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Combined acoustical and economical noise barrier optimization using genetic algorithms

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Preliminary note

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Combined acoustical and economical noise barrier optimization using genetic algorithms

This paper studies noise barrier optimization using the Boundary Element Method (BEM) as a numerical technique and Genetic Algorithms (GA). Noise barriers are optimised according to acoustical, technological and economical properties so as to obtain an optimum noise barrier. In order to optimise acoustical and economical properties of noise barriers, the use is made of a genetic algorithm that forms a noise barrier out of given shapes. A new noise barrier evaluation parameter, named the noise barrier cost parameter (K_e), is also defined in the paper. Using the genetic algorithm and the noise barrier cost parameter (K_e), it is easy to create, develop and construct an appropriate noise barrier.

Key words:
noise barriers, optimisation, barrier acoustic-efficiency parameter, noise barrier cost parameter

Prethodno priopćenje

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Optimizacija akustičnih i ekonomskih značajki zvučnih barijera upotrebom genetičkog algoritma

U ovom radu proučavana je optimizacija zvučnih barijera pomoću numeričke metode rubnih elemenata i genetičkog algoritma. Zvučne barijere su optimizirane po akustičkim, tehnološkim i ekonomskim značajkama u svrhu dobivanja optimalne zvučne barijere. Kako bi se optimizirale akustičke i ekonomske karakteristike zvučne barijere korišten je genetički algoritam koji od danih oblika slaže zvučnu barijeru. U radu je definiran i novi parametar, nazvan parametar troška zvučne barijere (K_e). Primjenom genetičkog algoritma i parametra troška zvučne barijere (K_e) lako je stvoriti, razviti i konstruirati odgovarajuću zvučnu barijeru.

Ključne riječi:
zvučne barijere, optimizacija, parametar akustične učinkovitosti barijere, parametar troška zvučne barijere

Vorherige Mitteilung

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Optimierung akustischer und wirtschaftlicher Eigenschaften der Schallbarrieren durch Anwendung eines genetischen Algorithmus

In dieser Abhandlung wird die Optimierung von Schallbarrieren mithilfe der numerischen Randelementmethode und des genetischen Algorithmus untersucht. Die Schallbarrieren wurden gemäß den akustischen, technologischen und wirtschaftlichen Eigenschaften optimiert, um eine optimale Schallbarriere zu erhalten. Um die akustischen und wirtschaftlichen Merkmale der Schallbarriere zu optimieren, wurde ein genetischer Algorithmus angewendet, der aus den gegebenen Formen eine Schallbarriere zusammenfügt. In der Abhandlung wird auch ein neuer Parameter definiert, genannt Kostenparameter der Schallbarriere (K_e). Durch Anwendung des genetischen Algorithmus und des Kostenparameters der Schallbarriere (K_e) ist es leicht, eine geeignete Schallbarriere zu erstellen, zu entwickeln und zu konstruieren.

Schlüsselwörter:
Schallbarrieren, Optimierung, Parameter der akustischen Effizienz der Barriere, Kostenparameter der Schallbarriere

1. Introduction

Noise barriers are the most common way of reducing excessive noise levels in all sound emission areas, and are especially especially in cases when the noise sources are transportation noises. The continuously growing mobility of people and goods gives rise to surge in all means of traffic. Thus, traffic noise (from road, railway, air, and sea traffic) is one of the important issues affecting life quality in areas where noise values exceed the limits stipulated by legislative documents [1]. In general, the efficiency of noise reduction is calculated using the Insertion Loss (*IL*) parameter. This parameter is mostly dependent on the noise barrier height, and to a smaller extent on the cross-sectional shape and the shape of the noise barrier top [2-4]. Therefore, most of the nowadays research focuses on the optimization of the barrier's Insertion Loss parameter [5-9].

