Investigation of acoustical phenomenon in atria covered by structural glass roof

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Abstract

It is not exceptional that the new design is focused on sustainability in the process of restoration of historic buildings. Economics is often the reason why architects and investors are encouraged to transform exterior atriums into covered interiors in many cases of historical building renovations. Such space is valuable just because of possibility to acquire new unique function. The principles of monument protection do not allow the use of other atrium coverings than the structural glass roofs in most of the cases. Such spaces are characterized by a long reverberation times and, in connection with impulse sounds, the unpleasant background noise is generated as well as unwanted acoustical phenomena occurs. These problems also concerns the restoration of the manor house in the village of Halič, situated in the southern Slovakia. To determine the acoustic properties of the covered atrium, a series of measurements were performed, and an extremely clear phenomenon of flutter echo was observed. It is interesting since there are no mutually parallel structures in the atrium. That is usually a typical reason of flutter echo occurrence. Detailed analysis of measured data was performed, and the phenomenon of multiple reflections was investigated.

Keywords: background noise, flutter echo, rules, covered atrium, large volume space

1 Introduction

In the process of designing of buildings and their interiors, it is important to be able to predict the future characteristics of the spaces and to know how to use them. In architectural design, it is very beneficial to know how building interior environment can help to improve the quality of activity performed. Just like thermal and light comfort are standardly assessed in various types of buildings, the acoustic comfort needs to be taken into account as well.

In classrooms, offices, theatres and other monofunctional spaces it is rather straight forward to decide about acoustic solutions, since the location and characteristics of sound source as well as position of receivers can be quite accurately defined. In case of large shopping malls and atria the situation is rather different. The rooms are large and position of sources and receivers varies over time [1. In the case of existing spaces, we can measure the noise using a sonometer and subsequently statistically analyse it. However, this cannot be on one hand applied in the stage of design process when using predictions and simulations. On the other hand, a computational algorithm possibilities, allow us to create auralized sound, which can be further analysed as if it was recorded [2]. During the measurements of the manor house in southern Slovakia, which we performed for the needs of calibration of the virtual model, we encountered several acoustic problems associated with changing the purpose of the space.

A large-volume covered space was created from the former exterior space, which was designed as a public space for cultural events.

The main problem in large halls are not only high noise levels, but also their duration, defined as a quasi-constant background noise [3]. This phenomenon occurs mainly in large-volume spaces or in areas with a high proportion of reflective surfaces due to long reverberation time [4]. As an example of such spaces we could mention various covered atriums, shopping centre corridors, or covered shopping arcades.

Nowadays, it is already a common practice to cover even whole streets and shopping arcades, or other transit and public spaces, by roof structures on different material basis [5]. The most common types of roofs are pneumatic structures or structural skins on ETFE, tensioned, flexible and textile structures [6][7][8]. When acoustically hard materials are used, such as glass a multiple reflections of sound waves might cause an unpleasant quasi continuous background noise. It is known that long-term exposure to such noise can result in hormonal and cardiovascular problems as well as a wide range of other health complications [9][10]. Background noise is typically caused by presence of people in interior space. If they move, the friction of their clothes, sound from steps (walking) and breathing produce sounds which contribute to unwanted sound, especially in spaces with long reverberation time. In the atrium, described below, an unusually significant acoustic phenomenon, called flutter echo, was identified. It could be clearly perceived after impulse sounds played inside of the atrium.

2 Description of case study and experiment

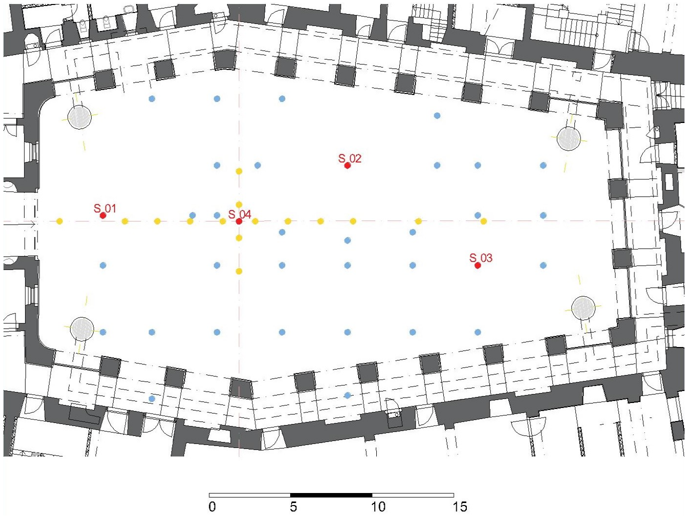

Figure 1 – Diagram of distribution of measured positions and arrangement of sound sources S01, S02, S03 and S04

As a case study, we chose the manor house in the village of Halič in southern Slovakia, which includes a public space covered with a structural skin based on glass. One of parts of the renovation of this space was also replacement of the floor covering with a marble floor as well as cladding of columns with stone cladding, and thus newly created room became a highly reverberant space.

