Influence of a volume scale factor on the scattering coefficient effects on the prediction of room acoustic parameters

Louena Shtrepi (louena.shtrepi@polito.it)
Arianna Astolfi (arianna.astolfi@polito.it)
Energy Department
Politecnico di Torino
Corso Duca degli Abruzzi 24
10129 Torino, Italy

Monika Rychtáriková, (monika.rychtarikova@bwk.kuleuven.be)
K.U. Leuven
Laboratory of Acoustics and Thermal Physics
Celestijnenlaan 200D
3001 Heverlee, Belgium

ABSTRACT

Surface scattering has become an important input parameter in the work on geometric models and in the research concerning the enhancement of auralized sound. This contribution deals with the comparison of four scaled prediction models of the same concert hall and studies the scattering coefficient prominence in simulations while the size of the concert hall increases by two times. The hall is a fan-shaped hall with aspect ratios of around 4.5:2.8:1 and typical auditorium features such as stage and raked audience area. The influence of a volume scale factor on the scattered sound effects on the prediction of the objective room acoustic parameters like $EDT$, $C_{90}$, $D_{50}$, $LF_{80}$ and $G$, is investigated. Five different alternatives were simulated, where scattering coefficient values $s = 10, 30, 50, 70$ and $90\%$ respectively, were applied separately and combined to the interior surfaces of the ceiling, side and rear walls. Analysis has been performed by studying the results of the objective room acoustical parameters predicted by simulations carried out with two software: Odeon® 11.00 and Catt-Acoustic® v 8.0.

1 INTRODUCTION

There are several geometrical acoustics based software which are widely used in the preliminary designing of halls and theatres. Most of these methods use the scattering coefficient to determine the share between the specular and diffuse components of reflections. The main object of this contribution is to investigate the objective acoustic indexes sensitivity to input parameters selection in differently scaled models of the same hall.

The importance of diffuse reflections in the modeling of sound fields in enclosed spaces have been pointed out by many publications1-6. Although there has been many rigorous studies concerning scattering and diffusion coefficient measurement7-8, there is lack of data regarding these parameter values for certain surface patterns and moreover different modelling methods with different theoretical basis of modelling diffuse reflections might require different values of
scattering coefficient even for the same surface under the same room condition. Lam\textsuperscript{1} has conducted research on the selection of scattering coefficients for good correlation between computer modeled and physical spaces. The correlation between scattering and room size and shape have been investigated by Lam and Hodgson\textsuperscript{1,2,5}, and as reported in lower frequency bands the diffuse reflection coefficient show a stronger dependence on the room size. It is well known that the effectiveness of diffuse reflections is higher in disproportionate spaces such as concert halls, rather than in proportionate ones\textsuperscript{2,5}. Kim et al. investigated the effects of diffusive surfaces on concert hall acoustics using scale models with regard to hall shape and diffuser location\textsuperscript{9}. This work is a very important study too refer to when the accuracy of the scattering implementation by different algorithms is discussed.

In this study we use two software Odeon and Catt-Acoustic to simulate different sized scenarios of the same hall subjected to changes on scattering location and quantity. Thus this contribution deals with the comparison of four scaled prediction models of the same concert hall and studies the scattering coefficient prominence in simulations while the size of the concert hall increases by two times. The influence of a volume scale factor on the scattered sound effects on the prediction of the objective room acoustic parameters like $E DT$, $C_{80}$, $D_{50}$, $LF_{80}$ and $G$ is investigated.

2 EXPERIMENT

2.1 Test hall

The real hall used for this investigation is a fan-shaped, multipurpose auditorium which is used primarily for lectures and concerts at Politecnico di Torino, named "Aula Magna Giovanni Agnelli". The real size of the hall is about $3600 \text{m}^3$ and 453 seats characterize the stalls. The hall is a fan-shaped hall with aspect ratios of around 4.5:2.8:1 and typical auditorium features such as stage and raked audience area. An outline of the hall as well as the arrangement of the stage, ceiling and stalls is shown in Figure 1.