The main problem of most barriers with an optimized shape of cross-section, and even more with an optimized shape of their diffusive top element, is that the total cost of such barriers is usually completely neglected [5-8]. This is particularly emphasized in cases when these shapes are technologically very complex and pricy to manufacture or even more, if the materials are not especially cost-effective thus, making such a design economically not acceptable. In order to explain this in detail, we have to bear in mind that the materials used for the noise barriers manufacturing should have a sufficient sound insulation properties in order to prevent the noise from transmitting through the barrier to the other side. The sound reduction index and sound absorption index of barrier in octave band frequency range (125 Hz- 4 kHz) of interest in diffuse field conditions are often measured in laboratory conditions according to [10, 11]. The combination of parameters determined in laboratory conditions (sound reduction index, sound absorption) together with parameters determined in in-situ conditions (diffraction index according to [12] and reflection index according to [13]), have an influence on the insertion loss parameter at the site where the barrier is installed. Therefore, the dominant part of the noise energy from its source to the receiving location behind the barrier should always be the part diffracted around the barrier (usually over its top for long barriers) [14]. Furthermore, adding to that requirement the complex shape of barriers, which are technologically very complex and pricy to manufacture, we get a noise barrier design that is financially ineffective.

Noise barriers are always long (compared to their height) due to diffraction behaviour of sound waves. In real life, this can be noticed on highways and other high-speed roads where noise barriers can easily extend several hundred meters in length.

The efficiency of a noise barrier can also be increased by introducing active noise cancelation [15], although in that cases the efficiency is limited to a certain frequency range. Such solutions always introduce additional costs to the basic cost of the noise barrier. A certain improvement of the barrier's efficiency is gained also by adding various plant types to the construction of noise barriers and in that way increasing also its thickness [16]. This kind of improvement is also very limited and finally, it is very questionable if such solutions justify the increase of the total barrier cost.

Due to all the above mentioned reasons, this paper deals with the problem of economic feasibility of building noise barriers of various shapes and materials. Research and calculations done in this paper suggest a specific Noise Barrier Cost parameter (K_e) that must be taken into account during the optimization process of noise barrier shapes and materials while using computational calculations and optimization methods.

2. Numerical method for calculating efficiency of noise barriers

Several empirical expressions, as applied in various numerical models embedded in national and international standards and regulations, can be used to determine traffic noise levels at the receiving location [17]. The Boundary Element Method (*BEM*) is an efficient numerical method for calculating the barrier Insertion Loss (*IL*) parameter [18].

In this paper, BEM numerical methods are used for calculating the barrier Insertion Loss parameter. Assuming that the sound pressure is harmonically time dependent in each location of the calculated space, the sound pressure can be expressed according to eqn.(1):

$$p(x,y,z,t) = P(x,y,z) \cdot e^{j\omega t} \tag{1}$$

where *p(x, y, z, t)* is the sound pressure in time domain and *P(x, y, z)* is the pressure magnitude in three-dimensional space.

Furthermore, in order to obtain the sound pressure level in a single point, the homogenous Helmholtz equation has to be solved, as shown in eqn. (2) [19, 20],

$$\nabla^2 P(x,y,z) + k^2 P(x,y,z) = 0 \tag{2}$$

where k=2π/λ vis the wave number, anda λ s the wavelength.

The reason for using *BEM* is that barriers are easily meshable objects. Another important reason for using *BEM* is that usually only a half-plane in the two- or three-dimensional space is considered with a noise barrier, with a sound source on one side of the barrier, and one or more receiving points on the other side [20-23]. The final calculation was done using a computer application programmed in the C++ computer language, which is described in detail in [9, 24, 25].

3. The modelling method

Two main parameters (Barrier Acoustic Efficiency- L_{xi} and Noise Barrier Cost- K_e) are dependent on both shape and material. They are crucial in the barrier optimization process and are therefore considered and used in this paper. For practical reasons, the chosen barrier of known dimensions was divided into modules of pre-defined shape that can be manufactured in factory and easily assembled in-situ. All shapes and sizes were chosen after consultations with companies that have practical experience in noise barrier manufacturing. The second parameter, i.e. the Noise Barrier Cost parameter (K_e), considers the overall barrier cost, and mainly focuses on the newly designed algorithm for determining the noise barrier assembly optimisation cost at a certain location, by considering the complexity of its manufacturing process. Finally, both the Barrier Acoustic Efficiency parameter (L_{xi}) as a measure of the barrier's acoustic efficiency, and the Noise Barrier Cost parameter (K_e) as a measure of the barrier's cost, are used in Genetic Algorithms during optimization of the entire noise barrier.