The atrium is approximately symmetrical along the longitudinal axis. Its length in the longitudinal direction is 35.2 meters and in the transverse direction, at the widest point it is 18.7 meters wide. The roof structure is constructed as a glass dome, with a height at the highest point of 13.5 meters. The total volume of the atrium, including the corridor behind the pillar, which is also part of it, is 8767 m^3.

Measurements were performed using an integrated impulse response according to the ISO 3382 [11] methodology using a sweep signal. The measurement set up consisted of omnidirectional sound source (Qohm) connected with amplifier (Qam – DSP Controlled Signal Generator measurement Amplifier) vie sound card to computer. As a sound receiver a pair of microphones Behringer ECM8000 were used. The height of sound source and receiver was identically 1.5 meters above floor. Altogether, we performed measurements in 3 positions of sound source and 40 positions of the receiver. The measurement mesh is shown in the Figure 1. Red dots (S01 – S04) represent the sound source positions and blue dots represent receiver positions.

During the mentioned measurements, the presence of an unusually strong flutter echo was observed in the middle part of the atrium. For the needs of a more detailed analysis of this phenomenon, we performed another measurement using an omnidirectional sound source and a pair of receivers. We placed them to follow the floor plan of the atrium in which we observed the most pronounced presence of flutter echo, i.e. to follow the longitudinal and transverse axis of the atrium and the source was placed in their crossing. The measured positions for receiver S04 are shown in figure 1 and represented by yellow dots. The flutter echo is also obvious after looking at one of the measured impulse responses in the longitudinal axis of the atrium (Figure 2).

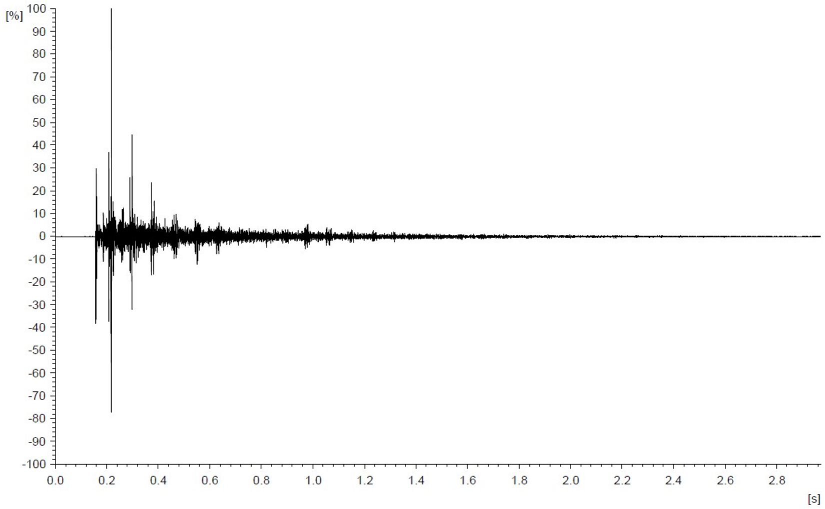

Figure 2 – Impulse response measured in the longitudinal axis with visible flutter echo effect.

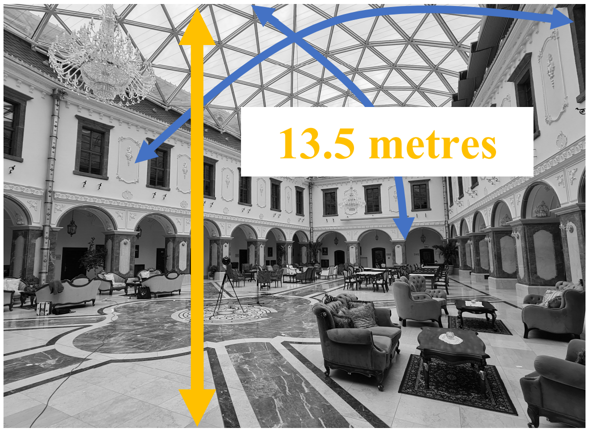

Figure 3 – Diagram showing the curvature of the roof structure and its height offset.

