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INFLUENCE OF SOUND SCATTERING ON REVERBERATION TIME IN LARGE ROOMS

Magdaléna Kaššáková[1], Daniel Urbán[2], Andrea Vargová[3] and Monika Rychtáriková[4]

[1] STU Bratislava, Faculty of Civil Engineering, Dep. of Building Construction, Radlinského 11, 813 68 Bratislava, Slovakia, Email: magdalena.kassakova@stuba.sk

[2] STU Bratislava, Faculty of Civil Engineering, Dep. of Building Construction, Radlinského 11, 813 68 Bratislava, Slovakia, Email: daniel.urban@stuba.sk

[3] STU Bratislava, Faculty of Civil Engineering, Dep. of Building Construction, Radlinského 11, 813 68 Bratislava, Slovakia, Email: andrea.vargova@stuba.sk

[4] KU Leuven, Faculty of Architecture, Research Department of Architecture, Hoogstraat 51, 9000 Gent/ Paleizenstraat 65, 1030 Brussel, Belgium, email, web: monika.rychtarikova@kuleuven.be

ABSTRACT

Simulation methods in room acoustics are usually based on algorithms that use rays to simulate sound waves. These algorithms are fast and efficient in prediction of acoustic parameters, but their shortcomings lay in neglecting of wavelengths of sound. Sound diffraction effects and non-specular reflections of rays from rough surfaces are therefore compensated by means of scattering coefficient δ assigned to interior surfaces in spatial models. In this article, we aim at investigation of the influence of sound scattering, modelled according to the Lambert's cosine law, on results of acoustic parameters in atria. Presented results compare 9 alternatives that differ from each other in absorption (reflective, typical and absorptive) and in surface scattering (1%, 10%, 20% and 30%). Comparisons between alternatives are performed for reverberation time RT (s).

INTRODUCTION

Room acoustic models based on ray tracing or image source methods use in their prediction algorithms rays instead of waves. This simplification has many advantages in term of calculation efficiency in architectural context, but since sound diffraction and sound scattering effects are not physically modelled, they need to be handled statistically. Diffuse reflections of sound from interior surfaces affects the predicted values of room acoustic quantities. The well-known round robin test in the year 1995, has shown, that surface scattering in ray-based prediction algorithms is extremely important [1].

Sound scattering is a parameter of material that indicate the ratio of a scattered sound to a total reflected sound. It can be either measured in a diffuse acoustic field (reverberant room) under strict conditions [2] or simulated in a frequency domain, such as in Boundary element method (BEM) or by means of finite difference method (FDM) in a time domain. In ray-trancing software, the rays that represent sound waves are sent out from a point sound source to a 3D architectural model, where they travel in different trajectories and lose their sound energy by $1/r^2$. Once a ray hit a wall or other model surface, the energy of a ray is decreased according to the sound absorption and sound scattering of the model surface, expressed in percentages.

The calculation program used for our experiment is based on a combination of image source and special ray-tracing method. Manual of the software declares, that the use of less detailed model with higher number of rays can provide better predictive results and shorter time of simulations [3]. In our room model only most important details are modelled geometrically. Scattering algorithm that is implemented in the acoustic software uses a Lamberts distribution.

Research on an influence of scattering coefficient on room acoustic parameters in the large gathering spaces with not enough diffusion has not been investigated in detail yet. This article therefore discusses the impact of surface scattering on known acoustic parameters in the example of an atrium with around 8900 m^2 covered by transparent TEXLON ® ETFE (ethylene-tetra-flour-ethylene) cushion system.

DESCRIPTION OF CASE STUDY

The case study is a large atrium that is a part of a school building in Oldenburg (Germany). Space has various functions, but most often it is used as a gathering space during breaks between lessons. In the corner of the atrium there is also a cafeteria and a part of the atrium is also a small stage that is used for lectures or cultural activities.