3.1. The element shape

When defining basic module shapes required for assembling noise barriers, the main question is: "*Can the chosen shape be fairly easily manufactured at a reasonable price?*" Although it is well known that many optimization processes yield various shapes with maximized insertion loss [5, 6], they are often too complicated for manufacture using standard technological processes and materials. For this reason, only simplified modules, without highly complex shapes, were considered. In total, five basic shapes were defined. These shapes can be made out of six different but common materials (wood, concrete, aluminium, steel, plastic, and polycarbonate). Table 1 shows calculated values of the specific acoustic impedance for the materials most commonly used in noise barrier construction. It can be seen that the values of the imaginary part of the impedances are negative for these materials [26]. The impedance values are used for the simulation of acoustic properties of noise barriers in the BEM calculation. The choice of materials, as well as input parameters used for calculation of acoustic parameters, are discussed in more detail in our previous work [9, 25].

Selected shapes are shown in Figure 1 and marked as types A to E. The various shapes were defined by geometrical characteristics of the basic shapes, and the materials by their acoustic impedance, which is used in the numerical calculation process. It is important to know that all shapes exhibited the same basic dimensions, e.g. they were 0.5 meters high and 4.0 meters long, and they could be assembled in any position of the test barrier setup. The test barrier measured 16.0 by 5.0 meters. The overall thickness of the barrier was 0.3 meters which is actually larger compared to the commonly used standard barrier thicknesses. Furthermore, the objective was to ensure feasibility of a module such as type A, which has protuberances on both sides, and to retain a viable static capacity of such module. The only exception to this setup was the barrier module type E, which could only be assembled on the top of the barrier. Another important aspect is that the barrier bottom layer was always made of plain concrete (0.5 meters in height), which is a common foundation for any noise barrier assembled on real-life projects.

Type A module is manufactured by pressing and is defined by the following parameters: a half of the basic module thickness, the height of each candidate unit's protuberance on the module, and the length of each candidate unit's protuberance. A half of the basic module's thickness is predefined. In other words, the

Table 1. Specific acoustic impedances of materials most commonly used in construction of noise barriers [26]

Materials	**Aluminium**	**Steel**	**Prefabricated concrete**	**Wood - locust**	**Concrete cast in-situ**	**Polycarbonate**
Specific weight [kg/m^2]	6.53	10.59	310	38	500	15
Frequency [Hz]	**Imaginary part of specific acoustic impedance** [10^3 Pa s/m]					
125	-5.13	-8.32	-243.47	-29.85	-392.70	-11.78
250	-10.26	-16.63	-486.95	-59.69	-785.40	-23.56
500	-20.51	-33.27	-973.89	-119.38	-1570.80	-47.12
1000	-41.03	-66.54	-1947.79	-238.76	-3141.59	-94.25
2000	-82.06	-133.08	-3895.57	-477.52	-6283.19	-188.50
4000	-164.12	-266.16	-7791.15	-955.04	-12566.37	-376.99

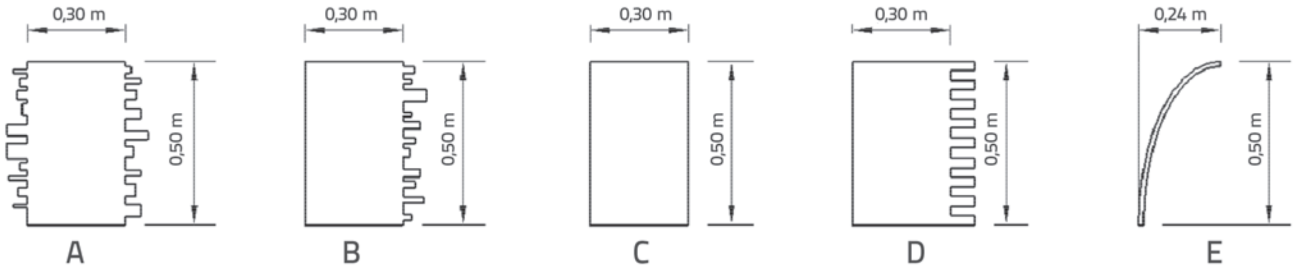

Figure 1. Cross section of all five module types used in barrier optimization process

