SOFTENING THE HABITATS
SUSTAINABLE INNOVATION IN MINIMAL MASS STRUCTURES AND LIGHTWEIGHT ARCHITECTURES

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Audiovisual comfort in shopping streets covered by structural skins

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Abstract

This article focuses on the prediction of acoustic conditions in wide shopping streets covered by transparent roof materials. This is done by analysing the impact of common glass and ETFE cushion systems on noise levels and sound reverberation. Research is done by simulation software, using a parametric study to deduce how architectural features influence the acoustic quantities. Three basic street models are tested: (1) a street without any roof, (2) a street with roof made out of ETFE foil and (3) a glazed roof. Firstly, the impact of roof (ceiling) elevation on sound pressure level distribution and reverberation time is analysed. Secondly, the impact of the shopping street (gallery) width on selected parameters is discussed. Analysis is done in detail, per octave band, in order to show the behaviour at low and high frequencies in the rooms separately. Lastly, recommendations are given for the optimization of acoustic comfort.

Keywords: acoustic comfort, daylight, structural skins, smart city, shopping streets, urban planning, protection of building monuments

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1. Introduction

Evolution of market places and shopping streets has a long history influenced by economic and societal evolution. The shopping streets in the 18th century had become important for the economy of cities, yet only little attention was given to the links between shopping and shops with the changing social, economic and physical structure of towns (Stobart, 1998). In the middle of the 19th century traditional open-air markets were very popular in the central squares of cities. These were later challenged by new urban concepts of the city centre, such as construction of market halls with fish markets etc (Toftgaard, 2016). One of the most influential factors in the urban planning of public spaces has always been urban traffic. The dominance of cars in the 20th century had a large impact on the urban development (Pooley, 2005).

In all probability the oldest of large shopping streets in Europe date from the 19th century. Most of them consist of a number of stores, nowadays accessible by public transportation. Examples of such historical places with a long standing tradition are the Avenue Montaigne in Paris, Bond Street in London and Bahnhofstrasse in Zurich. In the same historical period, many shopping galleries covered by a glazed roofing were built across Europe as well (complex of Galeries Royales Saint-Hubert in Brussel, Passage du Caire in Paris, Passage in Saint Petersburg and the Galerie Vittorio Emanuele II in Milano). These shopping galleries are covered along the entire length by glazed arcades, that contribute to changes in daylight quality and soundscape perception (when compared to uncovered streets or atria). Glass belongs to acoustically reflective materials, and its presence in rooms therefore contributes to an increase of noise and sound reverberation.

Nevertheless, glass is the most common roofing material when it is required that a construction is transparent (Polomová, 2013). Alternatively, tensile structures can be used that may bring many advantages for contemporary architecture in terms of indoor comfort. However, the impact of these structures hasn't been explored yet in detail (Vojteková, 2007). So far, the most appreciated features, such as light weight, thin layers, flexibility and innovative design options have been recognized not only in contemporary architecture, but also in restoration projects (Vojteková, 2018). More related to the matter of sustainability of light and ultralight structures, such as ETFE, can be found in Maywald (Maywald, 2016).

Preliminary case studies of large atria covered by an ETFE foil structure have shown a positive impact on acoustic conditions in- and outdoors (Rizzo, 2016; Urbán, 2017; Szabó, 2018). Concerning the room acoustics, it is known, that the influence of sound absorptive properties of building interior surfaces on noise is the most prominent in small rooms, where the density of sound reflections is high. In this paper, we focus on the analysis of acoustic conditions in relatively wide shopping streets, where the impact of glass and ETFE foil systems has not yet been investigated in detail. The parametric study reveals the influence of a roofing material in combination with a varying height and width of the shopping street with the same length of 100 m on the resulting acoustic conditions.

2. Description of the architectural case study

For the sake of understanding the influence of different architectural features and functions on acoustic situation in the shopping streets, a parametric study was performed for four virtual streets with different width and height of buildings. Cross sections of the street models for the four simulation cases are shown in the Fig. 1.

