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Workshop on Advanced Room Acoustic Prediction Modelling

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ABSTRACT

The use of acoustic 3D modelling software has become increasingly popular among acousticians. Some software developers offer introduction courses for starting users. However, there is a need for more advanced courses for experienced modellers. Such a course should not only consist of lectures with the scientific background of the model, but should also give room for sharing practical experience so one can learn from one another. In this context a master class on room acoustic prediction modelling has taken place in January 2010. A significant part of this master class consisted of a modelling workshop. By working on an assignment in small groups participants were stimulated to discuss ideas and exchange knowledge. The workshop was divided into four different parts, each part carefully tuned to the theoretical lectures in between. The workshop assignment was to compare predicted room acoustical parameters with measurement results concerning reverberation and speech intelligibility in an open plan office. Also an auralisation had to be made using multiple sound sources. The open plan office of the Laboratorium voor Akoestiek of Eindhoven University of Technology where the workshop took place served as an interesting modelling object. This room was interesting for educational reasons, since the participants were inside the room, as well as for acoustical reasons, because it consists of two coupled volumes, many details like furniture and a wide range of different materials. In this paper the assignment will be elucidated and the results will be presented. The response of the participants and the experience of the master showed that a workshop is an indispensible part of master classes in the field of room acoustics.

INTRODUCTION

There are many prediction modelling approaches available to estimate the room acoustical performance parameters of rooms. Some modelling techniques are statistical models, like Sabine and Eyring etc., and others are geometric models, like image source models and ray- or conetracing models etc. Besides the statistical models, most of these models rely on 3D geometric models which are not easily programmed in a spreadsheet and are too complex to program one self. Therefore the use of acoustic 3D modelling software has become increasingly popular among acousticians. One of the reasons for this popularity is the accessibility of user-friendly software that has been developed to manage complex calculation models and the increase of available computer power. On the other hand, the increasing complexity of architectural designs demand more and more complex acoustic modelling.

The calculation models and user interfaces that form the base of most acoustic 3D modelling software are being developed further and further, resulting in more accurate models and more modelling possibilities. However, the outcome of the computer model is still highly dependant on the input of the model. The improved user friendliness of the software programs, like the use of CAD import of (architectural) models, does not guarantee a meaningful acoustic model. The development of existing acoustic 3D modelling software has also resulted in an increased number of input parameters. This gives the user more modelling options to consider and more potential results to evaluate. A starting software user will likely follow the modelling instructions from the manual to get started, leaving many modelling options default or unattended. At some point, a more advanced user will have the need to know more about the background of the actual calculation model of the program to make effectively use of all the programs possibilities, to further improve his modelling skills and hopefully to make more accurate predictions.

Some software developers offer introduction courses for starting users. However, there is a need for more advanced courses for experienced modellers. Such a course should not only consist of lectures with the scientific background of the model, but should also give room for sharing practical experience so one can learn from one another. In this context a master class on room acoustic prediction modelling has taken place in January 2010, lead by J.H. Rindel as master and organised by Level Acoustics. A significant part of this master class consisted of a modelling workshop. By working on an assignment in small groups of two, participants were stimulated to discuss ideas and exchange knowledge. The modelling workshop was divided into four different parts of 1.5-hour time, each part carefully tuned to the theoretical lectures and demonstrations in between.

THE MODELLING OBJECT

The workshop assignment was to compare predicted room acoustical parameters with measurement results as reverberation time and speech intelligibility in an open plan office. During the master class the open plan office of the Laboratorium voor Akoestiek of Eindhoven University of Technology (figure 1) where the workshop took place served as an interesting object. Open plan office environments are an example of potentially very complex rooms to model. This open plan office consists of two coupled volumes, many details like furniture and a wide range of different materials. Another important reason to use this room was that the participants of the workshop were inside the actual room, which gave full opportunity to experience the room by all senses.

Figure 1: View into the open plan office.