Genetic Algorithm only changes the depth and length of module protuberance (see more details in Section 3.3). The phenotype F1 for this module type is represented with the number of protuberances (from 1 to N), the combination of their height ($h_{protuberance}$) and width ($l_{protuberance}$), and the materials the module is made of. Type A module can be produced from sheet aluminium, steel or plastic. Type B module is very similar to Type A, but one side is completely plain, without protuberances. It can also be made of aluminium, steel, or plastic. Type C module is completely plain, without any protuberances. It can be made of concrete, plastic, wood, or polycarbonate, and its thickness depends on the type of material. Type D module is a simplified version of Type A, with all equal dimensions of the protuberance. However, in this type, the protuberance can be rectangular or spherical in cross-section. Type E module is defined by its thickness and measures 0.5 meters in height. However, its gradient changes through Genetic Algorithm that randomly alternates chosen steps from 0.25 to 0.5 meters. It is produced by thermoforming or casting of plastics or polycarbonate.

3.2. Barrier acoustic efficiency parameter

3.2.1. Traffic noise spectrum

In order to be as close to real-life situations as possible, the sound source is modelled to emit a sound pressure level of 100 dB at one-meter distance in free field conditions at the frequency of 1 kHz. At other frequencies, the sound pressure level depends on the normalized traffic noise spectrum, as defined in Table 2. [27]. The calculations are made following this requirement with respect to the fact that the majority of traffic noise energy is located in the frequency range of around 1 kHz [27], which corresponds to the frequency range in which human hearing exhibits the highest level of sensitivity. It can be concluded that traffic noise components with frequencies between 500 Hz and 2 kHz are the ones that determine the total level of traffic noise. Therefore, the efficiency of the barriers has to be optimized for this frequency range. On the other hand, one of the goals of the car designing process is to reduce the traffic noise level and, in that way, to change its frequency spectrum so that it can be more acceptable [28, 29].

3.2.2. Acoustic efficiency of noise barriers

The acoustic efficiency of each candidate unit in each new barrier population is calculated by determining its barrier acoustic efficiency parameter (L_{xi}) for octave band frequencies between 125 and 4000 Hz. The calculation is based on our design of a *BEM* algorithm in a three-dimensional half-space for complex barrier design. The three-dimensional calculation model is shown in Figure 2 where the sound source is placed 5 meters in front of the barrier at the height of 0.5 meters. This height has been chosen as previous studies [30-32] show that the sound source of the combined rolling noise and engine noise is located at 0.5 meters above ground. Furthermore, the receiving points are found at the height of 0.5 meters from the ground level, which represents the worst case scenario when direct sound from the sound source is superimposed with reflection from the road surface in a frequency range where the traffic sound pressure has the maximum energy (around 1 kHz). The ground impedance is determined according to the Delany-Bazley model [33]. The impedance values for the ground on which the noise barrier is placed can be found in [25]. In calculations presented in this paper, it is assumed that the noise barriers are placed on the grass and that the surface below the source is asphalt, while that below the receiving points is grass. To calculate the barrier acoustic efficiency (L_{xi}), the average sound pressure level is calculated for receiving points that are located on a vertical line going through the centre of the noise barrier, 5 to 50 meters away from the barrier in 5-meter steps, also at 0.5 meters above the ground level. In this kind of case scenario, processing results enable us to obtain a significantly better and much more realistic overall view of the barrier compared to the usual observation of samples in several points of interest only. Furthermore, the optimization itself no longer depends on point positions and, therefore, optimization results do not depend on sampling point minimum and maximum positions.

