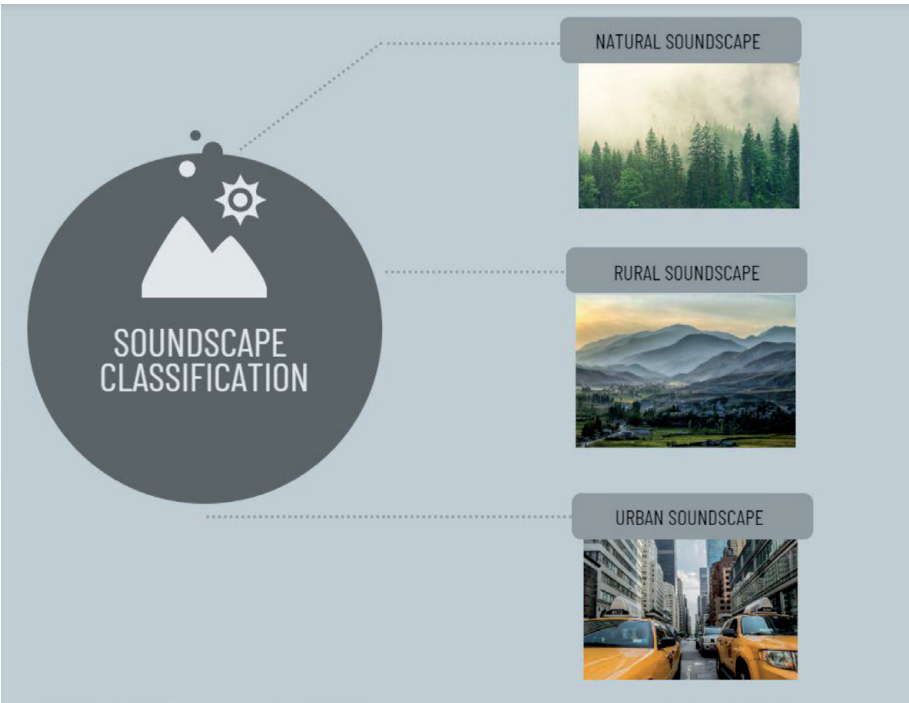
<b>Weather</b>
RS: wind, rain, thunder, earthquake, clouds
D: sound propagation, absorption, reflection, refraction, diffusion, diffraction, masking
<b>Animals</b>
S: sound of animals: birds, mammals, insects, reptiles, amphibians; moving of animals: running, flying, jumping, landing; non-voice expressions: moving of insects’ wings
D: sound propagation, masking
<b>Nature</b>
S: rivers and streams, waves, flux and reflux, vegetation excitation e.g. leaf rustle, falling of trees
D: propagation of sound, masking, absorption, reflection, refraction, diffusion, diffraction
<b>Terrain</b>
S: barriers, dams
D: propagation of sound, absorption, reflection, refraction, diffusion, diffraction
S—Sound sources or acoustic components and D—direct acoustic effects.

Table 2. Characteristics of non-anthropogenic sound elements (based on [17])

3.2 Soundscape classification

The most common soundscape classification is the one with respect to the related environment, and therefore we can distinguish them as follows (Figures 9 and 10):

- a. Natural soundscapes (e.g. marine, forest soundscape, etc.)
- b. Rural soundscapes.
- c. Urban soundscapes.



**Figure 9.**  
*Soundscape classification.*



A soundwalk is any excursion  
whose main purpose is  
listening to the environment.  
(Westerkamp, 1974.)

**Figure 10.**  
*Description of soundwalking (based on [18]).*

Considering the way and style of today’s life, it can be concluded that the urban soundscape is most explored and is changing in a fast pace. A city’s soundscape encompasses all three active components which describe a certain soundscape; however, the largest impact is anthropogenic, i.e. sounds generated by various human activities. Looking through history, after the industrial and electrical revolution, the look and sound of the city have changed remarkably. Today a similar thing is happening, however as a result of the accelerated construction work and overcrowding of cities. One of the biggest problems in the city has become noise, and the biggest source of this noise is traffic [19].

