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ROOM ACOUSTICAL MODELLING DIFFERENCES AND THEIR CONSEQUENCES

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Abstract

During the detailed design phase of the Pécs Conference and Concert Centre we had the great opportunity to use two different room acoustical modelling software in parallel for the evaluation of the acoustic design. As the basis, a three dimensional architect's drawing was used what was slightly modified in order to suit each programs' needs. Due to the different calculation algorithms and modelling approaches a difference of 20 percent was experienced in the predicted average reverberation times in the lower frequency range.

In this paper we present the results of investigations that were initiated by this difference. Simplified models of the hall were created and the calculations re-run, the comparison of different modelling approaches and their effects are shown in details.

Keywords: concert hall, room acoustics, modelling, reverberation time

1 Introduction

Pécs, a city in southern Hungary is one of the three cultural capitals of Europe in 2010. The cultural capital status served as a good occasion for designing and building a new concert hall and a conference centre for the city and for hosting the Pécs Symphonic Orchestra. The complex is called the Pécs Conference and Concert Centre. The building consists of a large concert hall in its core with section halls, rehearsal rooms as well as ballet and other dance rooms surrounding it.

In order to achieve excellent acoustics in the concert hall, the detailed design was carried out in a cooperation of two acoustic consultants, Mr. A. Chr. Gade (Gade & Mortensen Akustik A/S) – who had already been involved in the tender design phase as well, and Mr. A. Kotschy (Kotschy and Partners Ltd.). The two consultants have access to different modelling software (Odeon and CATT), and although both software performed very well in earlier Round Robins (see [1] and [2]), this cooperation seemed to be a great opportunity to

compare them in a real situation, by analysing the Pécs Concert Hall in different configurations. Altogether six different configurations were examined (configuration for symphonic orchestra, opera, rock music, rehearsal, banquet and conference). These configurations differ in (1) the setting of the stalls that can be raised (slanted) or lowered to be flat and horizontal, (2) the setting of the orchestra pit that can be covered and also raised to give an extension to the stage, (3) the curtains around the stage and the occupancy of the (4) seats and of the (5) stage. In all cases the spatial distribution of the main acoustical parameters (reverberation times (T_{30}), early decay time (EDT), clarity (C_{80}), strength (G), lateral efficiency (LFC, LF)) and stage parameters (ST_{early}, EDTstage) were determined and optimized.
When comparing the results, a difference of 20 percent was experienced in the predicted average reverberation times in the lower frequency range, whilst a good agreement was achieved at the mid and high frequencies. In order to find out the reason for this discrepancy, simplified models of the hall were created and the calculations were re-run. In the following the results of these investigations are shown in details.

2 Design of the Concert Hall

2.1 The Concert Hall

The concert hall is a modified shoe-box shaped hall with an asymmetric layout and two level balconies. The volume is app. 13000 m^3, the maximum extents are about $42 \times 22 \times 18$ m (length $\times$ width $\times$ height). The hall seats altogether 1000 people, the stage is designed to have place for large symphonic orchestra and choir. The walls and balcony fronts are covered with wooden panels, and the walls are equipped with pyramid shaped diffusers. Above the stage there is a canopy consisting of 7 individually moveable parts. The architect's model of the concert hall from the tender design phase is shown in Figure 1.
As the detailed design was carried out by a different architects' team, the hall has been slightly modified.

Figure 1 – Architect's model of the concert hall of the tender design phase

2.2 Acoustical studies

The basis for the simulations was a three dimensional architect’s drawing. Figure 2 shows this model from the detailed design phase (with seatings removed). This drawing was adopted in different ways to suit each modelling software's needs, therefore the resulting

models did differ in some aspects invisible for the untrained eye. Two typical room acoustical model views are shown in Figure 3. All configurations were analysed with both software. Being the acoustically most demanding configuration, the symphonic orchestra setting was examined more thoroughly than the others: all combinations of 6 source and 61 receiver positions (6 of which on the stage) were verified.
Unfortunately, at the time of the design, there was no decision yet regarding the type of the seatings, therefore we had to use a typical absorption data recommended by Beranek [3]. The initiator of this paper can be seen in Figure 4, that shows the spatially averaged reverberation time (T30) values in two settings. The symphonic concert setting means fully occupied hall, orchestra pit raised up to extend the stage, and canopy is lowered, whilst in the banquet setting the floor is lowered, curtains are hung around the stage, the canopy is raised and there are no seats in the stalls but tables and people. As it can be seen, there is a large difference in the results in the lower frequency range in both cases, and only above 500 Hz do the results agree. This phenomenon was present in all configurations (these are not shown).