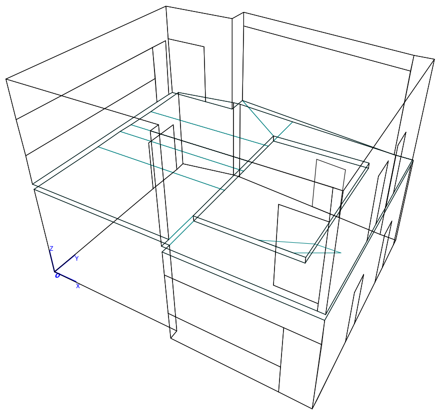
THE ASSIGNMENT

The assignment was divided into four parts. At first a given basic geometric model of the open plan office was to be worked out more in depth. After that, a prediction was made of room acoustic parameters related to reverberation time and speech intelligibility. Based on the participants' aural experience of the acoustics in the open plan office, the model was fine-tuned. With the optimised model, an auralisation has been made of a scenario of 3 simultaneous speakers heard at one listening position. In the end, the predicted parameters were compared to given results of in situ impulse response measurements and the auralisation was compared to a given convolution using measured binaural impulse responses. Performing room acoustical measurements by participants was not part of the workshop. During this workshop, 3D room acoustic prediction modelling software Odeon 10.1 and room acoustic measurement software Dirac 4.1 have been used. Participants were not expected to have particular experience in these two programs.

PART 1: Building the geometric model and preparing the calculations

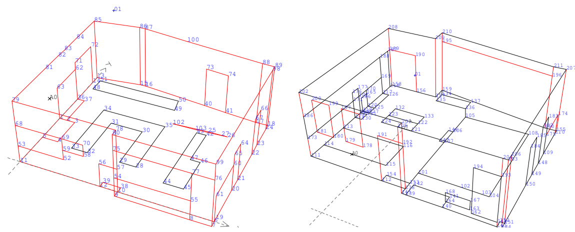
The goal of part 1 of the workshop was to discuss approaches to model the room geometry, sources and receivers, to predict material properties and to choose calculation model variables. During the master class, the available techniques and recourses have been discussed in advance during lectures.

Participants were expected to have experience in building basic 3D models. Therefore this part of the modelling process was skipped and a basic geometric model was given, made by the workshop organiser using coordinates and planes (figure 2), a technique used in most common room acoustic prediction modelling software. Also an overview of useful coordinates is handed over to the participants by pictures (figure 3) and a list with x, y, z coordinates (figure 4). Some coordinates were used in the given basic model to form surfaces, other coordinates show the footprint of obvious objects to be worked out, i.e. tables, chairs and cupboards. Participants were encouraged to give their own interpretation which surfaces or objects are most important to model, what the amount of detail should be and how one should model different parts. Besides the given coordinates, rulers were made available to measure dimensions in the room for unknown coordinates.



(Picture generated using Odeon software)

Figure 2. Given basic 3D model of the open plan office.



(Pictures generated using CATT Acoustics software)

Figure 3. Location of coordinates used in given model. (left: 1st floor, right: 2nd floor)

	No	x	y	z
Pt	1	0	3.75	0
Pt	2	0.4	3.75	0
Pt	3	0.85	3.75	0
Pt	4	0.85	2.05	
Pt	5	0		
Pt				

Figure 4. Excerpt of coordinate list used in given model.

The basic model did not contain any material information. Participants were encouraged to look around the room to see and feel what materials are used in the room. Sound absorption and sound scattering properties of these materials were then assigned to the various surfaces in the model, making use of the material library and/or by predicting the material properties from experience.

After building the geometry participants used various debugging tools to check whether their model contains errors or is 'leaking' sound. Finally, common calculation parameters were setup, such as the number of rays, the impulse response length and transition order between the Image Source Model and the Raytracing model. Also, a background noise level following NC curve 35 dB was entered into the model.