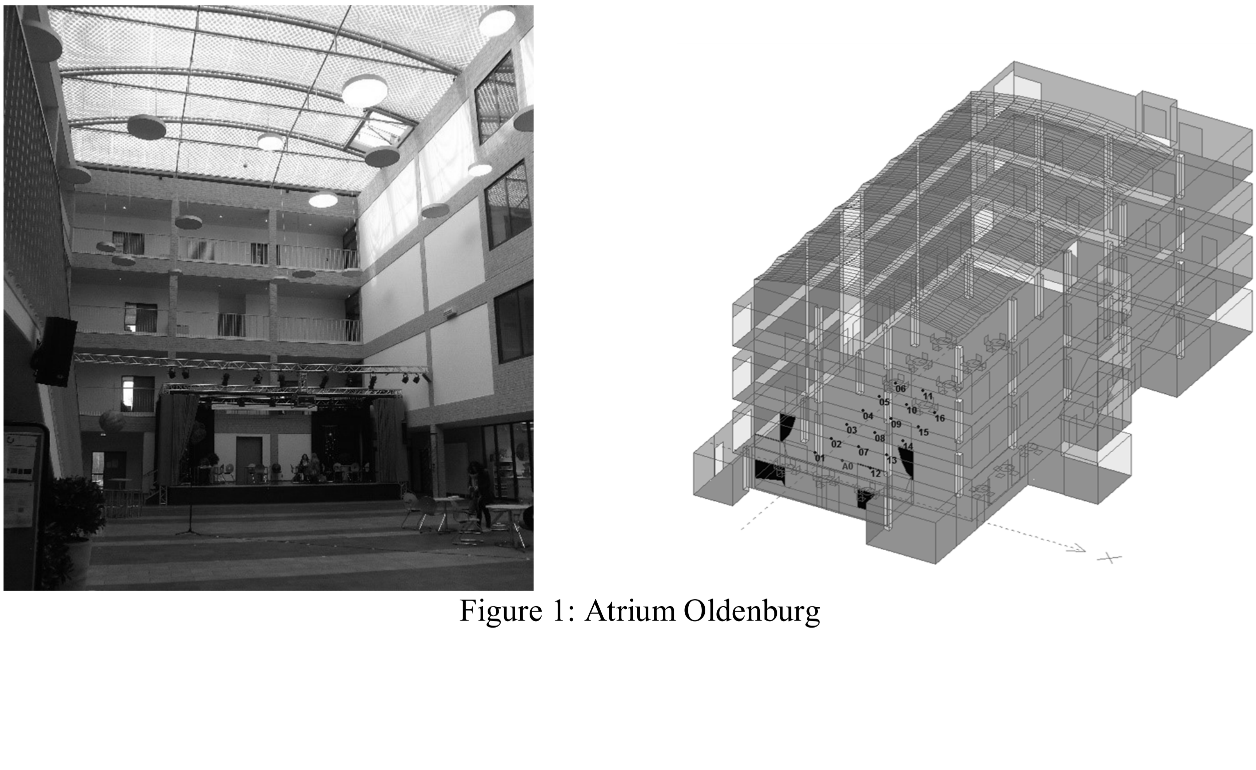

Figure 1: Atrium Oldenburg

Space is surrounded by corridors up to the fourth floor. Ventilation of the room is provided by a central air conditioning system. The atrium is covered by transparent TEXLON ® ETFE (ethylene-tetra-flour-ethylene) cushion system with printed texture for shading. Volume is ca. 8900 m^3. Its geometry is 'shoe box' shape with dimensions of approximately 16,5 m x 14, 6 m maximal height of 27,1 m. [5]

MEASUREMENTS

Impulse response measurements according to the ISO 3382 and ISO 18233 using sweep signal and measurements of background noise were performed in the empty atrium before the lessons started. This experiments were performed as part of the pilot study in the framework of the COST action 1303 [5]. Measured background noise was around 42 dB(A). Impulse response measurements were performed for two (2) positions of loudspeaker and 34 microphone positions and were used for calibration of the calculation model.

SIMULATIONS

To understand the impact of surface scattering on prediction of room acoustic parameters under different absorptive situations and its significance in diffuse/non-diffuse room environments, nine (9) different alternatives were chosen, that differ with absorption material properties. Table 2 summarizes the alternatives. Four (4) surface scattering coefficient values were considered (1%, 10%, 20% and 30%) within each alternative. Simulations were performed with automatically chosen number of rays (10 000) for calculation of each room impulse response.
In this study only reverberation time (T_{30}) was used for later comparisons. Reverberation time was analysed in octave bands as average values over 16 receiver's positions. The 3D model was designed with CAD software (Figure 2) exported to room acoustic software. Calibration of the initial alternative (real case scenario – current situation) was based on measurements of reverberation time.