An interesting fact is that there are no parallel structures in measured space of the atrium, which are the most common reason for the presence of such an acoustic phenomenon as flutter echo is. After inducing a short impulse sound (clap or foot tap), we located the most pronounced presence of flutter echo in the area where the glass roof structure reaches its maximum height. The mentioned roof structure is curved in 3 directions (Figure 3) and creates a dome above the atrium with the highest part above the position where we placed the sound source and where we also observed the most pronounced fluttering echo.

3 Results and discussion

The analysis of reverberation times in measured at receiver positions for sound sources S01, S02 and S03 does not differ significantly from each other (Figure 4). Solid lines represent reverberation time values measured from sound sources S01, S02 and S03. Dashed line is the average value from all of these sound source positions. The difference is most visible especially at low frequencies, where during the measurement, due to the shape, size and number of reflective surfaces, it was most problematic to achieve a suitable signal-to noise ratio necessary for the determination of T_{30}.

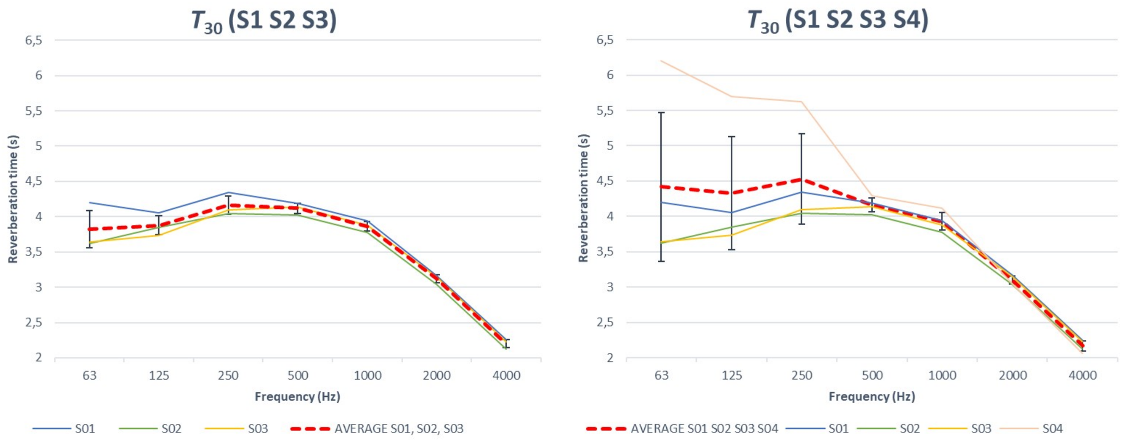

Figure 4– Graph showing reverberation times in the measured positions for sound sources S01, S02 and S03 (left) and for sound sources S01, S02, S03 and S04 (right) together with average values.

After taking into account the measurements at the position of sound source S04, which showed the most pronounced signs of the presence of flutter echo, the graph shows that this echo occurs mainly in the low and mid low frequency bands from 125 Hz to approximately 300 Hz and its presence significantly increases the reverberation time of the entire space by 0.5 s (Figure 4 right). Therefore, it is necessary to measure similar spaces with more detailed mesh of receivers as well as to increase number of sound sources for the purpose of correct calibration of virtual model.

To investigate the distribution of sound pressure level over the atrium, the decrease of sound pressure level with distance is compared and shown in Figure 5. The graphs compare the sound pressure level decrease from sound sources S02 (blue squares) and S04 (red squares). For better presentation of data, the measured values are expressed with logarithmic trend lines. All together 6 graphs are presented, each of them for particular frequency octave band in range of 125 Hz to 4000 Hz.