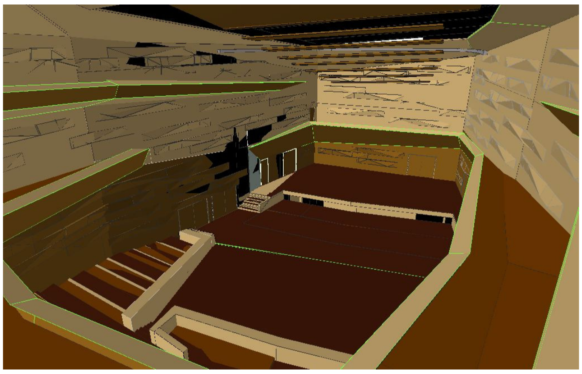

Figure 2 – Three dimensional architect's drawing used as an input for modelling

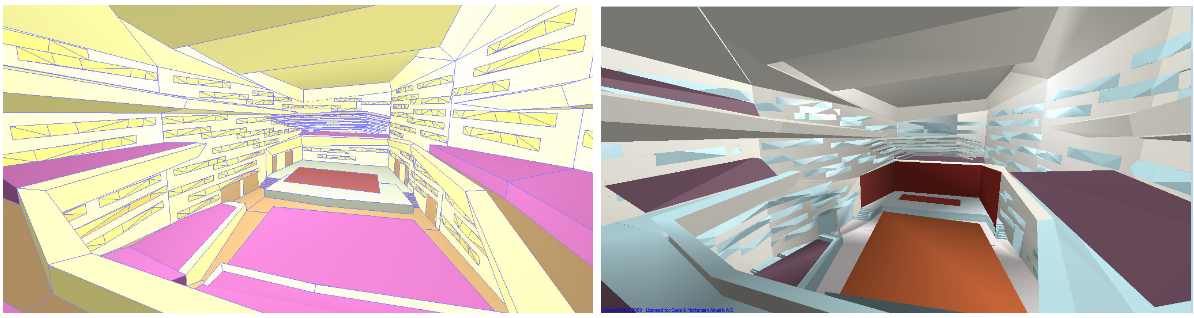

Figure 3 – Model view of symphonic concert settings (left, CATT, Kotschy and Partners Ltd.) and of banquet setting (right, Odeon, Gade & Mortensen Akustik A/S)

3 Investigations

The reason for the difference between the reverberation times in the lower frequency bands is not obvious. It can be a consequence of different modelling approaches, like using audience boxes or planes in shoulder height; of different tracing algorithms; different diffusion modelling algorithms; or of all of the above combined. In order to eliminate some of the uncertainties, a simplified model of the concert hall was built up from architect's drawings.

The discussion of different tracing algorithms is beyond the scope of this paper (see e.g. [4])., therefore only the different modelling approaches are considered below.

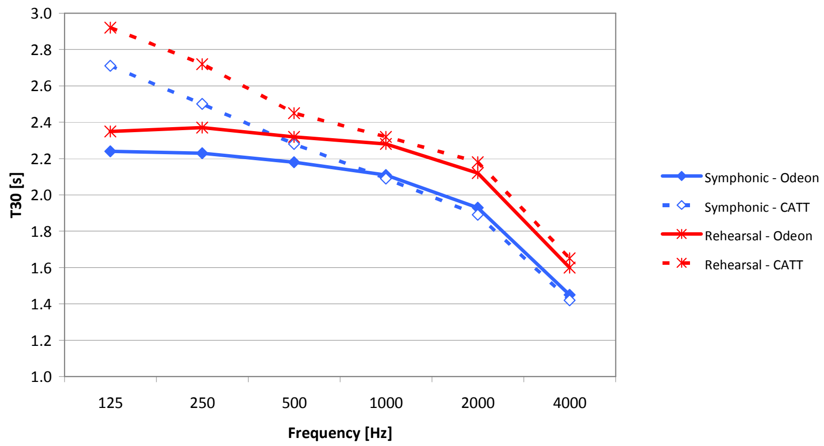

Figure 4 – Predicted reverberation times for two configurations with different software

3.1 Different modelling approaches

Beside the acoustically unnecessary details and irrelevant parts that are recommended to be removed from a room acoustical model, in order to achieve reasonable calculation results and to make the software accept it, the model must fulfill several requirements. In our case, CATT-Acoustic [5] is a bit more rigorous and has more strict rules than Odeon does [6]: the model must be closed; there cannot be single sided surfaces inside the hall; no overlapping or penetrating surfaces allowed, etc. This means that the architect's three dimensional model is typically useless, and in most cases it is better to build a new model from the beginning than to start cutting, trimming and stitching the surfaces.
On the contrary, Odeon is more permissive, architect's model can be imported more easily, and calculations run immediately. The question is if this freedom was dangerous, e.g. do extra surfaces slow down simulations, or do the indolence of the architect result in an acoustically incorrect model.