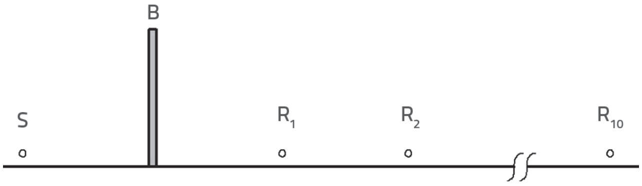

Figure 2. Graphical presentation of positions where: *S* is the source, *B* is the barrier, and *R* are receiving points for calculation

The evaluation of the barrier acoustic characteristics is based on the ΔL_{rel} value or, in other words, it is calculated as the difference between the average sound pressure levels for the reference plain concrete barrier L_{ref} and the simulated barrier L_{xi} as shown in eqn. (3):

$$\Delta L_{rel} = L_{ref} - L_{x_i} \tag{3}$$

Table 2. Normalized levels of road traffic noise L_i for one-third octave frequency bands [27]

f_i [Hz]	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
L_i [dB]	-20	-20	-18	-16	-15	-14	-13	-12	-11	-9	-8	-9	-10	-11	-13	-15	-16	-18

Table 3. Example of numerical values of coefficients for calculating noise barrier cost parameter

Module number	Module type	Module material	Characteristics of module [m]	K_m (material cost coeff.)	K_p (complexity coeff.)	K_t (transport cost coeff.)	K_e (noise barrier cost parameter)
1	C	aluminium	-	327	1	0.61	199.5
2	C	concrete	-	224	1	0.62	138.8
3	D	plastics	number of protuberances: 9 $h_{proturberance} = 0.028$ $l_{proturberance} = 0.061$	64	1.72	0.62	68.2
4	D	wood	number of protuberances: 5 $h_{proturberance} = 0.05$ $l_{proturberance} = 0.05$	214	1.6	0.63	215.7
5	D	wood	number of protuberances: 9 $h_{proturberance} = 0.028$ $l_{proturberance} = 0.05$	214	2.08	0.63	280.4
6	C	wood	-	224	1	0.63	141.1

3.3. Noise barrier cost parameter (K_e)

As stated previously, barrier cost is a crucial parameter when deciding whether an innovative design will be applied in real-life cases or not. However, the cost cannot be considered with usual Genetic Algorithms if it is not parameterized. Thus, the noise barrier cost parameter (K_e) has to have a numerical value, which directly depends on all noise barrier characteristics that define its price, and that can be calculated directly by an analytical expression. Therefore, a numerical procedure was developed based on research and discussions with noise barrier manufacturers, while keeping in mind all aspects that add-up to the total price of an installed barrier [9, 25]. This numerical procedure has resulted in a new optimisation parameter, the so called noise barrier cost parameter, (K_e). It represents the total cost of the barrier assembled at a chosen location. Furthermore, the noise barrier cost parameter (K_e) reflects the overall cost of placing the barrier in an area of interest, and depends on the overall product of two coefficients K_t (transport cost coefficient) and K_b (barrier productivity coefficient), as shown in eqn. 4. The transport cost coefficient (K_t) is proportional to the weight and volume of the barrier module. In most cases, modules measuring 4 m x 0.5 m are used for the barrier construction, and their volume is approximately equal. Thus, only the barrier's mass is used in budget calculations. The coefficient is standardized for a mass of 10,000 kg, and so the coefficient is dimensionless, and its values are used only for comparison between different barrier designs [9, 25].

$$K_e = K_t \cdot K_b \tag{4}$$

The barrier production coefficient K_b also depends on two other dimensionless coefficients, the material cost coefficient (K_m), and the production complexity coefficient (K_p), as shown in eqn. (5):

$$K_b = K_m \cdot K_p \tag{5}$$

A more detailed analysis and clarification of these coefficients is given in our previous work [9, 25].

An example of numerical values of previously defined coefficients is shown in Table 3. Each barrier is made of modules. The modules measure 4 meters in length and 0.5 meters in height, and can be manufactured using various materials (e.g. aluminium, concrete, plastics, etc.). In addition, the number of protuberances differs depending on the module type (see Table 3). It can be noted that, for the same type C module made of different materials, e.g. aluminium and concrete, K_m is larger for the aluminium thus influencing the total K_e coefficient (it is higher than the one for concrete, see rows 1 and 2). If we observe two modules of the same type D, both made of wood but the first having 5, and the second 9 protuberances, the one made of 9 elements will have a larger K_p, and also a larger K_e. Nevertheless, all other coefficients for these two modules are very similar to each other (see rows 4 and 5). On the other hand, if we observe two modules made of the same material, e.g. wood, but shaped into different module types, e.g. D and C, then K_p for the D type module will be larger than that for the type C module (see rows 5 and 6). After these observations, it can finally be concluded that the type of material greatly influences the total price of noise barriers. Furthermore, an even stronger influence is exerted by the shape of a module - the more complicated it is, the larger is the increase in the noise barrier cost parameter.

