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COMPUTER AIDED ACOUSTIC DESIGN AT A THEATRE RECONSTRUCTION - REALITIES AND SIMULATION RESULTS

A. Nagy*, A. Kotschy, A. Fürjes*, F. Augusztinovicz***

* Budapest University of Technology and Economics, Sztoczek u. 2., H-1111, Budapest, Hungary

** R&M Construction and Isolating Ltd, Akna u. 2-4., H-1106, Budapest, Hungary

Tel.: +36 1 463 1806 / Fax: +36 1 463 3266 / Email: s7110nag@hszk.bme.hu

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ABSTRACT
At a theatre reconstruction in Hungary we had to design the new interior. We have carried out several measurements in the existing auditorium in order to see whether, the subjective opinion was right about its acoustical quality. Parallel to the measurements we have prepared the computer model of the original condition and performed a ray tracing based analysis. The model of the designed auditorium was also created to verify the design. The two analyses were compared, which proved the improvement of the acoustical qualities.

1 - INTRODUCTION
In the last two decades, geometrical acoustics based software has become a routine tool for developing and verifying the acoustical parameters of an auditorium. During the design of the reconstruction of a Hungarian theatre we used one of these software packages to examine the interior. We have prepared the computer model of the current state and also carried out room acoustic measurements in several points. By comparing the results our aim was to find out, how to achieve a proper simulation in order to perform a reliable verification of the new designed interior.

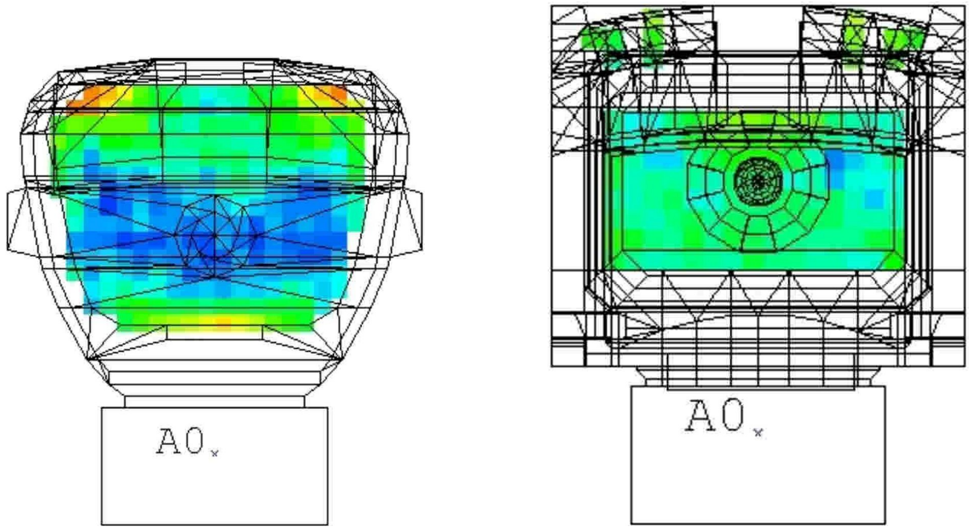
2 - MODELLING
Geometrical acoustics is based on three main conditions that give a good approach of the real situation. These are homogeneous media in which the sound propagation is rectilinear [1]; rigid boundary surfaces, so the angle of incidence equals the angle of reflection; the size of the room is much bigger than the wavelength. In most cases we can assume with homogeneous media, although in larger halls the possibility of temperature changing with height is not negligible. We can also forget about the third condition when modelling concert halls or theatres (about modelling smaller rooms e.g. studios see [2]). The only problem we have is the second condition, for specular reflection does not describe reality properly. Flat as well as more complex surfaces scatter waves, diffusion appears. Acoustic absorbers, such as membranes and resonators have flexible surfaces; the condition of rigidity is hurt. Describing their behaviour within geometrical acoustics is yet unsolved, the usual approach is modelling them as rigid objects. Diffusion itself can be easily modelled by randomising the reflection angle with the amount required. An another phenomenon that is not easy to describe with rays is diffraction.
There is a wide variety of methods with different names (Conical Beam Tracing, Triangular Beam Tracing, Cone Tracing) based on ray tracing, and also hybrid method that combine ray tracing with others (e.g. Image Source Method). Each has its advantages and disadvantages. Discussing them is beyond the scope of this article.

3 - PROBLEMS OF SURFACE PROPERTIES
Assuming that we know all of the surface properties, the model can be generated very fast. If the subject of our analysis is a room under design (as the model of the new interior was), we can measure the

absorption values of the materials in laboratory, or we can rely on the values given by the manufacturer – if they are given. Of course there are plenty of well-known materials and more libraries where these data can be found. We are facing almost the same case, if we have to re-design a room that is already built, but all the selected materials are known.
The third case is when we have an already built room, without any information about the materials of it. At creating the model of the existing auditorium we were facing this problem. There were materials, which we knew (e.g. parquet on concrete, painted brickwork) and materials which were hard to determine (mostly acoustical absorbers). An important and hard task would be to develop an in situ measuring technique of absorption coefficients, for this would ease the modelling procedure. Although most built in structures are known, it is not obvious to recognise them. In the models we tried to substitute these unknown materials with known ones.
Another noticeable problem is that beside the frequency dependency of absorption, the coefficients also depend on the angle of incidence which – as far as we know – no modelling program can handle, and no measuring technique is available to determine it properly.
Using these approximations can make us uncertain about the accuracy of the simulations.

