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SENSITIVITY TESTING IN ROOM ACOUSTIC MODELING ON CHANGES OF INPUT PARAMETERS ON THE EXAMPLE OF SELECTED CONCERT HALLS

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ABSTRACT

Sensitivity testing of room acoustic models on changes of material and environmental parameters, as well as sound source and receiver locations is very important for the validity of the calibration of the models to the measurement results obtained in the existing rooms. Awareness of the sensitivity of the acoustic model is also very important in supervising the renovation of existing objects. It helps to adapt corrections in the modeling and outfit of the object during successive stages of disassembly and assembly of the elements of the interior. In the paper an analysis of the influence of the sound absorption and the sound scattering coefficient changes on the acoustic parameters of the room is presented. Reverberation time and sound clarity were especially investigated. A group of materials was selected, for which measurement or modeling accuracy had crucial importance for the correctness of the room acoustic parameters prediction. Special attention was paid to the sound scattering coefficient. Its influence on averaged as well as locally analyzed parameters was investigated.

Keywords: *scattering, sensitivity, reverberation time*

1. INTRODUCTION

Modeling acoustic parameters of existing room is always a demanding task. Requirements from the user, architects, heritage inspectors and acousticians must be fulfilled. While in some objects, there is a place for acoustic corrections, in others the user insists on preserving existing acoustic parameters as a part of cultural heritage. Especially for the second case, it is important to be conscious of existing acoustic parameters and the possibility of recreating them using new, or renovated materials and structures on a ceiling, walls and floor. Information about absorption coefficients of materials used in the specific room is usually taken from the literature and corrected in the process of room calibration. Simple calibration based on the mean value of reverberation time ensures that the total absorption of materials is properly calculated, but the distribution of absorption amongst all materials can be very imprecise. That is why calibration based on the spatial distribution of EDT and C_{80} should be performed [1]. This method can even validate scattering coefficients of materials if they are also included in the calibration process. To estimate sound absorption coefficients of materials used in the room, it is also possible to perform in-situ sound absorption measurements using *pp* [2] or *pu* probes [3]. That type of measurement is especially useful for locally absorbing, non-scattering surfaces. In-situ measurement of surface reflection properties is also possible using multi-sensors hemispherical measurements [4].

Irrespective of the absorption coefficients measurement method, its results are biased with high uncertainty, which results in uncertainty of room acoustic parameters [5]. While dependence between absorption and reverberation time is described by many equations, the influence of sound scattering coefficient impact on room acoustic parameters is not so straightforward. Embrechts [6] presented equations for some types of rooms linking surface scattering and reverberation times, while [7] showed, that even scattering algorithm used in ray tracing can significantly impact on results. That is why introducing new materials or renovating the existing ones in rooms, precisely planned room acoustic parameter measurements should be done during the disassembly and assembly of materials and structures used in the room. Based on these measurements, some corrections should be done (if necessary). To define the most efficient places in the room for room acoustic parameters corrections, sensitivity analysis was done of all materials used in two music rooms. Analysis was done for absorption and scattering coefficients. Amongst analyzed parameters were reverberation times and energy ratio defined in ISO 3382 standard [8].

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Table 1. Sound absorption and scattering coefficients of materials used in acoustic models.