3.4. Use of Genetic Algorithm (*GA*)

To optimize a barrier, bearing in mind all important aspects, e.g. the barrier efficiency and cost, the newly introduced economic noise barrier cost parameter (K_e) must be considered, as well as the barrier acoustic efficiency parameter (L_{xi}). The Genetic Algorithm (*GA*) was developed and used for the numerical optimization method. The algorithm starts by selecting a starting population of the complex barrier, with each barrier consisting of 36 modules (9 x 4 modules while the tenth base module is the concrete foundation). Each module is randomly chosen by the algorithm. In real life applications, all modules would be placed between metal poles fastened to the concrete base, however, no reduction of Insertion Loss (*IL*) due to these poles was taken into consideration in the calculation. This can be practically achieved by applying appropriate sealing between the barrier's modules, and between the modules and the metal poles.

It is important to emphasize that the optimization algorithm considers both the acoustic performance of the barrier, and the noise barrier cost parameter for each barrier, i.e. for each candidate unit. This is analytically defined as a simple multiplication of the average sound pressure behind the barrier, e.g. the barrier acoustic efficiency parameter L_{xi} and the previously defined noise barrier cost parameter K_e, as shown in eqn. (6).

$$E_{x_i} = L_{x_i} \cdot K_e \qquad (6)$$

The resulting coefficient E_{xi} is the survival ability of each barrier, i.e. of each candidate unit for the Genetic Algorithm. Moreover, it represents the overall rating of the barrier.

4. Results and discussion

In order to compare the results to a reference case, all barriers (or, better to say, all candidate units) are compared with the simplest possible barrier, i.e. with a plain, precast, assembled in-situ, concrete barrier of the same size.

Furthermore, three starting populations varying in size are created in order to examine the influence of the number of candidate units on optimization results. The first, second and third populations (P1, P2, and P3) consist of 10, 20 and 40 candidate units, respectively.

First, the acoustic efficiency parameter L_{xi} for each barrier in all populations (candidate units) is calculated. The noise barrier cost parameter is also calculated for each candidate unit in order to obtain the overall barrier rating E_{xi} [9, 25].

Figure 3 shows values of overall barrier rating normalized with respect to overall rating of the reference concrete barrier. It can be seen in Figure 3 that the value of the overall noise barrier rating E_{xi} decreases with the number of optimization algorithm iterations, which means that both the acoustic and economic features of the noise barrier are improving with every optimization step.

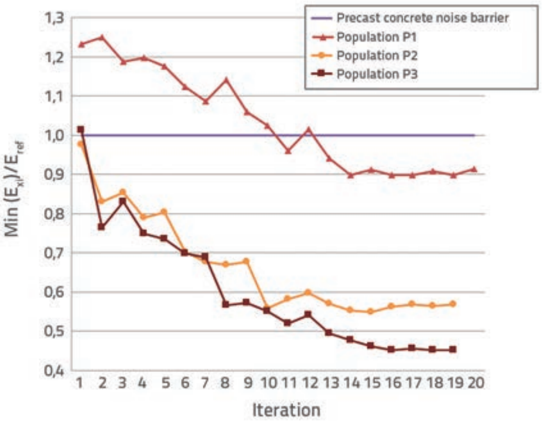

Figure 3. Normalized overall barrier rating with respect to reference concrete barrier for populations P1, P2, and P3

The barrier acoustic efficiency parameter is highest for population P3. At the same time, the overall barrier rating E_{xi} is the highest for this population P3. This led us to the conclusion that the number of barriers or, more precisely, candidate units, in the starting population directly influences the optimization limits. Therefore, population P3 was chosen for all comparisons of optimization results.

Figure 4 shows the average sound pressure levels, i.e. the barrier acoustic efficiency parameter L_{xi} relative to the distance from the barrier position for the reference concrete barrier, for the acoustically best barrier, and for the best barrier according to overall rating. The optimized barriers, keeping in mind both optimization premises, are considerably better than the precast concrete barrier, and the acoustically best rated barrier is, albeit to a minor extent, better than the best barrier according to overall rating.