**3.3 How to record a soundscape?**

One of the possible ways to record a soundscape is the soundwalk method. *Soundwalk* method, as a concept, was first introduced by an urban planner Kevin



Lynch [20, 21]. His idea was to follow the usual routes which people use on their commute and which are specific to places of interest with the goal of “capturing” their soundscape. The usual recording of a soundscape has the duration of 30 minutes. The 30-minute choice corresponds to the distance a man would walk across in an average European city and, on the other hand, keeps a certain homogeneity as far as activities in that particular soundscape are concerned. Recording takes place several times a day, for several days, however always at a nice and dry weather. Depending on the research premises, the question how to exactly and accurately process the data obtained from the recordings remains. Although most scientists in their studies claim that the *soundwalk* “walks” lasted for an average of 15 minutes, it is possible to record soundscapes for a longer period depending on the focus and goal of the research. It is also possible to “cut” or shorten the longer soundscape recordings and apply other acoustic “tools” to the soundscape recordings.

The *soundwalk* method uses a recorder and a pair of binaural microphones places in the ears of the person who is performing the *soundwalks*, i.e. *soundwalker*. The *soundwalker*, as the name suggests, performs “walks” through a certain environment. The *soundwalker* needs to carefully breath while walking, and this kind of recording is performed normally in dry and sunny weather, unless we want to record a certain natural manifestation, such as rain. Recording is performed at the height of the walker (the binaural microphones are placed in the ears of the walker) and therefore the recorded signals are similar (at the highest possible level) to the signals heard by the pedestrians in that environment (**Figure 11**).

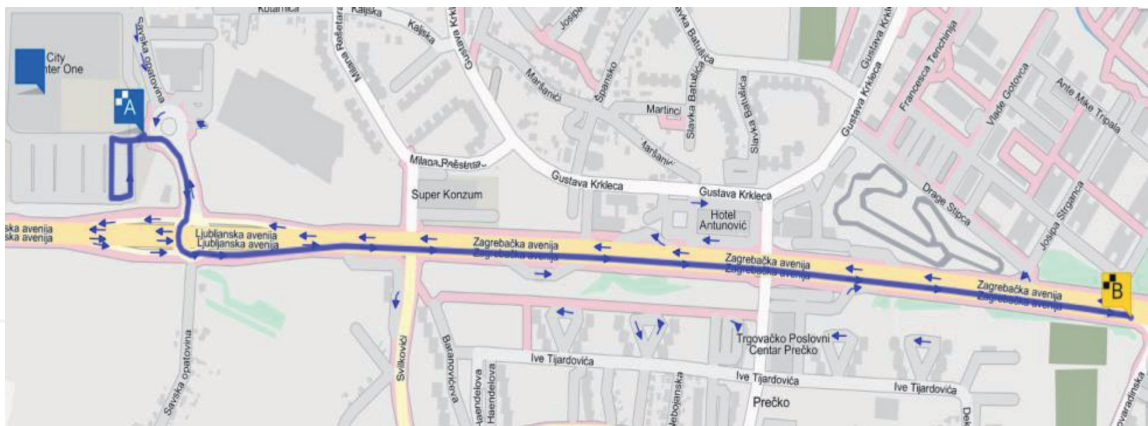
There is still no consensus among scientists regarding the recording length of the soundscape. Namely, there is no clearly defined time limit that would determine the difference between authentically play backed soundscapes while simultaneously avoiding the listener’s fatigue. Reproduction of soundscapes in terms of its length depends on the researcher and the purpose of his research from a few minutes to several hours.

### 3.4 Soundscape analysis

Alongside the soundwalk method, the researchers usually perform the analysis of the recorded soundscape with the “help” of the questionnaire which is again not defined by any standard or norm. The concept of the questionnaire, whose purpose is a detailed analysis provided by the listener, is not clearly defined, and moreover it depends again on research premises and focus [22–24]. Questionnaires vary from direct questions to listeners about the soundscape, requirements for a more detailed descriptions of the soundscape in terms of defining them as pleasant or unpleasant, attributes that may or may not be related to mathematical scales and adjective pairs that are not standardised so each researcher can use “their own” adjective pairs which they consider to best describe the soundscape and fit their research. An example of questionnaire [25] which uses bipolar adjective pairs is shown in **Table 3**.

**Figure 12** shows an example of performed soundscape analysis, in particular an expressway which stretches from the east to the west exit of the Zagreb, capital of Croatia [26]. To be more precise, **Figure 12** shows a photograph of the recorded location using the *soundwalking* method, the route of the *soundwalker*, the spectrogram of the recording and the sound sources which were characterised as distracting obtained through a specially designed questionnaire for that particular research [26].