3.1.1 Escaping sound

Figure 5 shows a cross section of the architect's three dimensional model about the left rear part of the concert hall. The gaps between the floor slab and the balcony fronts are clearly seen, they might act as a sound trap, the sound-ray entering in the gap is unlikely to return into the hall.

3.1.2 Modelling the audience

There are different approaches for modelling the audience. The most common solutions are to build a brick with shoulder height (around 0.8 m) or to place a floating plane in shoulder height. These are suitable for predicting average reverberation times and other parameters, but are inaccurate if we place receivers close to these reflecting surfaces and would like to predict e.g. the impulse responses in these points. A conventional way to overcome this is to place the audience plane slightly above the floor surface thus having the right absorption and diffusion effect but without the hard reflections in the receivers.
The effect of using a floating plane for audience might cause again some loss of rays compared to the brick audience approach: the ray (or beam) entering below such a plane can suffer several reflections in a row, bumping between the floor and the highly absorptive

audience plane, which means its energy is quickly absorbed and the tracing of that ray stops. On the other hand, a rigid audience brick might underestimate the absorption effect of seated people, as the sound ray is directed away from the brick only after one reflection.

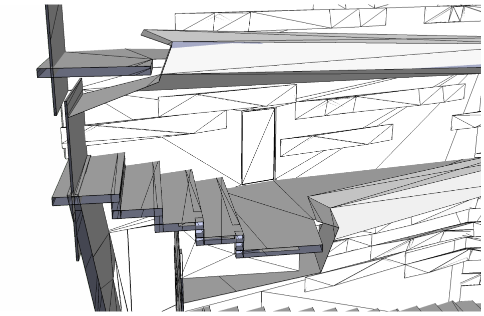

Figure 5 – Cross section of the architect's three dimensional model with gaps between slabs and balcony fronts (potential sound traps)

3.2 Models used for the investigations

The investigations were carried out on simplified models of the concert hall, built up from architect's two-dimensional drawings. The simplification implied removing small details and also the pyramid diffusers from the wall. The diffusion and absorption effects of the latter were taken into account by merging the absorption and diffusion coefficients with that of the basic wooden wall panels, proportional to the ratio of their total surfaces. This resulted in a lower number of surfaces and a more clear view.

In order to verify the assumptions regarding the modelling differences, two models were created and analysed by both software. The first one uses audience bricks, whilst the second uses floating planes (see Figure 6). The floating planes are (almost) identical to the top face planes of the audience bricks, but are raised by 5 cm. A third model with floating planes raised by 15 cm was also examined with CATT to see the effect of larger gaps.

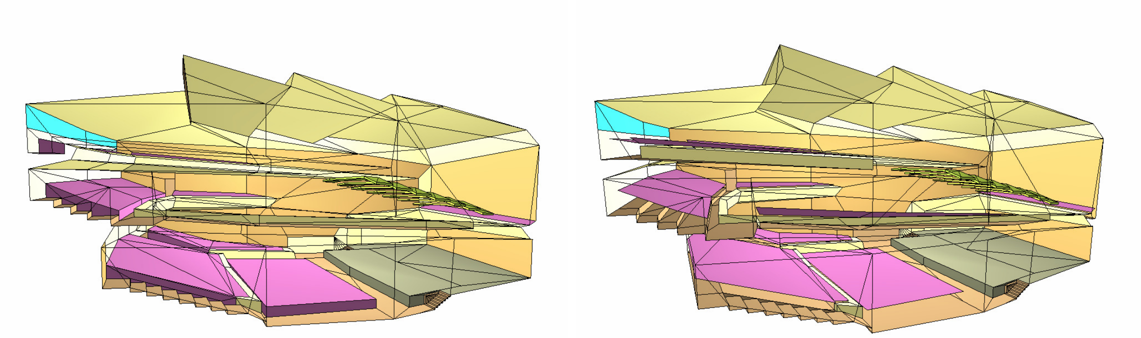

Figure 6 – Models used for the investigations: audience modelled as brick (left) and as floating plane (right)

The structure of the simulations and comparisons is shown in Figure 7. These comparisons should reveal any differences due to the modelling of the audience, however give no information on the effect of gaps (escaping sound).