4 - THE DESIGN PROCESS

According to the subjective opinions of the mixing engineers and the audience of the theatre, the biggest problem of the existing auditorium is its lack of reverberation and the fact that speech intelligibility is much better in the rear rows than in the middle of the stalls.
In order to verify these opinions, we have measured acoustical parameters in several points of the auditorium. The applied instrumentation was an MLS (Maximum Length Sequences) based digital signal processing system of DRA Laboratories, with a dodecahedron speaker system and a condenser microphone. We have measured the impulse responses, and from that the Energy Decay Curves, reverberation times among other parameters were determined.
The second way of verification was to create the geometrical model of the interior and perform analysis with a Ray Tracing based simulation software. There were two interesting points in the modelling process: modelling the audience (the stalls) and modelling the stage. By modelling the stage we decided to make a stage without scenery. We placed curtains in front of the walls of the stage, which gives good approximation of a sparsely furnished stage. The other point by doing so is that this state can be easily realised in the theatre, thus the measurements could refer to the same situation as the simulation. A highly absorbent material placed as a ceiling above the stage represented the stage-loft.
At modelling audience we relied on earlier measurements in which statistical values of absorption of the audience in each octave band were determined. Taking in account the high diffusity of the audience, we set the diffusion coefficients increasing with frequency as suggested by Dallenbäck in [3]. We represented the stall with a cubic object, with flat top and with height of normal shoulder-height: 80 cm. To model the empty auditorium, we took the same cube, changed the material to the so-called "cloth-upholstered chair", and set the diffusion high, where the wavelength was of the order of the distance between the rows (above 250 Hz).
As a result of the simulation analysis, the left picture of Fig. 1 shows the distribution of RASTI values over the audience. It can be clearly seen that in the rear corners, where there is lots of absorbing surfaces around, the RASTI values are higher than, e.g. in the middle of the stalls, as it was subjectively described by the audience.
To compare the measured and simulated results, see Fig. 2, which shows reverberation times versus frequency at one of the detection points. The two lower lines are minimum and maximum values measured with MLSSA, while the upper solid line shows the results of the simulation. The difference in between might origin from the fact that the chosen material properties are only rough estimates of the real ones. We have discussed the problems of surface properties above, in section 3. The fourth – upper, dashed – line shows results from a gunshot measurement. It is interesting note how much the measured results differ from each other.
If we assume the MLSSA-measured results to be right, we can draw the consequence that although the results are similar in tendencies the simulation overestimates reverberation time, therefore it might underestimate speech intelligibility.
Due to the reconstruction the whole interior has been redesigned by an architect, therefore a new acoustical design was also essential. The aim of the design was to increase reverberation while maintaining or improving intelligibility at the same time. The main idea was to use so few absorbing materials, as it is possible. To verify the effect of the new design we have also prepared the model of the new interior and performed the analysis, with the same considerations as at the model of the existing state.



(a): Existing auditorium. **(b):** Designed auditorium.

Figure 1: RASTI values according to the simulations (scale ranges from 55 (dark grey/blue) to 70 (light grey/green)).

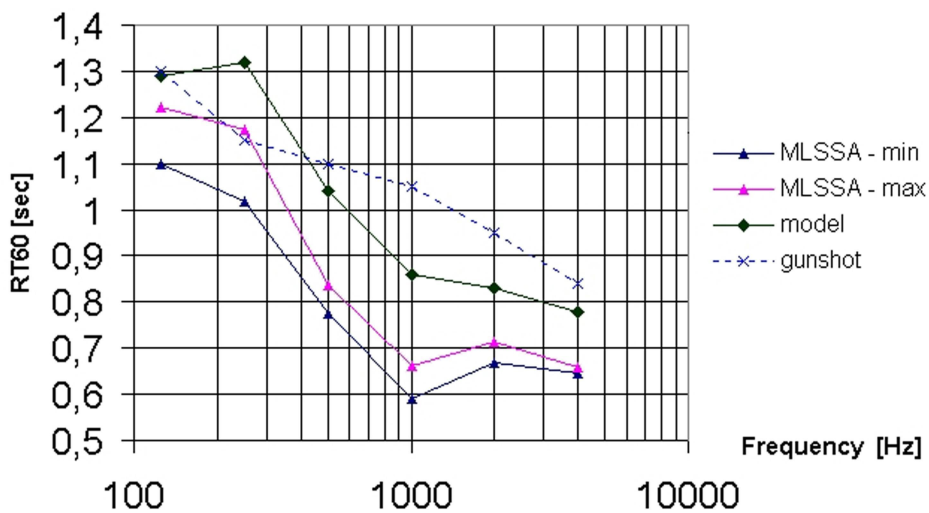


Figure 2: Reverberation times at a detection point.

5 - RESULTS

As the result of the design process, see the right picture of Fig. 1, the distribution of RASTI values are shown. We can say, that with the new interior the speech intelligibility is more even across the stalls, as it is under the current conditions. We can also add, that the variation and position dependency is smaller and the minimum value has increased by 7.

6 - CONCLUSIONS

We have performed measurements in an existing theatre to examine its acoustical quality. The results showed that the subjective opinion was right, the speech intelligibility is low and highly dependent on position. We have generated the geometrical model of the current state, and performed ray-tracing analysis. The results of the simulation gave more detailed information about the dispersion of the acoustical parameters. A new interior has been designed to improve acoustical quality. The ray-tracing analysis of the new auditorium predicts that the average RASTI values will increase at least by 7, their range of variation gets smaller and shows a lower spatial dependency.

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