To sum it up, the questionnaires are not an objective acoustic parameter; however, they present a good measure of the listener’s perception of the soundscape. A major problem is how to correlate such a subjective parameter with objective acoustic parameters, i.e. loudness, sharpness, roughness and fluctuation strength [27].



**Figure 11.**  
*An example of the soundwalker's route.*

Pair no.	Assigned bipolar adjective pair	Type of pair
1	quiet – loud	Auditory
2	deep - high-pitched	
3	diverse - monotonous	
4	pleasant - unpleasant	Emotional
5	dynamic – calm	
6	natural - artificial	
7	harmonious - chaotic	
8	appealing - repulsive	
9	soothing - stressful	
10	conspicuous – inconspicuous	
11	gentle – rough	

**Table 3.**  
*The adjective pairs used in questionnaire [25].*

3.5 Using the soundscape as a noise reduction instrument

The ISO 12913-1 standard defines soundscapes as acoustic environments “as perceived by people, in context”. Thus, nowadays more and more soundscape studies are oriented towards human health, well-being and overall quality of life [28–31]. In addition, the WHO Environmental Noise Guidelines for the European Region provide certain guidance on protecting human health from harmful exposure to environmental noise. The guidelines strongly recommend reducing the noise levels ( $L_{den}$  and  $L_{night}$ ) for the cases of environmental noise sources such as road traffic noise, railway noise, aircraft noise, wind turbine noise and leisure noise [32]. In the past the only possible approach to resolve this issue and reduce noise levels in an efficient way has been noise barriers which have been described thoroughly in previous sections. However, in order to construct and position an effective noise barrier, first one needs to have enough space for it, i.e. noise barriers can serve as a solutions only if they are planned before the actual building which is today a quite rare case scenario. In addition, if there is an opportunity to incorporate a noise barrier into an existing urban environment, researchers should take into account the “visual pleasantness” as well as the economic feasibility of the noise barrier.