PART 2: Calculating and interpreting room acoustic parameters

The goal of part 2 of the workshop was to discuss room acoustic prediction and analysing approaches. Often 3D room acoustic prediction modelling software offers statistical calculation models as well as geometric calculation models. The principles of these models have been explained during the lectures in between part 1 and 2 of the workshop.

Using their own geometric model made in part 1 of the workshop, participants could choose out of available calculations and presenting styles to judge the acoustics of the open plan office objectively regarding the following subjective parameters:

- Reverberance
- Decay of sound level
- Speech Intelligibility
- Speech Privacy

Unlike most statistical models, the geometric models require source and receiver positions to calculate an impulse response to determine acoustic parameters. Participants had to think of source-receiver pairs to investigate and to program into the model taking into account the sound source properties like sound power and directivity.

Participants were encouraged to judge whether the calculated parameters are as expected by experiencing the acoustics in the room. The model was fine-tuned until a certain level of satisfaction was reached. A break halfway part 2 of the workshop allows participants to make the more time-consuming calculations.

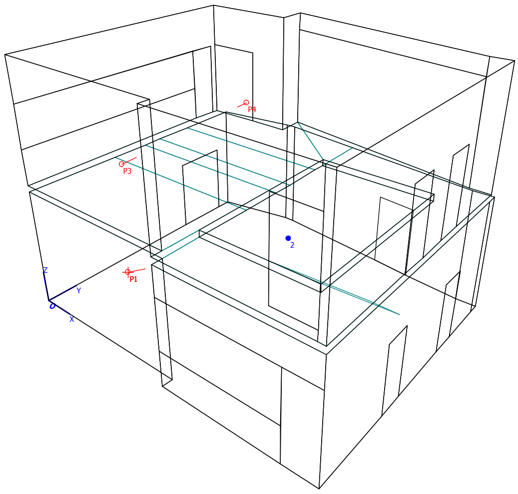
PART 3: Making multi-source auralisation of 3 sound sources and 1 receiver

During part 3 of the workshop auralisation was introduced as a tool to judge the acoustics as predicted by the model. Auralisation can be used to get an impression how a modelled room will sound and is the process where a calculated impulse response and a dry recorded sound are combined using convolution. The final result is a recording of that sound together with the acoustics of the modelled room, taking into account source and receiver directivity.

During the master class, the theory and benefit of auralisation was explained in lectures in between part 2 and 3 of the workshop and recent acoustic projects with auralisation were presented via a surround sound loudspeakers setup.

Then, the following scenario was to be auralised binaurally for the use of headphones:

> A student (S3) and teacher (S4) are discussing a report on the 1st floor working area; they are speaking more or less simultaneously on a normal voice level (60 dB(A) at 1m). In the meanwhile, another teacher is standing in front of the whiteboard (S1), giving a lecture with a raised voice (65 dB(A) at 1m), while a student is listening to it on the ground floor (R2). Produce an auralisation of speech sound as perceived by a student, trying to listen to the lecture, while hearing the conversation on the second floor. Take into account the background noise from the building services (see figure 5 for source and receiver positions).



(Picture generated using Odeon software)

Figure 5. Auralisation scenario with 3 sources + 1 receiver.

For this workshop anechoic recordings had been collected and given. For source 1, a male speaker was chosen talking about a scientific subject as if he is giving a lecture. For source 3 and 4 two samples were given of two women talking to each other as if they are having a conversation with short sentences. Also the positions of the sound sources and receiver had been given in the basic room model. This was done to be able to compare the results of different groups with each other and to compare the results with the given measurement results.

PART 4: Discussing the results and comparison to measurement and recording data

In the last part of the workshop the results from the prediction modelling were compared to the measurement results. Impulse response measurements had been performed by the workshop organiser at the exact same source and receiver positions in the open plan office. At all source positions, a mouth simulator was used as loudspeaker. At all receiver positions, an omnidirectional microphone was used and for the auralisation at receiver position R2 a head and torso simulator with two microphones in the ears was used.