Name/location of the material	Absorption coefficients						Scattering coefficients						Area, m^2
	125	250	500	1000	2000	4000	125	250	500	1000	2000	4000	
Philharmonic													
Stage wall	0.25	0.20	0.13	0.13	0.08	0.08	0.20	0.30	0.35	0.40	0.45	0.50	164
Auditorium wall side low	0.24	0.33	0.10	0.05	0.10	0.10	0.20	0.30	0.35	0.40	0.45	0.50	143
Auditorium wall side	0.25	0.20	0.10	0.08	0.06	0.06	0.10	0.15	0.15	0.20	0.20	0.20	282
Auditorium wall back	0.31	0.31	0.25	0.22	0.20	0.12	0.20	0.30	0.35	0.40	0.45	0.50	103
Doors	0.21	0.20	0.17	0.17	0.15	0.05	0.10	0.15	0.15	0.20	0.20	0.20	41
Auditorium ceiling	0.15	0.10	0.10	0.07	0.07	0.05	0.20	0.20	0.20	0.25	0.25	0.25	373
Stage ceiling	0.15	0.10	0.10	0.08	0.08	0.05	0.20	0.20	0.20	0.25	0.25	0.25	221
Plaster	0.21	0.15	0.10	0.12	0.10	0.05	0.10	0.15	0.15	0.20	0.20	0.20	311
Stage floor	0.25	0.20	0.10	0.10	0.06	0.06	0.10	0.15	0.15	0.20	0.20	0.20	185
Auditorium floor	0.30	0.20	0.15	0.12	0.10	0.12	0.10	0.15	0.15	0.20	0.20	0.20	101
Armchairs	0.15	0.25	0.29	0.35	0.48	0.53	0.20	0.30	0.40	0.50	0.50	0.60	563
Organ wood	0.30	0.25	0.25	0.20	0.12	0.08	0.20	0.30	0.40	0.45	0.45	0.50	119
Organ steel	0.68	0.73	0.72	0.79	0.91	0.90	0.20	0.30	0.40	0.50	0.50	0.60	25
Stairs	0.30	0.20	0.15	0.10	0.16	0.11	0.20	0.30	0.35	0.40	0.45	0.50	61
Ventilation	0.30	0.40	0.50	0.50	0.50	0.40	0.20	0.30	0.35	0.40	0.45	0.50	12
Windows	0.25	0.10	0.07	0.06	0.04	0.02	0.10	0.15	0.15	0.20	0.20	0.20	4
Wood	0.09	0.10	0.08	0.08	0.10	0.10	0.10	0.15	0.15	0.20	0.20	0.20	46
Auditorium wall	0.13	0.16	0.16	0.18	0.19	0.19	0.10	0.12	0.15	0.20	0.25	0.30	1937
Auditorium floor	0.13	0.16	0.16	0.18	0.19	0.20	0.20	0.30	0.40	0.45	0.50	0.50	358
Armchairs	0.70	0.78	0.81	0.85	0.84	0.81	0.30	0.40	0.50	0.60	0.70	0.70	568
Doors	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.12	0.15	0.20	0.25	0.30	34
Windows	0.20	0.16	0.16	0.18	0.19	0.20	0.10	0.12	0.15	0.20	0.25	0.30	22
Stage floor	0.21	0.19	0.11	0.12	0.13	0.15	0.10	0.12	0.15	0.20	0.25	0.30	422
Stage walls	0.13	0.16	0.16	0.18	0.19	0.20	0.20	0.30	0.40	0.45	0.50	0.50	1077
Stage ceiling	0.24	0.48	0.99	0.99	0.99	0.99	0.10	0.12	0.15	0.20	0.25	0.30	372

2. METHODS

Sensitivity analysis was performed for a shoe-box-shaped philharmonic room with a volume of about 6200 m^3, where 17 different materials were used (total surface area 2754 m^2). In the second object – a horseshoe-shaped music theater, with a volume of about 10300 m^3 only seven different materials were used (total surface area 4790 m^2). For both rooms, calibration of the models was made by correcting sound absorption coefficients to minimize errors in the spatial distribution of EDT and C_{80}. Sound scattering coefficients were defined according to previous experiences in room acoustic modeling and based on values given in [9]. With calibrated material parameters as a base (Tab. 1), sound absorption and sound scattering coefficients of every material and for every frequency range was modified separately in the range of $\pm 50\%$ in 5% steps. The ray tracing method was conducted in I-SIMPA software [10] with one omnidirectional sound source position using 600 000 rays for the philharmonic and 1 000 000 for the theater. The time of the ray tracing was set to a maximum value of reverberation time measured in each room respectively.

Reverberation times (EDT, T_{20}) and energy ratio (C_{80}) were calculated for all positions of receivers (22 positions in the philharmonic, 10 positions in the music theater). To unify the influences of different materials, an equivalent absorption area (instead of sound absorption) was used. All acoustic parameters of materials, as well as their surface areas in both rooms, are presented in Tab. 1.

3. RESULTS

The influence of sound absorption coefficient changes on reverberation time was compared with the results from Sabine equation calculations. The biggest changes of T_{20} (compared to the Sabine equation) were observed for the auditorium side wall. Figure 1 presents values of calculated reverberation, and linearization of results as well as values calculated according to the Sabine equation. On the other hand, for the wooden organ case (situated on the stage), the influence of sound absorption changes was much smaller than predicted from Sabine's equation (Figure 2).

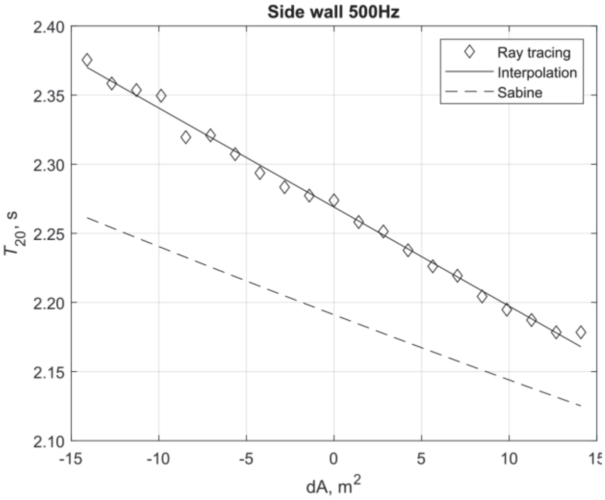

Figure 1. Comparison of the impact of equivalent absorption area changes of the side wall of the auditorium of the philharmonic on reverberation time T_{20} calculated for 500 Hz.