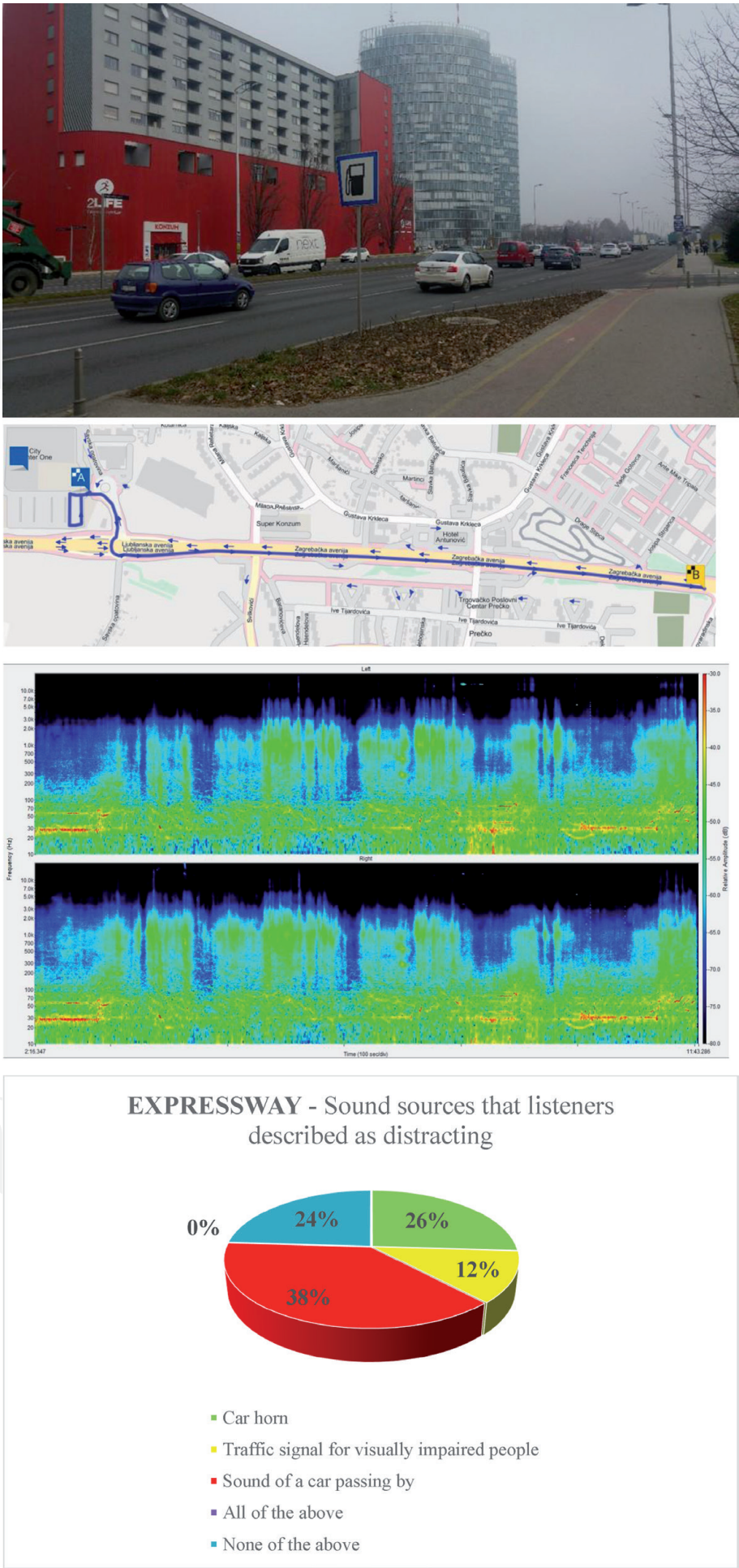


Figure 12.  
Soundscape analysis.



Finally the noise barriers as a solution are focused only on reducing the noise levels from traffic sources, while the common and final goal of the WHO and researchers, with different types of expertise, is to improve the overall quality of life by using different tools, guidelines, descriptors and an interdisciplinary approach by designing, preserving and investigating pleasant acoustic environments, i.e. positive soundscapes [33–36].

There are several paths where soundscape research can be used as an instrument for reducing noise pollution.

One of them is discovering what in particular makes a certain acoustic environment perceived as pleasant and then utilising those sound sources in negatively perceived soundscapes. Several soundscape studies have shown that the majority of population responds very well to the sound of water and birds singing, and therefore, those sound signals can be used for acoustic masking of unpleasant parts of other acoustic environments which may be rated as less pleasant [37].

When considering negatively perceived indoor soundscape, improvements regarding noise reduction can actually be achieved using specific acoustic absorptive materials and collaborating with architects regarding the layout of, e.g. open-space offices [38].

Another solution can be mixing soundscapes with music. Music is something that is deeply personal, something that consumes us, and it alters our mood. It can lift us up, it can comfort us, and it can make us feel calm and relaxed. Because of that recent studies show good results in creating innovative “music soundscapes” which can be a powerful tool for healing the people from a stressful and overvibrant urban everyday life. To be precise by installing special gazebos in urban parks and providing the user to combine the preferred music with an existing soundscape, one can create calming and relaxing zones that could provide a short music break from everyday obligations and help to endure the day in a better mood [39].

#### 4. Combining the traditional and contemporary approach

When considering only noise barriers as an instrument to combat noise and noise pollution, they have the ability to reduce noise levels by 3–20 dB. Over 3000 km of noise barriers have been installed alongside European rail networks. They are even more widely used alongside roads, including countries such as Austria, Denmark, France, Germany, Italy, Poland, Spain and Netherlands. Keeping that in mind, it can be concluded that noise barriers as a solution are mainly focused on reducing the noise levels from traffic sources, while the goal of the WHO and many researchers is to improve the overall quality of life by using different tools, guidelines, descriptors and an interdisciplinary approach by designing, preserving and investigating positively perceived soundscapes as previously mentioned.

For each noise barrier, its acoustic performance can be determined, as described in Section 2.1. Noise levels reduction with noise barriers. Here are some practical examples regarding the different performance of several noise barriers:

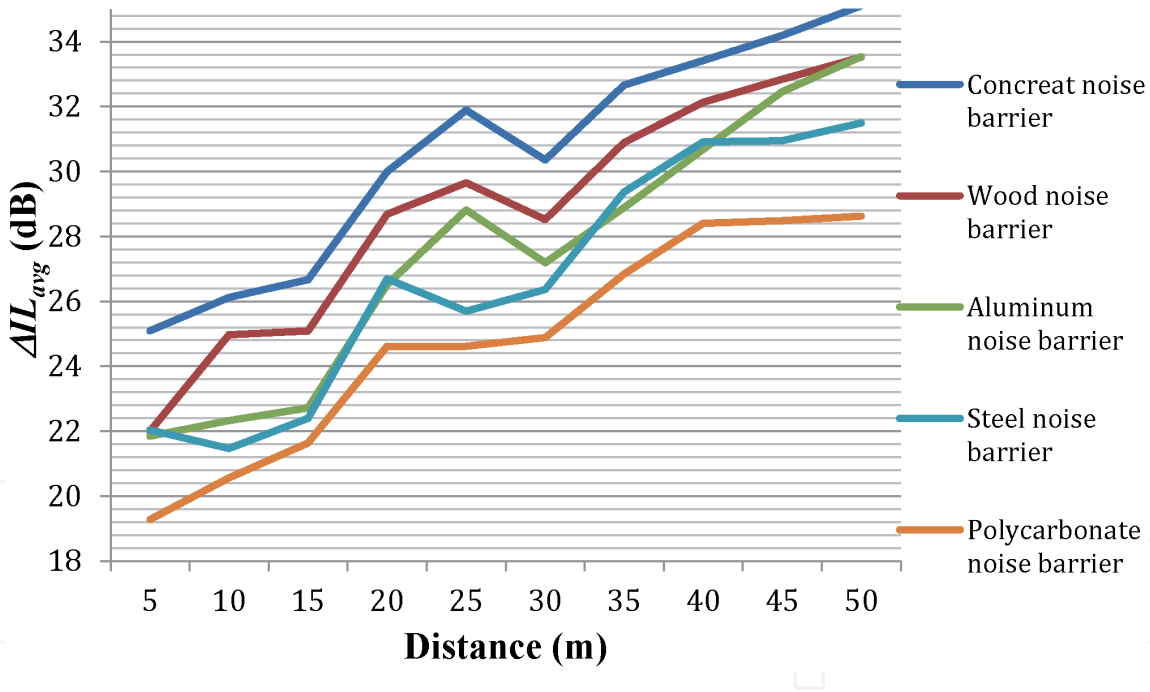
- First, the results obtained by simulation for five simple 5-m straight noise barriers (made of different materials) are presented. **Figure 13** shows the parameter of average noise reduction ( $IL_{avg}$ ) depending on the receiving position [40].
- In [41] insertion loss values at 1/1 octave band were calculated bearing in mind the noise barrier types, while the height of all noise barrier was fixed at 5 m and the receiver's position was 2 m from the noise barrier. Prediction of sound pressure levels for five types of road traffic noise sources attenuated by

different types of barriers was conducted using acoustic simulation software Enpro (Environment Noise Prediction and Design Program). Predicted insertion loss data is shown **Table 4**.

- In [42] a comparison of the obtained values for the green wall sound absorption coefficient and different common building materials was carried out (**Figure 14**).

In addition, for each type of noise barrier, its visual stimulus can be determined by using soundscape research which is described in [41] where images of five types of noise barriers were investigated. In the aforementioned research, timber, metal, transparent glass, vegetation and concrete barriers were created using Adobe Photoshop CS4 software. A viewpoint was fixed in order to avoid influence of view angles. Furthermore, small and large portion of ivy images were covered on the transparent and concrete barriers images in order to evaluate the visual effect of vegetation.