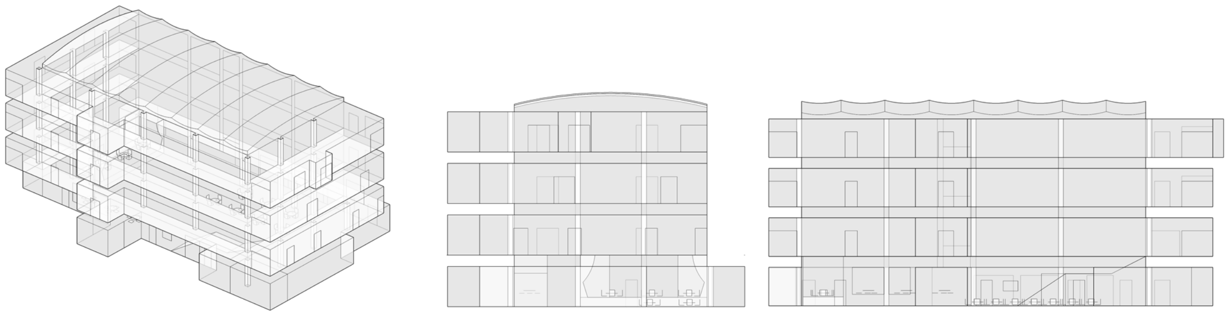

Figure 2: 3D model of atrium in Oldenburg. Axonometric projection (left) cross section (middle and right)

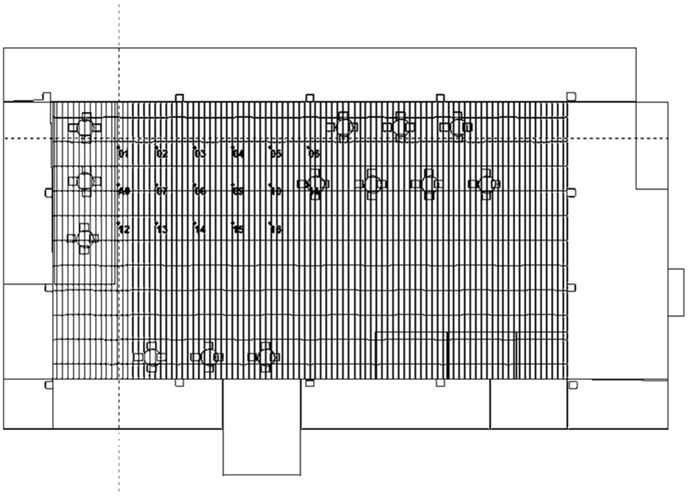

Figure 3: Floor plan with location of microphones

For easy comparison between alternatives, virtual source and 16 receivers were kept in all predicted scenarios at the same positions in the height 1,5m above the floor (
Figure 3).

Table 1 : Description of nine (9) alternatives, created based on variation of walls/floor and ceiling absorption

Walls/ Floor	Current situation			Sound reflecting			Sound absorbing		
Ceiling	foil	glass	concrete	foil	glass	concrete	foil	glass	concrete

Table 2 : Absorption coefficient of walls and floors used in simulations

Walls / Floor	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Current situation	0,21	0,20	0,20	0,16	0,16	0,16
Reflective situation	0,02	0,02	0,02	0,02	0,02	0,02
Absorptive situation	0,50	0,50	0,50	0,50	0,50	0,50

Table 3 : Absorption coefficient of roof/celling material used in simulations

Roof / Ceiling	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
ETFE foil cushions	0.42	0.35	0.26	0.17	0.08	0.02
Glass	0.15	0.05	0.03	0.03	0.02	0.02
Concrete	0.01	0.01	0.01	0.02	0.02	0.02

RESULTS AND DISCUSION

Results concerning prediction of reverberation time T_{30} (s) can be seen in the Figure 4. As already mentioned above, values are shown for octave bands 125 – 4000 Hz, obtained as average values of 16 receiver positions in each alternative. Standard deviation between individual positions within one alternative is very small (0,057) and it is therefore not included in the Figures. Results in all alternatives are also compared with a diffuse field theory, according to the Sabine formula.