The measurement software Dirac offers the possibility to directly import measured results into the prediction software Odeon. The measured and predicted results can then be presented in graphs for comparison and improvement of the model (figure 6). Another useful comparison tool is making a graphical overlay in Dirac of a measured impulse response and a calculated impulse response from Odeon (figure 7).

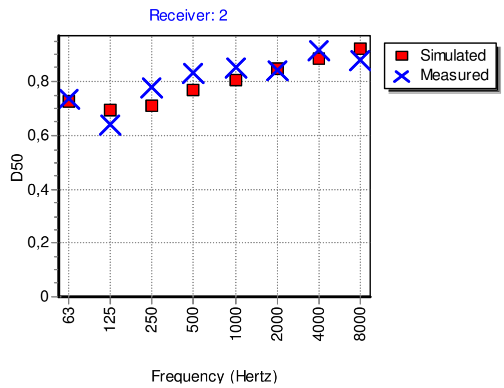


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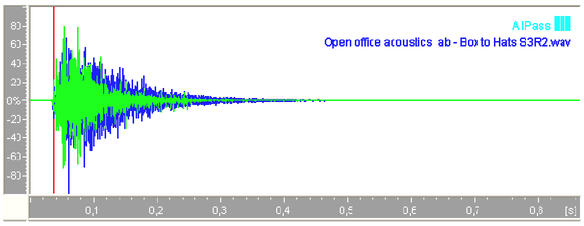
Figure 6. Comparison of measured and predicted results.



(Picture generated using Dirac software)

Figure 7. Comparison of measured (blue) and calculated (green) impulse response of source-receiver S3R2.

In between part 3 and 4 of the master class workshop the measurement system and comparison tools were demonstrated and some measured room acoustical parameters were presented to the participants on paper in tables and graphs. Also the measured impulse responses and auralisation were made available. To save time, all the measurement data had already been imported into the modelling software by the workshop organiser while participants were having a break.

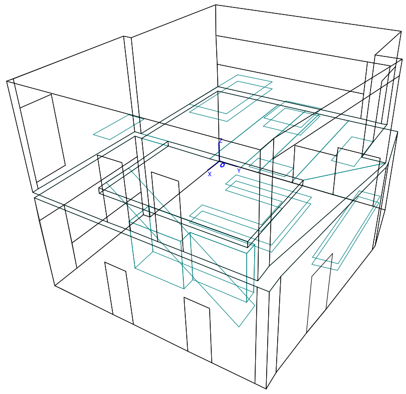
After the data import, participants could check their models and make comparisons between the measured room acoustical parameters and the modelling results from part 2 of the workshop. Also the auralisation from part 3 of the workshop could be compared to the auralisation based on the measurements. Participants were encouraged to discuss possible improvements to their model.

RESULTS

To conclude the three-day master class and workshop on room acoustical prediction modelling the results of all the groups were collected by the organiser and presented to the group. The results were taken from the last version of the models, after the models have been calibrated to the reverberation time. In total four different models were produced by three groups of two participants (group names 1, 2 and 3) and one group consisting of the master and organiser (group name MO). The MO model was prepared before the workshop with more modelling time then the participants.

Geometric model (part 1)

At first the geometric models made during part 1 of the workshop were compared (figure 8). Within the available 1.5-hour time the groups managed to discuss and model most of the relevant details. All groups considered the open doors towards other offices important to model, as well as some tables, chairs and cupboards. All groups modelled the furniture on top of other surfaces like floors and walls. A difference between the four groups was the way of modelling tables and upholstered chairs. Group 1 modelled the tables and chairs as two floating double sided surfaces, group 2 as a horizontally table surface and a vertical chair surface on the side of the sitting person. Group 3 also used a floating surface as a table, but used separate surfaces for seat and back of the chair. Group MO used a box with one side sound absorbent. Most groups modelled the cupboards as boxes and the stairs as one single surface without steps. Only group 3 modelled the two carpets on the 1st floor. Only group MO modelled the light fixtures on the 2nd floor.