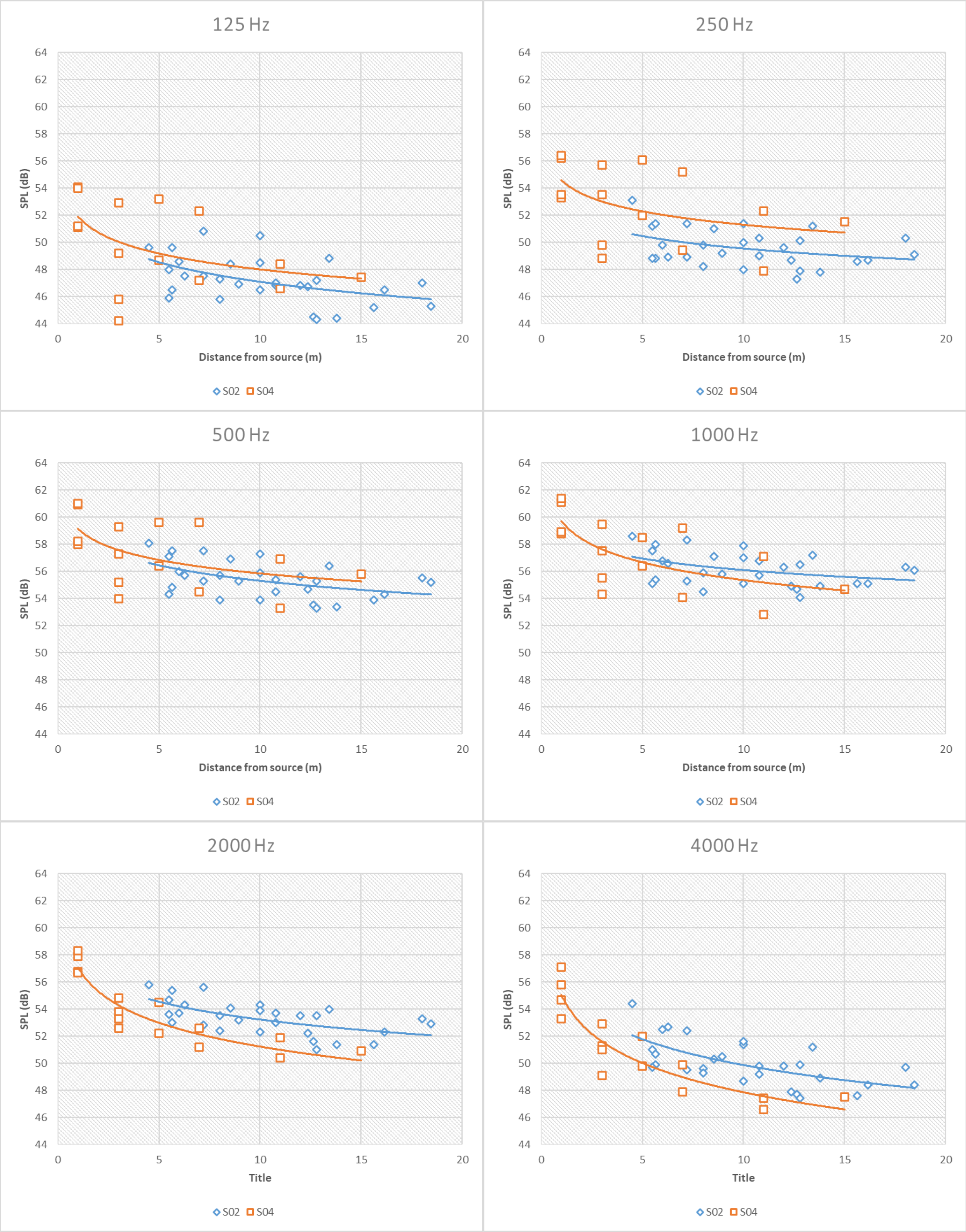

Figure 5– Charts describing the comparison of the decrease of the sound pressure level with the distance from the sound source for the positions of the source S02 and S04

As we can see the effect of flutter echo is visible also in the distribution of sound pressure level over the entire space. The decrease trend is very similar for both sound source positions. But comparing the values we can see that the present flutter echo increases the sound pressure level values from source S04 for 250 Hz by 3 dB. For other frequency bands is the increase not significant. This confirms the reverberation time measurements where the largest increase of values was also in 250 Hz frequency band. Interestingly, for 1000 Hz and more, this trend is reversed and the levels from source S02 are higher in comparison with S04.

4 Conclusions

Measurements of impulse responses in atrium of the manor house in the village Halič were performed. The results show us that for the purpose of further correct calibration of virtual model of such complex space and to get real picture about acoustic comfort space with large volume, it is necessary to measure more position of sound source which could possibly reveal all unwanted acoustic phenomena such as flutter echo. Without considering all of the properties of the room, further calibration of virtual model could be inaccurate for the purpose of research. We can also conclude that before refurbishing of such special space with large volume, consideration of acoustic comfort is necessary. With reasonably distributed sound absorption (e.g. represented by different material of roof structure) we could avoid unwanted acoustical artefacts such flutter echo.

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