3.3 Results of investigations

The basis of the investigation is the comparison of averaged common room acoustical parameters. Although the analyses of echograms or energy decay curves could yield a more detailed insight on how these prediction software work, this would need unnecessary enormous efforts in the end-user's point of view.

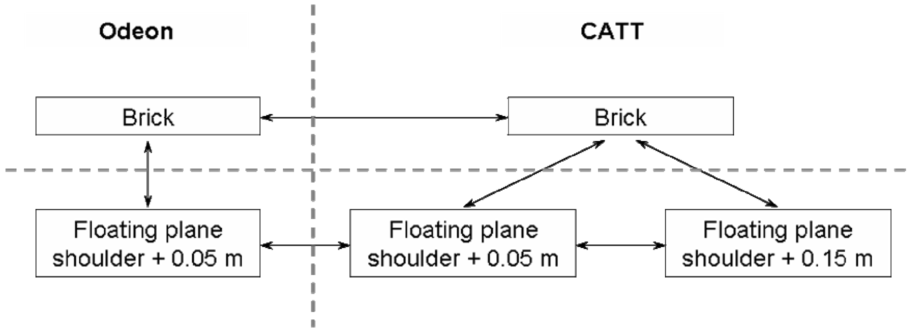

Figure 7 – Structure of simulations and comparisons of different modelling approaches

The comparison of T30, EDT and C80 is shown in Figures 8-10. Solid lines are used for Odeon, and dashed lines for CATT results. The total average reverberation times and the deviation of the results of the different analyses (two software and 3 models) are given in Table 1.

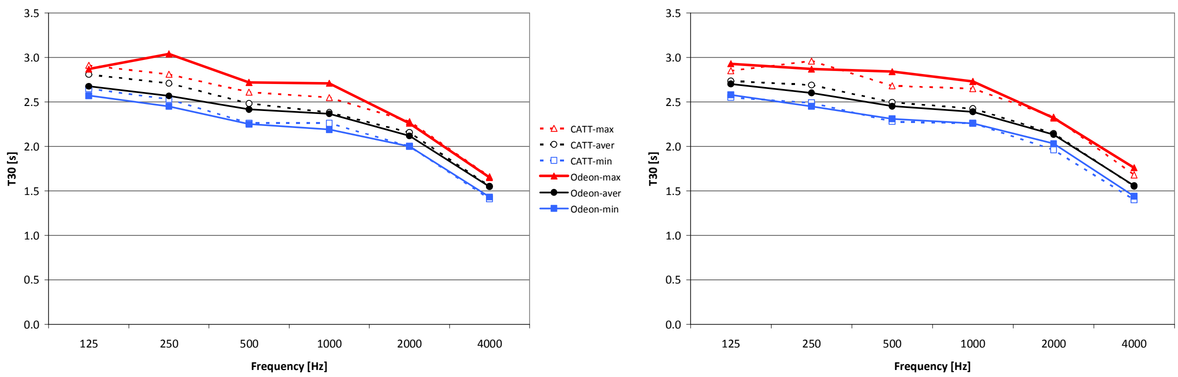

Figure 8 – Comparison of predicted reverberation times (T30 [s]), audience modelled as brick (left) and as floating plane (right)

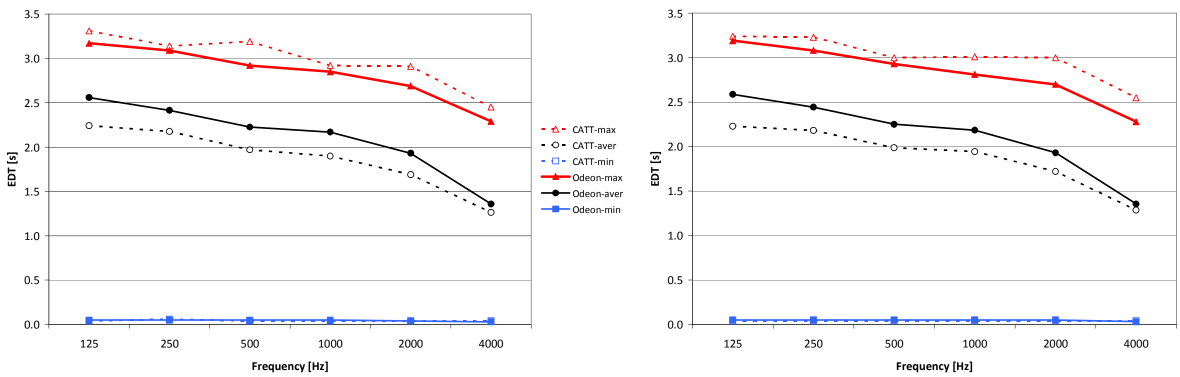

Figure 9 – Comparison of early decay times (EDT [s]), audience modelled as brick (left) and as floating plane (right)