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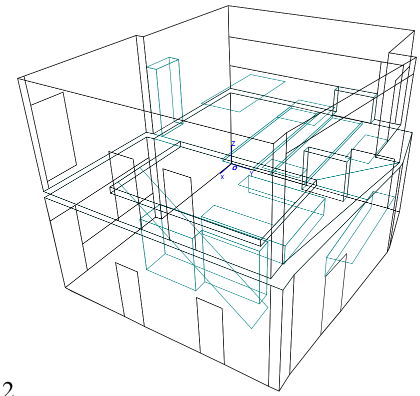

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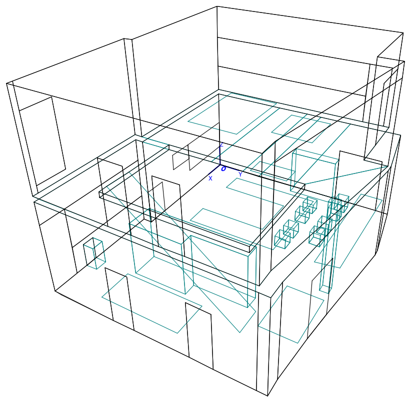

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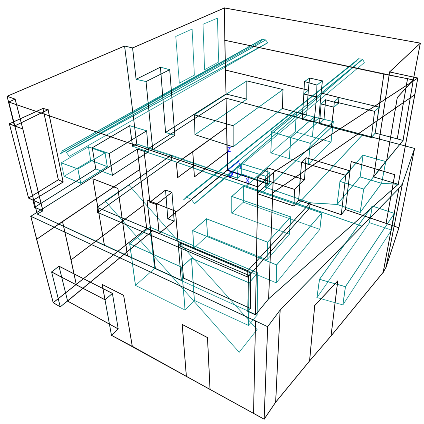

MO

(Pictures generated using Odeon software)

Figure 8. Overview of the four different geometric models.

Material properties (part 1)

Also the sound absorption and sound scattering coefficients of the materials used in the models were collected. The properties of some materials that seemed less straight forward to estimate are shown in figure 9 and 10.

Figure 9a shows that most groups assigned some low frequency sound absorption to the wooden tables, except for group 1.

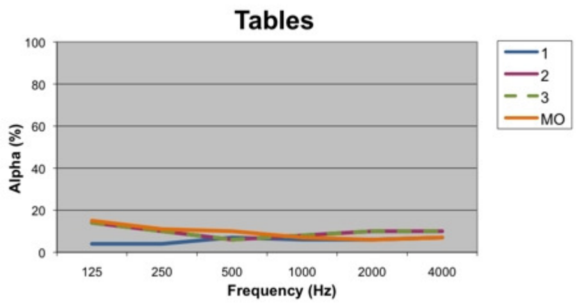

Figure 9a. Sound absorption of tables.

The choice of sound absorption of the upholstered chairs varies a lot between the groups, see figure 9b. Most groups used an increase of sound absorption with frequency, however the amount of absorption varies heavily. The variety of choices may be related to the choice of geometric modelling. However, in general it proved to be hard to estimate sound absorption by chairs.

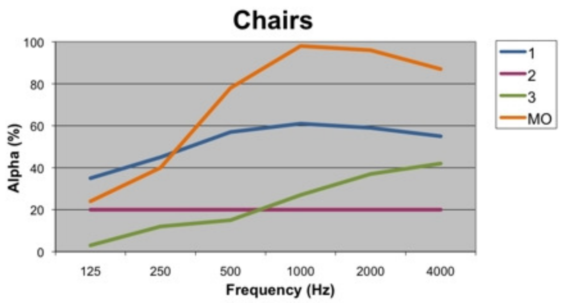

Figure 9b. Sound absorption of chairs.