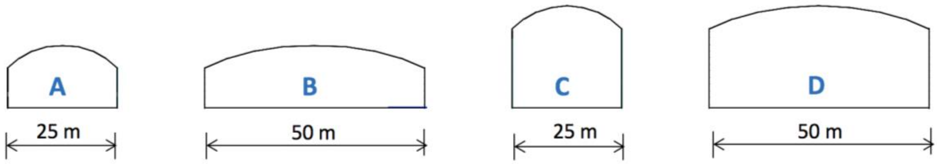

Figure 1: Four simulated shapes of shopping streets with the length of 100 m.

Variants A and C have the same street width of 25 m, and variants B and D are 50 m wide. In the first two variants (A and B) the streets are formed by buildings with the heights of 10 m, representing 3 storey buildings. In the variant C and D the surrounding houses are twice as high, i.e. 6 storey buildings. Each variant was simulated under 3 different conditions of roofing system: (1) open and thus without a roof, (2) an ETFE system, and (3) a glass roof.

All other surfaces in the simulation models (besides the roof) were the same in all variants. In the simulation model plaster was used as the finishing material of the building façade, the windows were simulated as ordinary double glass windows, and the road surfaces were simulated as an acoustically hard material, such as asphalt or concrete. An overview of the simulated models is shown in the Figure 2.

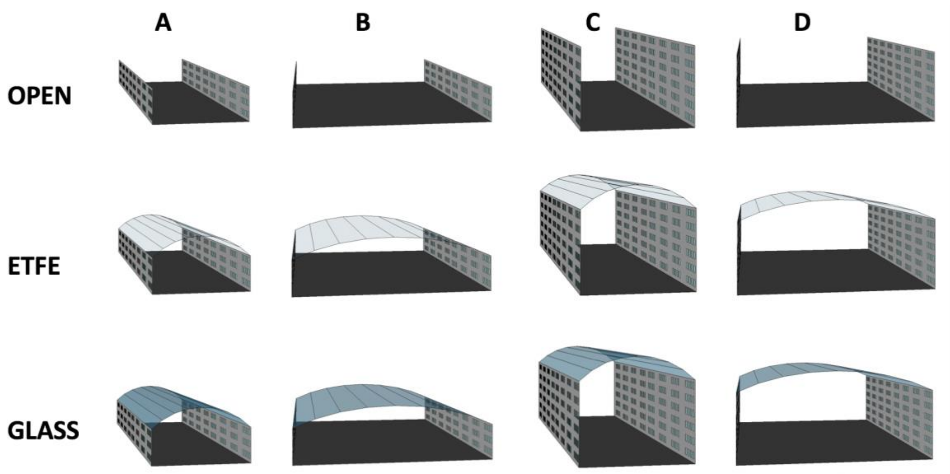

Figure 2: Overview of the twelve simulation models

3. Simulations

The simulations of the 3D models were performed in acoustic prediction software, ODEON v.14. This software uses an image-source simulation method combined with a modified ray tracing algorithm with an advanced sound scattering model (Christensen, 2013).

Each street variant was evaluated for three kinds of linear noise source position and composition (Figure 3). These sources represent typical pathways of pedestrians, tram lines or other noise sources. For this article, the detailed point receiver calculations were performed for pink noise and thus in a general way, in order to understand the sound distributions in different rooms. The simulated values were compared to the so-called free field situation (also simulated), i.e. a situation in which all the surfaces absorb 100% of sound energy. This has given us the opportunity to work with the relative sound pressure level values, instead of the absolute levels that would be valid only for one type of the noise source. In this way we didn't calculate the the absolute noise level in the street, but instead, only the contribution of buildings and roofing materials to the overall noise situation (as compared to the situation without buildings, i.e. free field). In doing so, the result of the paper is more general and more useful for comparisons with other research works.