![Figure 1: 1V-2V halls’ plans and models](image)

Reverberation times measurements were carried out previously in the empty hall by measuring the impulse responses in 32 positions. The source used for the measurement was a dodecahedron source which was omnidirectional up to about 4 kHz. The impulse response at each receiver position was measured by swept sine signals following the procedure recommended by the ISO 3382-1:2009\textsuperscript{10} using the software DIRAC 6.0 for signal generation and acquisition.
Two fan-shaped models are designed: 1V and 2V. Their respective nominal sizes are 3600 m$^3$ and 7300 m$^3$. The hall is geometrically symmetric but presents an asymmetric distribution of the sound absorptive surfaces which are mainly positioned in the audience area and, rear wall and rear ceiling surface. Measured reverberation times are used to calibrate the four models.

### 2.2 Simulations

Simulations are performed with two geometrical acoustic (GA) based software: Odeon® 11.00 and Catt-Acoustic® v 8.0. The first one uses a hybrid calculation method\(^{11}\), where early reflections are calculated by using a hybrid Image Source Model with stochastic scattering process using secondary sources, while late reflections are calculated by using a special ray-tracing (RT) method, where secondary sources are assigned with a frequency-dependant directionality, the so-called “reflection-based scattering coefficient”. The secondary sources may have a Lambert, Lambert oblique or Uniform directivity, depending on the properties of the reflection as well as the calculation settings. Catt-Acoustic® v 8.0\(^{12}\) combines the Image Source Model (ISM) for calculation of the early reflection, and special ray-tracing with randomized Tail-corrected Cone-tracing (RTC) for full detailed calculation. Diffuse reflections in the late part are handled by randomizing the direction of reflected rays according to the Lambert’s distribution law\(^{13}\). The implementation of these scattering techniques is subject to changes in the new versions of Odeon and CATT. Figure 2 depicts the entire structure of the surveyed simulations.

![Figure 2: Simulations scheme](image)

### 2.3 Hall model

A 3D-CAD room model is provided to run the software simulations. The geometry of the hall is simplified in order to reduce the simulation time, though without compromising the resemblance to the real space it represents. Some features are maintained the same in all the models: the height and width of the ceiling steps and audience stairs, the stage height and width, the distance of the front stage to the first seats, the distance of the rear wall to the last audience rows and the distance of the lateral rows to the lateral walls. Also the audience area is modeled
as a 0.8 m high “box” in all the models\textsuperscript{11}. The metallic grid as well as the heating and cooling pipes hanged over the ceiling are not modeled and a scattering coefficient value of 10\% is assigned to the ceiling surface instead. In order to avoid uncontrolled effects of the complex geometries present in the hall, also the two sound reflectors located on the front and rear part of the ceiling, are omitted.

The same set-up of source-receivers is used in the different simulation models: a simple omnidirectional source, with a sound power level of 90 dB, is placed in the center of the stage at 1 m distance from the front border, at 1.5 m above the stage floor and far enough from the side walls to make sure the preservation of the source’s features. 32 and 48 listener positions in the 1V and 2V models respectively are analyzed as in the measurement set-up, considering a crossed evenly spaced array distribution of 1.7 m \times 1.4 m, and extended to one of the two symmetric halves of the audience area as shown in Figure 1. The receivers are positioned at a height of 1.2 m from the floor level under each seat i.e. 0.4 m above the box upper plan.

In our simulation model the hall’s boundaries are characterized by their acoustic absorption and scattering coefficient in the GA domain. As the correct input data for simulations is usually a crucial point and source of uncertainty, they have been gathered in detail from the project documentation and literature databases in order to put the focus on the actual simulation algorithm themselves. The computer model of this hall has 8 different materials and there are no properly measured absorption data, thus for these materials “typical” data have to be assumed. The seats are with cloth upholstery, and are judged to be similar to those commonly found in multipurpose halls. The other materials presumed for the hall’s surfaces are shown in Table 1.

The absorption coefficient values of the main absorptive surfaces such as audience, lateral walls’ panels, rear wall and ceiling, are slightly varied in order to obtain the calibration of the models and fit the simulated reverberation times to the measured one. The graphs of Figure 3 show the absorption coefficient variations for both software compared to the presumed values.