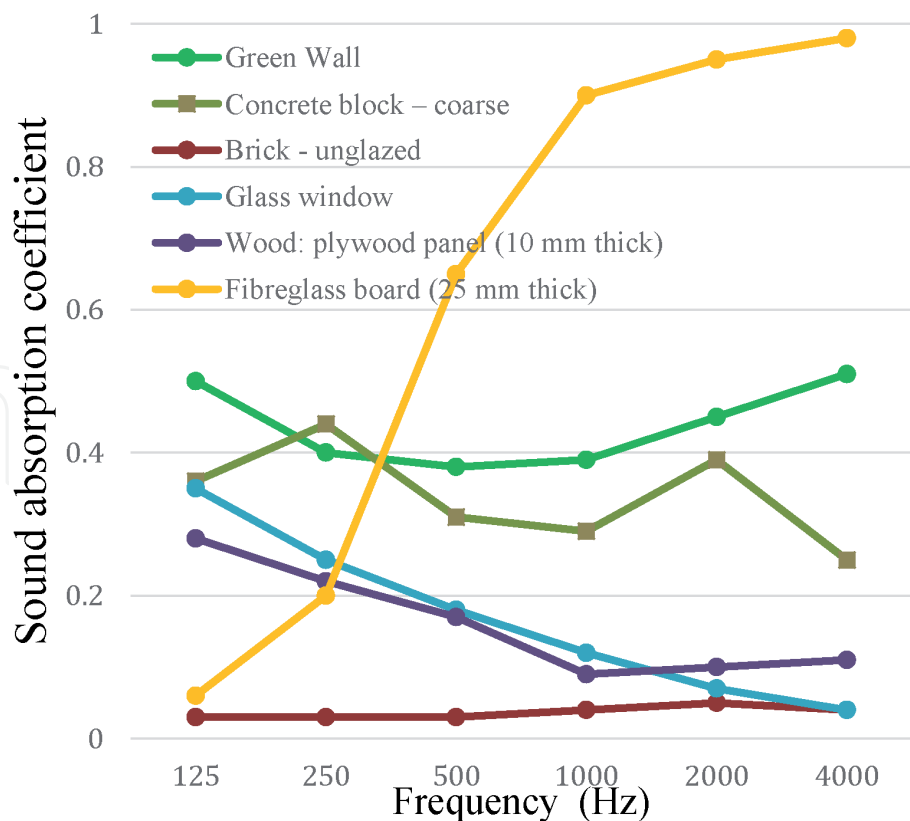
Furthermore, in [43] a case study is presented, where a sample of residents living close to a railway line assessed noise-related aspects for several barriers with different visual characteristics in an IVR laboratory test. In particular, three main factors were analysed: the barrier type concerning the visibility of the noise source through the screen, the visual aspect of the barrier concerning some aesthetic



**Figure 13.** Parameter of average noise reduction (ILavg) depending on the receiving position [40].

Frequency (Hz)	63	125	250	500	1k	2k	4k	8k
Timber	2.0	2.5	9.7	13.1	15.9	17.9	18.0	18.0
Metal	2.2	7.7	16.6	19.0	19.6	18.9	19.0	18.7
Transparent	2.0	3.4	7.8	12.7	14.7	14.9	15.4	15.7
Concrete	14.7	14.4	17.7	19.0	19.6	19.9	20.0	20.0
Vegetation	6.3	7.3	12.3	17.0	18.6	18.9	19.3	18.0

**Table 4.** Predicted insertion loss data [41].



**Figure 14.**  
*Comparison of sound absorption coefficient for the green wall and common building materials.*

issues and the noise level at the receiver concerning the acoustic performance of the barrier and the magnitude of the sound source. The main results of the ANOVA analysis showed that for transparent barriers, perceived loudness and noise annoyance were judged lower than for opaque barriers; this difference increased as noise level increased.

A much more effective way of reducing noise and noise pollution is to use noise barriers and soundscape together, by incorporating noise barriers, auditory ratings and visual assessment. Here we note that this way allows the design of better noise barriers and soundscapes and thus better acoustic urban environments. It has been proven that a noise barrier that better attenuates low frequencies such as a concrete noise barrier has a better acoustic rating. When considering user ratings, it has been proven in [41] that people respond much better to noise barriers made from natural materials and especially green walls, i.e. the visual pleasantness is much higher for that type of noise barriers.

To sum it up, the best way to tackle this burning issue, i.e. noise pollution, is the combination of both methods (noise barriers and soundscape research). Both methods complement each other in a very good and effective way while moving and in a way breaking the limitations which each individual method has.

### 5. Conclusions

In this chapter two different approaches for noise reduction have been described and discussed in detail. Finally, by comparing these approaches, it can be concluded that each one of them has its advantages, disadvantages and limitations. The final choice of noise reduction measure in most cases depends on the limitations regarding the location, cost, etc. It can be concluded that the best results regarding the reduction of noise pollution can be obtained by combining both described



approaches. The approaches work very well and effective together and, in that way, extend the limitations which occur when using only one approach.

Bearing in mind all of the aforementioned, urban planners, architects, doctors, psychologists as well as acoustic engineers should work together and benefit from each other's work with a common cause to improve the overall quality of life. By collaborating together, it is possible to reduce noise pollution and moreover improve the human health and well-being of the residents, especially the ones living and working in urban areas.

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