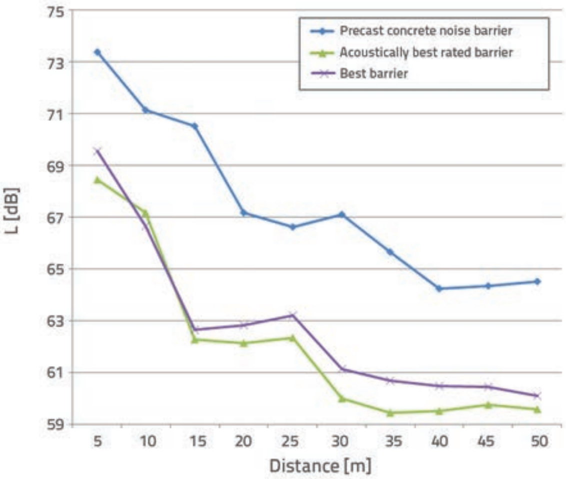

Figure 4. Average sound pressure level for reference concrete barrier, acoustically best barrier, and best barrier according to overall rating

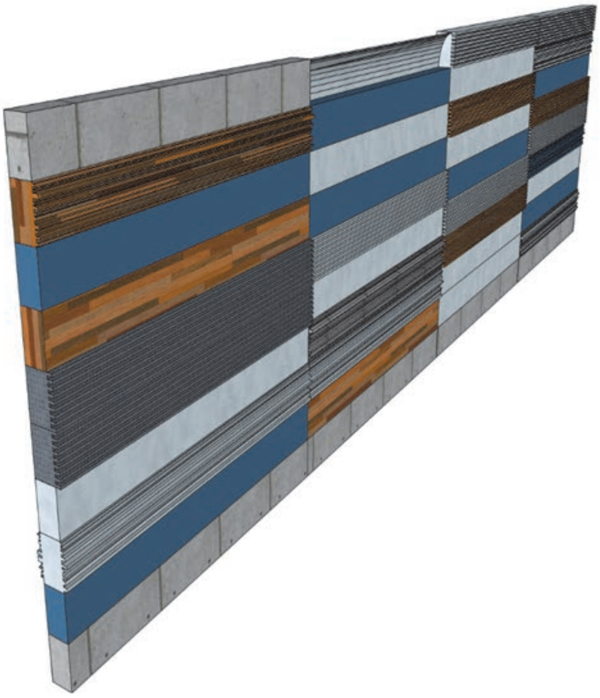

Figure 5. 3D visualization of acoustically best barrier

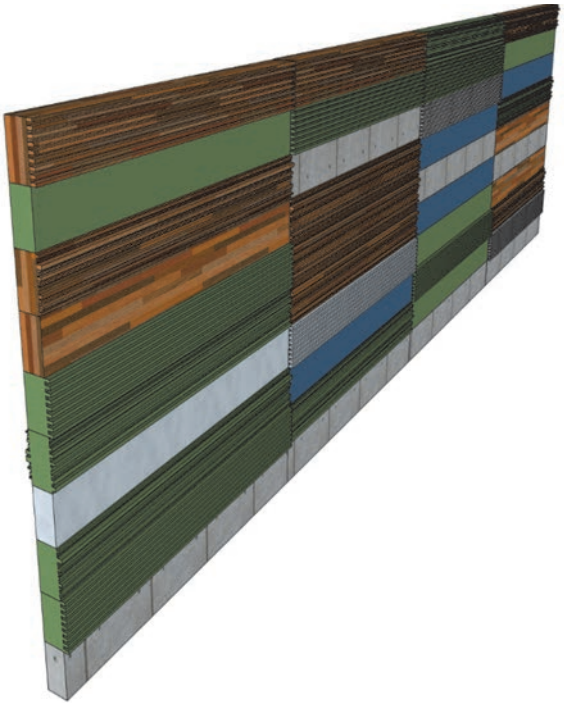

Figure 6. 3D visualization of best barrier according to overall rating E_{xi}

Figure 5 shows the 3D visualization of the acoustically best barrier, and Figure 6 the 3D visualization of the best barrier according to the overall rating E_{xi}. It can be noticed that the optimized barrier, according to the overall rating, has a much greater number of wooden (coloured brown) and plastic modules (coloured green). In addition, the overall noise barrier rating also considers the noise barrier cost parameter, and wooden and plastic modules are generally cheaper than modules manufactured using other materials (e.g. polycarbonate coloured blue, and aluminium coloured grey).