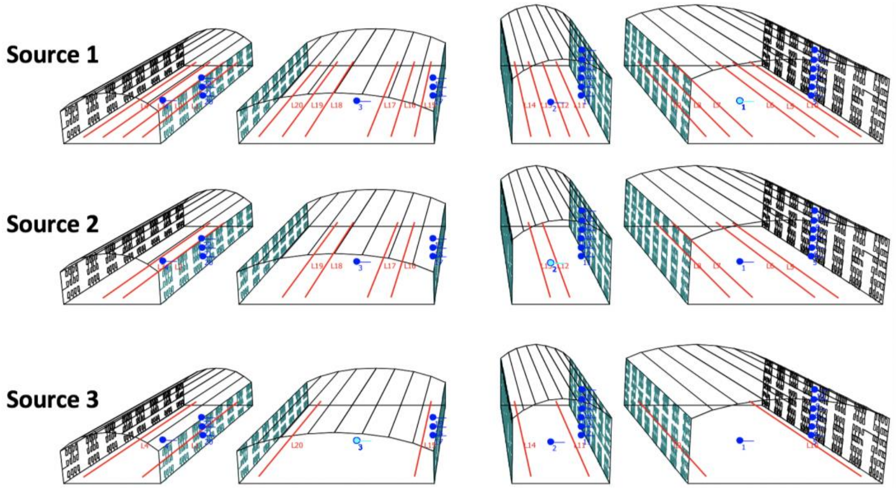

Figure 3: Each of the 12 variants were evaluated for 3 kinds of noise source compositions.

The receiver positions were chosen as follows. A point receiver was placed in the middle of each room, followed by placing several receivers at a 2 m distance from the building facades (in front of the windows), which are indicated in a blue colour in the Fig. 3. The second part of the analysis was performed in the so-called audience plane (ca 1,4 m above the ground), in order to get an overview of the sound distribution in each of the situations.

In the description of the acoustic situation of public spaces, typically only noise assessment is done. Concerning shopping galleries, there is no standardized acoustic parameter for the assessment of acoustic comfort. The equivalent noise level is surely not the only relevant parameter. Late sound reflections should be also taken into account in the assessment. They will not increase the equivalent sound levels significantly, but they are responsible for the continuous background sound in large spaces that contributes to the overall people's judgement of acoustic pleasantness or annoyance in situ. For this reason, we show also the reverberation time that might affect the perception of sound.

4. Results and analysis

4.1. Sound pressure level

For the sake of simplicity, in the graphs summarizing the results (Fig.4), we will present only the total sound pressure level L_p (dB) as an integration over all frequencies. Nevertheless, we will reflect on the frequency dependent results in the text. The Fig. 4 shows an overview of the results of the sound pressure level L_p (dB) for all the simulated cases expressed (in each case) as a difference between each of the simulated case and the free field situation. In other words, these values show the impact of the architectural design on the increase of noise levels compared to the situation with no buildings.

In general, the noise level in the considered shopping street is lower in the cases without a roof compared to the models with a roof, which is rather logical. These simulations are useful in particular for understanding the impact of the surrounding building facades on the resulting acoustic situation. In our cases, the overall sound pressure level increase is between 2-7 dB, depending on the situation. The strongest impact of the building facades on the increase of noise is noticeable the most at the receivers' positions near the building walls.

Looking at the data from a global point of view, we can conclude, that the smallest impact of the surrounding buildings and roof on the noise level is observed in the largest shopping street (D). This is expected, since the sound reflections arriving from far distances (due to the large volume of the room) carry less sound energy, and thus result in an overall lower total sound pressure level. If we consider the receiving position in the middle of the street, the noisiest situation is the case B when glass is chosen as the roof material. When analysing the results of the receivers at the distance of 2 m from the building facades, the noisiest situation occurs in the case A, i.e. the smallest room. This can be explained by the highest density of sound reflections in such a space.

When comparing glass and ETFE systems in general, the roof made out of the ETFE scores in average better in all cases, by ca 2 dB. However, if we look in the frequency dependent analysis (Fig.5), we will see that the differences between the glassing and foil structure will become much larger, up to 4 dB at low frequencies, since these thin foils reflect less than 50% of the sound back into the space, whereas in the case of the glass this is around 80-90% (depending on the type of the glass).