We should note that the absorption coefficient measured in a reverberation chamber does not always accurately represent the actual absorption coefficient in an auditorium. Differences up to 5\% or even 10\% or more can be expected depending on the reverberation chamber measurement method used. Given these uncertainties, the computer models’ predictions of the average reverberation time were reasonably good.

Table 1: Absorption coefficients

<table>
<thead>
<tr>
<th>surface</th>
<th>material</th>
<th>f [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>125</td>
</tr>
<tr>
<td>lateral walls</td>
<td>Plaster on a brickwall</td>
<td>14</td>
</tr>
<tr>
<td>lateral walls’ panels</td>
<td>Plasterboard on frame, 13 mm boards, 100 mm empty cavity</td>
<td>8</td>
</tr>
<tr>
<td>rear wall</td>
<td>Plasterboard on frame, 12.5 mm boards, 100 mm mineral wool</td>
<td>20</td>
</tr>
<tr>
<td>ceiling</td>
<td>Plasterboard on frame, 13 mm boards, 100 cm empty cavity</td>
<td>14</td>
</tr>
<tr>
<td>audience</td>
<td>Chairs, medium upholstered, concert hall chairs</td>
<td>35</td>
</tr>
<tr>
<td>floor</td>
<td>Linoleum stuck to concrete</td>
<td>2</td>
</tr>
<tr>
<td>stage</td>
<td>Wooden floor on joists</td>
<td>15</td>
</tr>
<tr>
<td>doors</td>
<td>Solid wooden door</td>
<td>14</td>
</tr>
</tbody>
</table>
The hall is considered in an unoccupied state. More than 140 simulations were performed varying the mid-frequency scattering coefficient values (Figure 4, left) separately and combined on the ceiling, side and rear walls (s=10, 30, 50, 70, 90%). Since the two software differ on the way the scattering parameter is given, we choose to apply to the CATT-Acoustic simulations the same frequency dependent scattering values as assumed automatically in Odeon\textsuperscript{11}. To enable comparison between alternatives also the same boundary conditions such as absorption coefficients, air temperature and relative humidity are considered for all the simulations, and the same settings (transition order, number of rays), type of source and receiver, and source-receivers’ positions are kept.

Figure 3: Absorption coefficient in 1V and 2V models compared to the presumed absorption coefficients in Table1.

Figure 4: Scattering coefficient curves s=5%, 10%, 30%, 50%, 70% and 90% corresponding to averaged values at mid-frequencies $s_{500\text{Hz}}$ and $s_{1000\text{Hz}}$ (left) and reverberation time calibration for Odeon and CATT-Acoustic 1-2V models (right).
3 RESULTS

The simulation system is designed so that the reverberation times values obtained for the different scaled models for both software A and B, stay within 5% close to the reverberation time in the real hall (Figure 4, right), i.e the models are calibrated in order to have the same reverberation time for all the frequency octave bands. By keeping the reverberation time the same for all the basic models, the variation of the acoustic parameters could then be related to the combined changes of the scattering coefficient and model size. The following parameters are predicted for each model: Early Decay Time (EDT), Clarity ($C_{80}$), Lateral Energy Fraction ($LF_{80}$), Definition ($D_{50}$) and Strength ($G$). The analysis is performed by studying the results of these objective room acoustic parameters as a function of source to receiver distance (Figure 5 and Figure 6) on one hand, and versus the increasing quantity of scattering coefficients on the other hand (Figure 7 and Figure 8). Averages of mid-frequency range results are considered for the analyzes as recommended by the ISO 3382-1:2009. In the graphs of Figure 5 and Figure 6 are represented averaged values on the overall receiver positions obtained from simulations with software A and B. The most affected parameters by the scattering increasing values are EDT and $C_{80}$. Results of $G$, $LF_{80}$ and $D_{50}$ values didn’t present any variation across scattering coefficient selection for both software, therefore their graphs are not reported here.