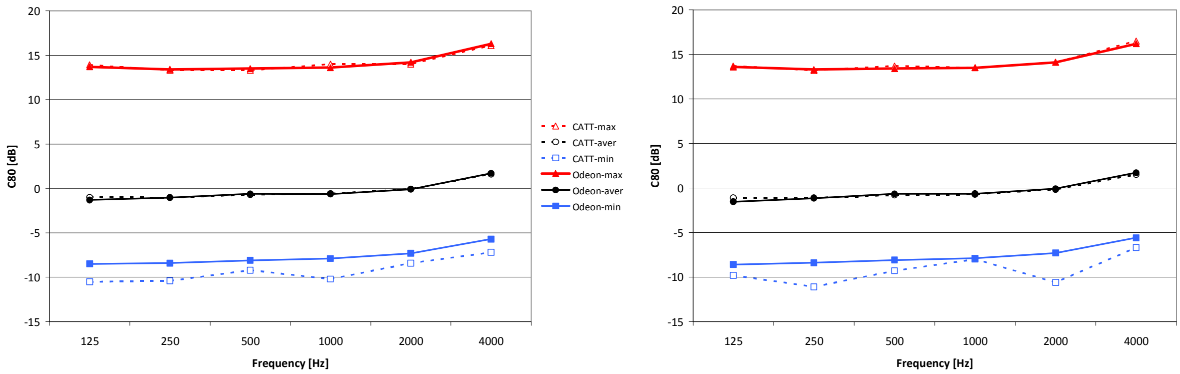

Figure 10 – Comparison of clarity values (C80 [dB]), audience modelled as brick (left) and as floating plane (right)

Table 1 – Average reverberation times and deviation of the results of different modelling approaches (in %)

		Frequency [Hz]	**125**	**250**	**500**	**1000**	**2000**	**4000**
		Total average T30 [s]	**2.72**	**2.63**	**2.45**	**2.38**	**2.13**	**1.54**
Deviation from average	CATT	Brick	3.4	2.9	1.4	0.1	1.3	0.5
	CATT	Plane at 5 cm	0.6	2.2	2.0	2.0	0.8	0.4
	CATT	Plane at 15 cm	-1.8	-1.5	-2.3	-2.1	-1.9	-1.9
	Odeon	Brick	-1.6	-2.5	-1.3	-0.5	-0.5	0.1
	Odeon	Plane at 5 cm	-0.6	-1.2	0.2	0.5	0.3	0.9

We can see that there is only a slight difference in averaged reverberation time values between the two software in each modelling cases, which is what one would expect from Round Robin results and which is reassuring. The larger difference in EDT values can be explained by the uncertainty and difference of methods for determining the decay times from readings of the Energy Decay Curve (EDC) – this diminishes when using a longer part of the curve for calculating the reverberation times, thus giving a smaller difference in T30. The EDT values around zero are results in receiver points close to the sources (ie. stage receivers).
In case of clarity, the division point of the decay process into early and late parts is clearly defined as 80 ms, which excludes reading errors and results in a very good agreement of the values.
Comparison of the results of using a plane raised only by 5 cm above the original shoulder height and of using bricks shows much smaller differences than expected, although the effect is present, as proven by the case when raising the planes by 15 cm above shoulder height (see Table 1.)

4 Conclusions

During the detailed design phase of the concert hall of the Pécs Conference and Concert Centre we have used two different room acoustical modelling software to evaluate the acoustical design. In the lower frequency range a large (20 percent) difference in average predicted reverberation times was experienced between the two software. In this paper we have presented the results of investigations that were carried out in order to find the reason for this differences.

We assumed the main reason to be a difference in modelling approaches, both in modelling the audience and the way of converting architects' drawing to geometrical models. Our investigations have shown that when using identical models, there is no significant difference between the results of the two software. We have also shown that modelling audience as floating planes placed at shoulder height or as solid bricks of shoulder height might give dissimilar results: especially when sound is likely to get below the audience planes, reverberation time tends to lower, the sound decay is faster. Although not examined, gaps (sound traps) in the model might speed up the sound decay even more.
Unfortunately our investigations have not revealed the reason for the large deviation in reverberation times of the design cases. In the simplified models, wall diffusers pyramids were omitted. The high number of these small surfaces and the difference in algorithms for modelling diffusion and diffraction might be the basis of the experienced deviation and should be the subject of our further investigations.

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