Current situation

Figure 4 summarizes simulated reverberation time T_{30} for alternatives with absorption of walls and floor as in current atrium, i.e. the average absorption coefficient is around 20%. The three graphs in the Figure 4 correspond to different variants of ceiling: (Alt.1) ETFE foil cushion (left picture), (Alt.2) glass roof (picture in the middle) and (Alt.3) concrete ceiling (right picture). The differences between 20-30% of scattering are negligible. In cases where the scattering was assigned to all surfaces uniformly to 10%, difference is at a limit of just noticeable difference when compared to rest. However, in cases with only 1% of scattering, predicted reverberation time is significantly higher in comparison to the other situations.

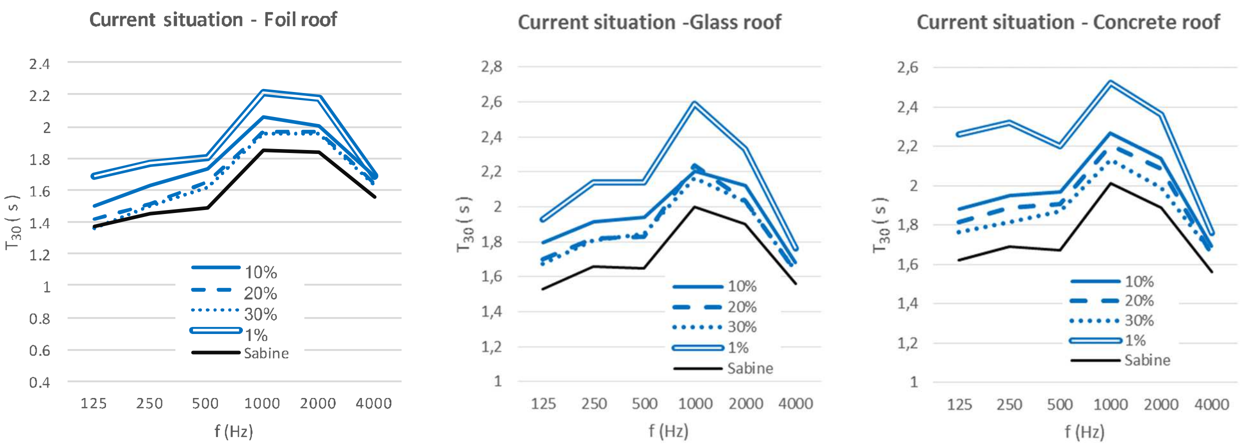

Figure 4: Results of T_{30} (Hz) for Alt.1-3, in an atrium with at walls/floors surface as in current condition.

Figure 5 shows, that in cases where highly reflective materials (with only 2% of sound absorption) are applied at floor and wall surfaces most significant differences between simulations can be found in low and middle frequencies. Similar to previous data, there is almost negligible difference between simulations with values of 20% and 30 % of scattering coefficient. In case of hard materials – glass and concrete roof. It can be concluded that the impact of scattering above 2000 Hz completely negligible. Sabine theory corresponds the best with alternatives with highest scattering coefficient. With exception of a situation in which ceiling is most absorptive (made out of foil cushions) Reverberation times at low frequencies are in highly reflective environments much longer in comparison with high frequencies, despite the fact, that the average sound absorption at low frequencies in all cases is larger or equal than in middle and high frequencies. So, this is most likely caused by the long trajectories of sound in highly reflective conditions and as known, air absorption sound at high frequencies is much bigger than at low once.