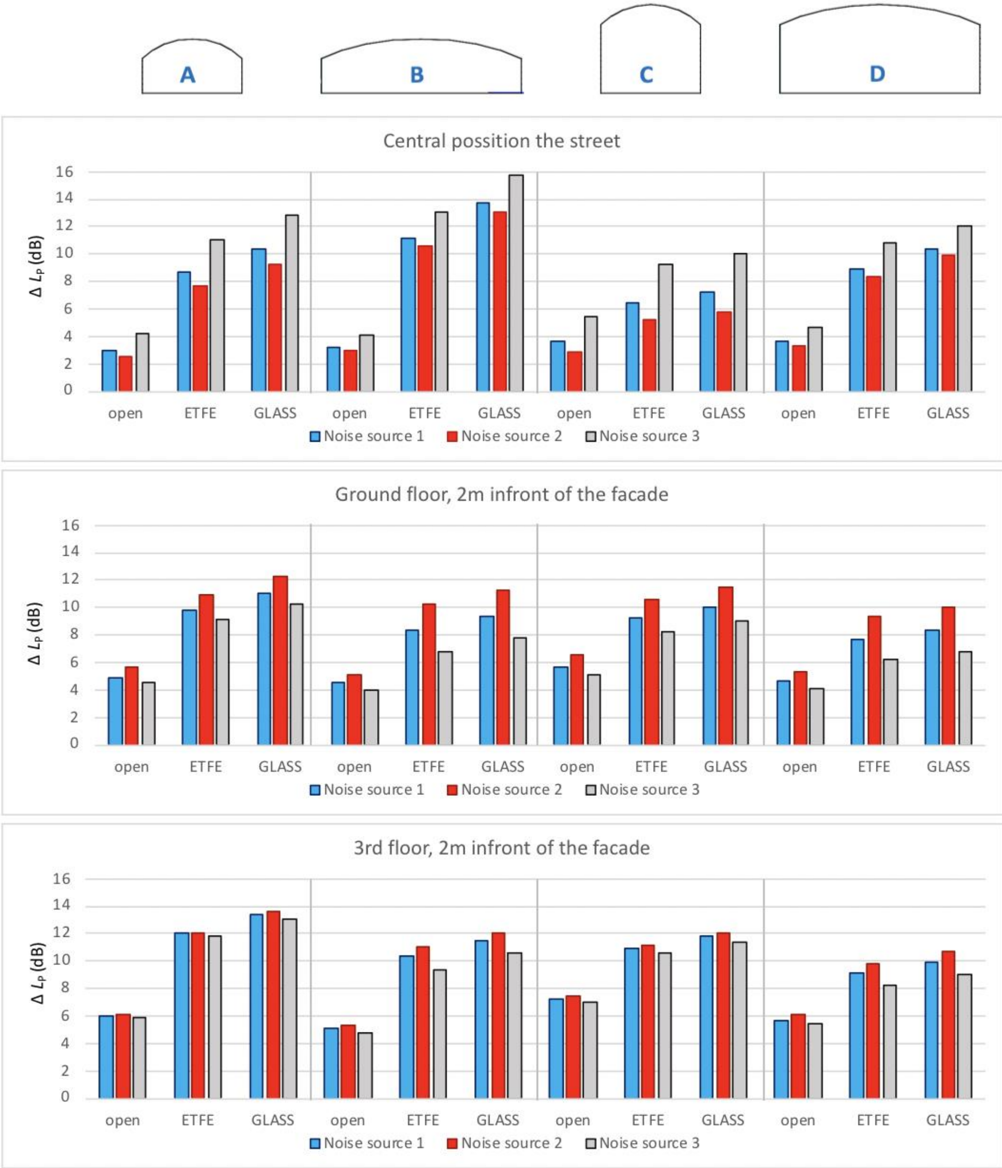

Figure 4: Differences in total the sound pressure level ΔL_p (dB) for each of the simulated case and the free field situation; the receiver position placed: in the middle of each room (upper picture); at a 2 m distance the façade in the height of 2 m (middle picture); and at a 2 m distance in front of the façade at the 3rd floor (bottom picture)