The choice of sound absorption by the carpet on wood on the 2nd floor shows also some interesting variation, see figure 9c. All groups used a moderate sound absorption increase per frequency. However group 2 and MO increased the sound absorption at the low frequencies to take into account the panel absorption of the wooden floor below the carpet.

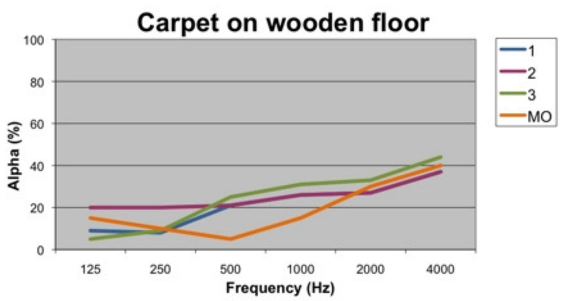

Figure 9c. Sound absorption of carpet on wooden floor.

Figure 9d shows the estimation of sound absorption of the porous concrete blocks that cover a large part of the wall surfaces of the open plan office. All the groups decided to use a more or less frequency independant sound absorption with a large variety from 30 to 60%. After the first comparison of predicted and measured results, most of the groups increased the amount of absorption of this material to fine-tune the model.

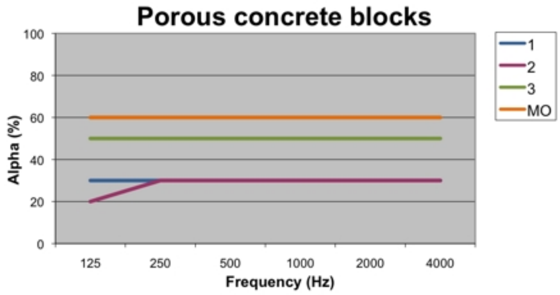

Figure 9d. Sound absorption of porous concrete blocks.

Another interesting 'surface material' are openings towards outside the modelled room, see figure 9e. Examples of openings in the acoustics laboratory are open doors towards smaller offices and air gaps next to the sound transmission rooms to seperate the rooms from the rest of the building. In many cases these openings can be modelled as sound absorbing surfaces in stead of modelling the geometry behind the openings. Most groups estimated a large absorption of openings from 60% to 90% for all frequencies.

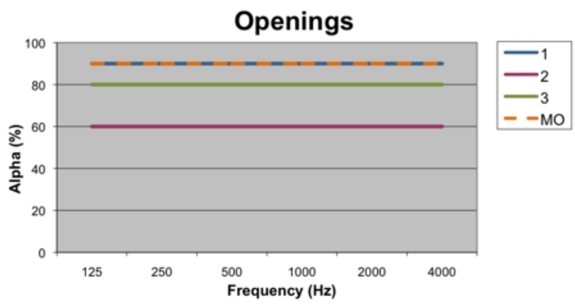

Figure 9e. Sound absorption of openings.

Besides the sound absorption of the materials, also the sound scattering of these materials have been evaluated, see figure 10. Most groups assigned higher scattering to the chairs, except group 2 that did not consider scattering at all. Also most groups assigned high scattering to the stairs, to model the zigzag shape of the steps. Group 3 assigned high scattering to the carpet on wood to compensate for the lack of furniture in their model on the 2nd floor.

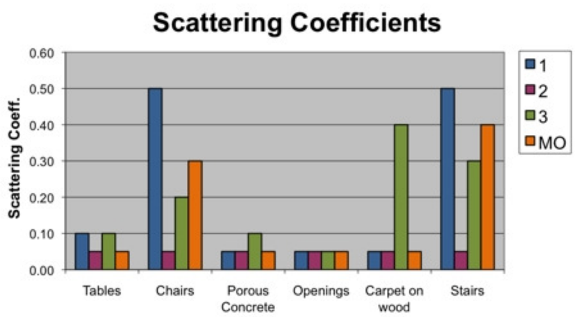

Figure 10. Scattering coefficients.