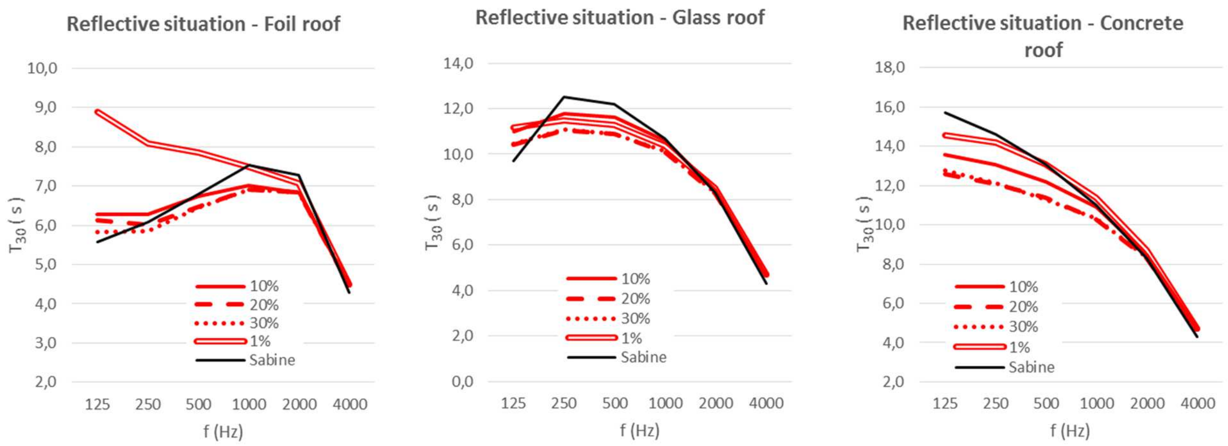

Figure 5: Results of T_{30} (Hz) for Alt.4-6, in an atrium with a highly reflective walls/floors surface

In absorptive environments, i.e. Alt.7-9, reverberation time varies from 0, 6 to 0, 9 s. Values predicted by Sabine theory are much lower than the simulations. Also, here it has been conformed, that the less scattering the higher reverberation time.

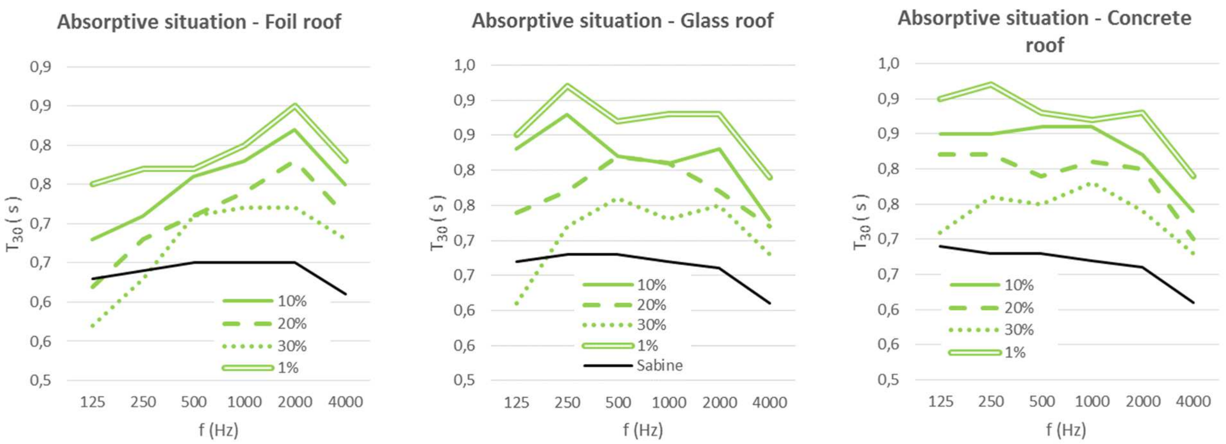

Figure 6: Results of T_{30} (Hz) for Alt.1-3, in an atrium with at absorptive walls and floor.

CONCLUSION

Results have shown, that the in cases with low absorption in a room in general, the higher influence of scattering coefficient in simulation can be observed. It has been found, that higher values of surface scattering cause lower values of T_{30} especially at low frequencies.
Calculation according to the Sabine theory predict in all cases most cases reverberation times. This can be explained by the fact that the model is not diffuse due to uneven distribution of sound absorption (different absorption on ceiling in comparison to other room surfaces) and so the sound reflections are not regularly distributed in the reflectogram, which is bases for reverberation time calculation in software that combines image source method and ray-tracing.

ACKNOWLEDGEMENT

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