In order to test the results obtained with *GA*, three different barriers (precast concrete noise barrier, acoustically best rated noise barrier, and the overall best noise barrier) are placed at exactly the same place, near expressway passing through the city, for visualization purposes (as shown in Figure 7). The idea was to compare the barrier acoustic efficiency parameter L_{xi} and the overall barrier rating E_{xi} (which also covers the noise barrier cost parameter) for all three barriers, as given in Tables 4 and 5.

Figure 7. Location of noise barriers near expressway passing through city

Table 4. Barrier acoustic efficiency parameter

Distance from barrier [m]	10	20	30
Precast concrete noise barrier L [dB]	71	67	67
Acoustically best rated noise barrier L [dB]	67	62	60
Best barrier L [dB]	67	63	61

When considering only the barrier acoustic efficiency parameter, there is a significant improvement for the acoustically best rated noise barrier and the overall best barrier in comparison to the precast concrete noise barrier. On the other hand, the difference between the acoustically best rated noise barrier and the overall best barrier is not drastic (see Table 4). When comparing the overall barrier rating E_{xi}, the difference is significant for the best barrier, and the costs are reduced by 55 %. For the acoustically best rated noise barrier, these savings are somewhat lower, but are still significant (20 %), see Table 5.

Table 5. Normalized overall barrier rating with respect to reference concrete barrier

	E_{ref}	E_{xi}	E_{xi} /E_{ref}
Precast concrete noise barrier	401093	401093	**1.00**
Acoustically best rated noise barrier	-	320749	**0.80**
Best barrier	-	181138	**0.45**

When placing noise barriers as a means to reduce traffic noise in urban areas, significant savings can be accomplished if their acoustic and economic properties are taken into account. Such savings can be made by analysing the barrier acoustic efficiency parameter. This type of calculations can become an efficient tool for designing, planning and budgeting noise barriers all in order to minimize traffic noise in residential areas.

5. Conclusion

This paper studies barrier optimization using the Boundary Element Method as a numerical tool by introducing the Genetic Algorithms. The optimization procedure is done in a way to get acoustically, technologically and economically optimal barrier.

The used barrier models were modularly assembled from modules, defined from five different shapes and six different materials. It is important to emphasize that when deciding about the basic selected module shapes for assembling the barrier, the main argument was the simplicity in manufacturing a certain shape. Their setup was changed by the Genetic Algorithm in order to optimize their acoustical and economical features.

Furthermore, considering only the acoustical aspects, the best gained Insertion Loss was around 3 dB above the Insertion Loss of the reference plain barrier, while considering the economical parameters, an average Insertion Loss increase of 2 dB was still achieved. Results have shown that the size of the population is the most important parameter for the algorithm optimization. The improvement in Insertion Loss also depends on the location of the source and receiver in respect to the barrier and is of course very frequency dependent. Future research will be focused on the optimal shape and material combinations while taking into account position of a noise source and noise protected area. We also have to emphasize that the focus of this paper is designing and determining acoustical and economical parameters for noise barrier. Keeping that in mind, another aspect of future work can be a detailed analysis of barrier's maintenance cost.

This paper also suggests the introduction of a new noise barrier evaluation parameter, Noise Barrier Cost parameter, due to extensive research which has shown that it is one of the most important decisive factors when choosing and creating the noise barrier itself.

Nowadays, when noise and especially traffic noise are an increasing problem which directly influences the quality of life, not only in urban environments, it is necessary to use and develop all possible tools to minimize this noise. One of the most effective instruments for reducing noise are noise barriers. Using the Genetic Algorithm and the Noise Barrier Cost parameter it is easy to create, develop and construct the appropriate noise barrier while keeping in mind and respecting the original budget. Creating, developing and manufacturing these kind of noise barriers in combination, with designing pleasant acoustic environments (soundscape), can be the main tool for noise reduction in smart cities.

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