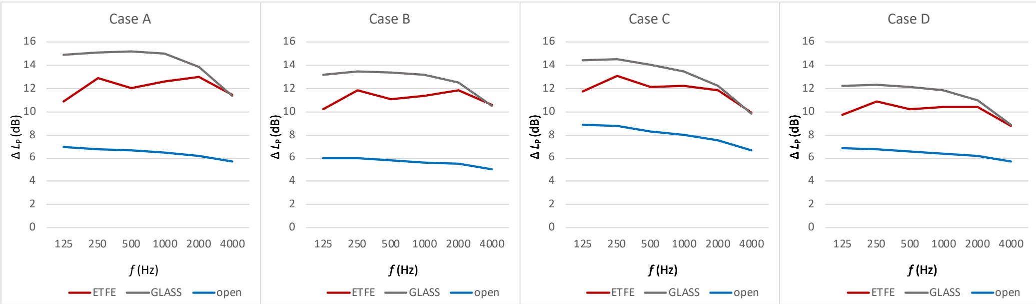

Figure 5: Differences in the total sound pressure level ΔL_p (dB) in the octave bands. Example of the situation with the sound source 2 and the receiver placed at a 2 m distance in front of the façade at the 3rd floor.

4.2. Reverberation time

As mentioned above, the overall noise is not the only performance indicator of acoustic comfort. The sound reverberation creates a special environment which influences the perception of the room quality. The reverberation time analysis (Fig.6) shows that the potential of continuous background noise due to reverberation is higher in shopping streets covered by glass. The Reverberation in spaces with bigger volumes is longer (Fig.6) and thus the roof (ceiling material) is a potential factor in acoustic comfort also in large spaces. In the case of the glass structure the reverberation time is more than twice as long.

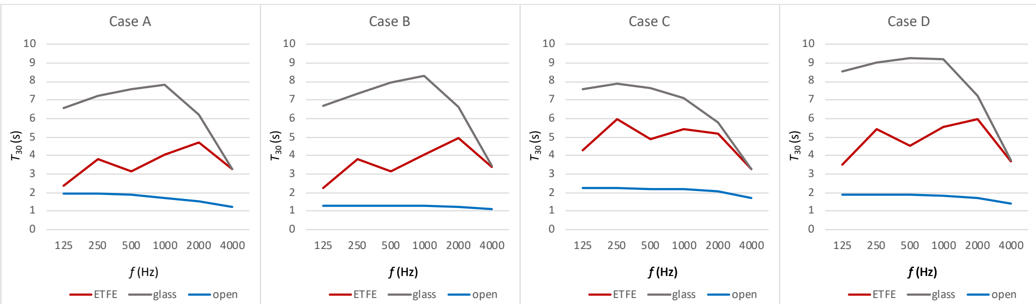

Figure 6: Average reverberation time T_{30} (s) in the four simulated cases.

5. Discussion and conclusion

While historical shopping galleries covered by glass were characterized by their narrow dimensions and high ceilings, contemporary architecture brings also other types of covered shopping street corridors. The parametric study presented in this article has shown the impact of building facades and materials used as a roof construction for relatively wide streets with a low and high ceiling. The article has shown, that in cases where the ceiling is low, the selection of the material will have a strong impact on the overall noise level. Furthermore, the positive impact of a structural skin, in our case the ETFE roof structure, has been proven to be a better solution, not only in terms of noise, but mainly in terms of the reverberation time.

The real correlation between the reverberation time (and /or other room acoustic quantities) in relation to the unpleasant continuous background noise, background noise caused by impact noise during a heavy rain or hails storms, in shopping galleries and large covered atria still needs to be investigated in detail and a reliable parameter needs to be defined.

Acknowledgements

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