Changes in scattering coefficients of materials had a smaller impact on the reverberation time. Only early decay time (EDT) was changed above just noticeable difference (5%). Figure 3 presents results of changing scattering coefficients of the audience floor and stage walls in the music theater. Two opposite results were selected: for the audience floor, changes in the scattering coefficient did not influence the EDT (results $\pm 5\%$). For the stage walls, the changes in EDT are much higher than JND. Higher scattering coefficient of the stage wall results in a shorter early decay time.

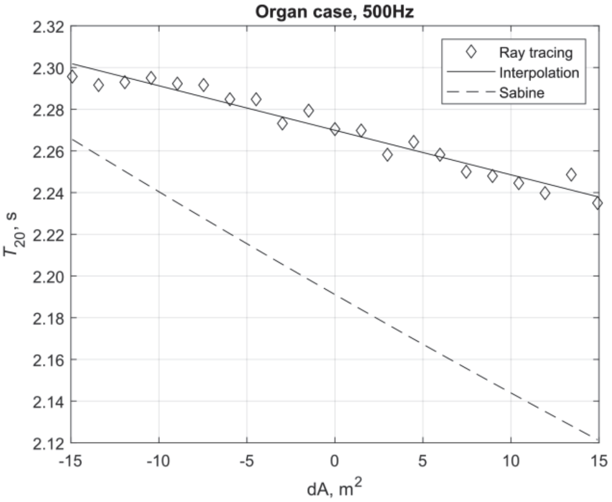

Figure 2. Comparison of the impact of equivalent absorption area changes of organ case on the stage of the philharmonic room on reverberation time T_{20} calculated for 500 Hz.

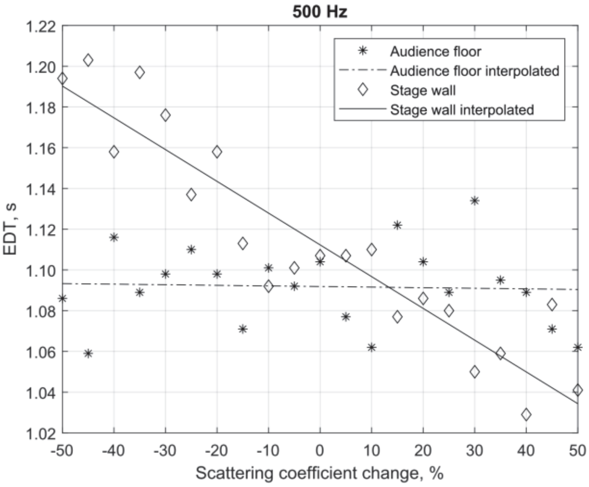

Figure 3. Comparison of the influence of sound scattering coefficient changes of selected surfaces of the music theater on the early decay time calculated for 500 Hz.

Figure 4 presents the maximal changes of clarity C_{80} parameter observed during the stage wall sound absorption coefficient changes in the music theater. Values for all frequency bands are presented. The farther from the sound source, the bigger the influence of the sound absorption changes. That phenomenon was not observed so clearly for other materials.

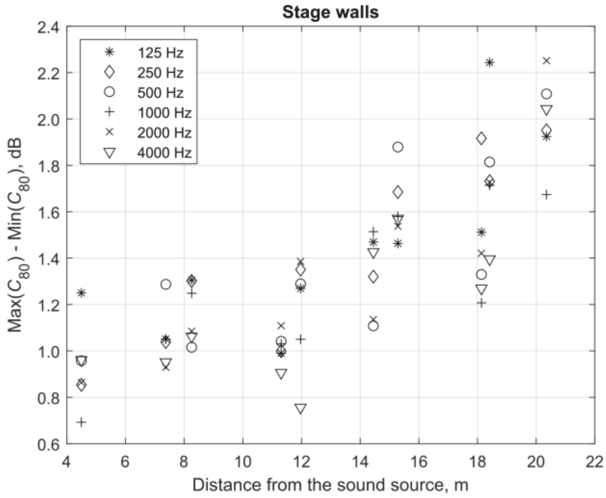

Figure 4. Differences between maximum and minimum C_{80} observed during the stage wall sound absorption coefficient changes for music theater.

4. CONCLUSIONS

In the paper, sensitivity analysis of the room acoustic parameters was conducted. Sound absorption as well as sound scattering coefficient were changed in the range of ±50% to observe changes in reverberation times T_{20}, EDT and clarity index C_{80}. It was observed that changes in reverberation time were almost linear. Depending on the location of the surfaces, the influence of a given material was higher or lower than calculated from Sabine's equation. Changes in scattering coefficients of materials did not influence significantly the reverberation time T_{20}. Only early decay time was modified by some materials scattering coefficient changes. For the clarity index, it was observed that parameter changes in a given point depends on the distance from the sound source – the farther from the sound source, the bigger the impact of the sound absorption changes.

5. ACKNOWLEDGMENTS

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