In Figure 5 a, b and Figure 6 a, b can be noticed that at all listener positions, higher amounts of scattering increase EDT and decrease $C_{80}$. Moreover $C_{80}$ values become less fluctuating for s=90%. This is more evident in software A results, though similar behaviour is observed for software B as well. In Figure 5, graph a,b show that EDT and $C_{80}$ at rear seats for 1V model seem to be strongly influenced by scattering changes on the ceiling surface, on the contrary in graph c and d in Figure 5 is evident that there is no influence of the scattering located on smaller volume hall’s lateral walls.

Graphs in Figure 7 and Figure 8 show that EDT becomes longer and therefore $C_{80}$ values decrease for higher values of the scattering coefficient ($JND_{EDT}=5\%$, $JND_{C80}=1dB$). This is evident in both models (1V and 2V) mostly in those cases where the ceiling area is included as a scattering surface, i.e. the ceiling supplies important late reflections to the hall’s sound field. Figure 7 and Figure 8 show clear differences in behaviour across halls with and without scattering applied to ceiling surface. Also in these results can be seen that software A seems to be more sensitive to scattering selection. For this software, the differences in parameter values between the two models are probably due to the influence of the model calibration and the choice of absorption coefficients for the second model. This differences are not the object of this paper which aims the analyzes of the parameter trend as a function of scattering increasing values, though it highlights the importance of the input parameters selection. Less differences due to scattering increasing values occur in the simulations with software B (Figure 7 and Figure 8). EDT and $C_{80}$ are almost constant for scattering located on the rear and lateral walls.
Figure 5: The effect of scattering coefficient selection on Early Decay Time (EDT) in the mid-frequency range (averaged across 500Hz to 1kHz octave bands) in different receiver positions. Data are shown in seconds for two different scattering values (10% and 90%) applied two different positions in the hall (ceiling and lateral walls).
Figure 6: The effect of scattering coefficient selection on Clarity index ($C_{80}$) in the mid-frequency range (averaged across 500Hz to 1kHz octave bands) in different receiver positions. Data are shown in dB for two different scattering values (10% and 90%) applied in two different positions in the hall (ceiling and lateral walls).
Figure 7: The effect of scattering coefficient selection on Early Decay Time (EDT) in the mid-frequency range (averaged across 500Hz to 1kHz octave bands) overall the receiver positions. Data are shown in seconds for six different positions in the hall (c=ceiling, lw=lateral walls and r=rear wall).
Figure 7: The effect of scattering coefficient selection on Clarity index \( (C_{80}) \) in the mid-frequency range (averaged across 500Hz to 1kHz octave bands) overall the receiver positions. Data are shown in dB for six different positions in the hall (c=ceiling, lw=lateral walls and r=rear wall).
4 DISCUSSION AND CONCLUSIONS

The presented study aimed to analyze the influence of scattering variations in the audience area of a fan-shaped hall. Simulations were performed using Odeon 11.00 and Catt-Acoustic v8.0, while the scattering coefficient of the ceiling, side and rear walls, assumed five different values. The results showed that the combined effects of the scale factor and scattering input data have some influence on the values obtained for some of the objective acoustic parameters such as on Early Decay Time (EDT) and Clarity index (C80). The increased late energy for listeners far from the source provided longer (EDT) and consequently a decline on the Clarity was evident. This effect is pronounced in both volumes (1V and 2V) and becomes more evident in those models where the ceiling becomes highly diffusive. Compiled results confirm that the choice of scattering coefficients affects Early Decay Time (EDT) and Clarity index (C80) more than Lateral Fraction Energy (LF80), Definition (D50) and Strength (G).

Further research is being pursued to investigate how the scattering coefficient affects the hall’s sound field, as well as on selecting the most effective quantity and position on the hall’s surfaces. Future work should be integrated with listening tests on the audibility of the volume and position dependent scattering effects, and on the sound quality sensitivity to sound scattering quantity.

Since real concert halls present a disproportionate space concerning the location of absorptive surfaces, it should be important to improve the algorithms by implementing the scattering directivity of diffuse surfaces. This will help to have more reliable results on the distribution of the objective parameters across the audience area and enhance perception of scattering in auralized sounds.

REFERENCES