Finally, some calculation model input variabels were compared between groups, see figure 11. The groups 1 and 2 did not change the default number of rays of 1000. Group 3 and MO followed the amount of rays that is recommended by the software. Due to the higher amount of detail of the group MO model, a higher amount of rays was recommended.

The impulse response length for groups 1, 2 and MO was set to the default 1000 ms value. According to the software manual this values should be at least 2/3rd of the expected reverberation time of the room. Group 3 increased the impulse response length to 2000 ms.

The transition order for group 1, 2 and 3 was set to the default value of 2. Only group MO decided to decrease the transition order to avoid excess use of the image source model because of the room having many small details.

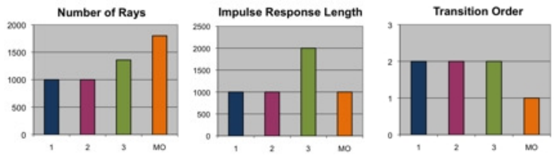

Figure 11. Calculation model input variables.

Calculation results (part 2)

Some estimated room acoustical parameters were collected from the four groups and compared to the measured parameters. All calculations were performed by the geometric model using the Image Source Model and Raytracing. Source and receiver pairs S1R2 (with direct sound) and S3R2 (without direct sound) were chosen for the analysis.

Important parameters related to reverberance are Early Decay Time (EDT) and Reverberation Time (T30). Figure 12 and 13 show that the calculated results of most groups are reasonably close to the measured results, which may be explained by the calibration of the models to the measurements (the groups predicted a higher T30 at first).

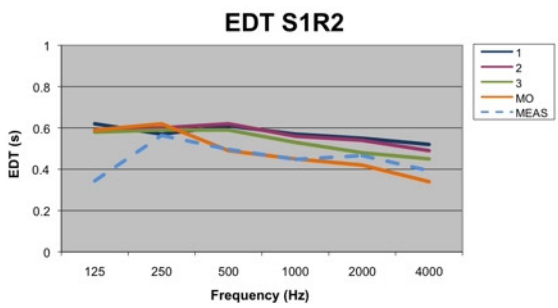

Figure 12a. EDT with source on receiver floor.

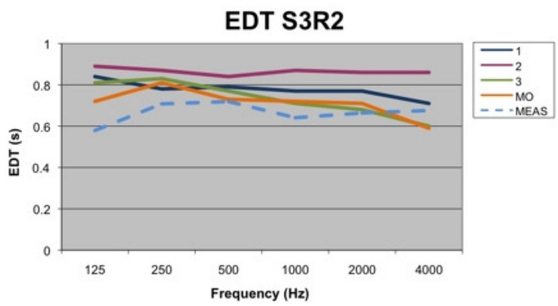

Figure 12b. EDT with source on floor above receiver.

Looking at the EDT a clear difference of +/- 0.2 s is shown between the source on the 1st floor (S1) and the source on the 2nd floor (S2) with the same receiver position R2. This difference is found in the measured results as well as the predicted results. It seems that all groups were able to model this trend well.

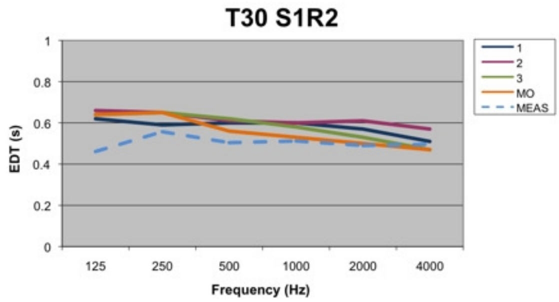

Figure 13a. T30 with source on receiver floor.

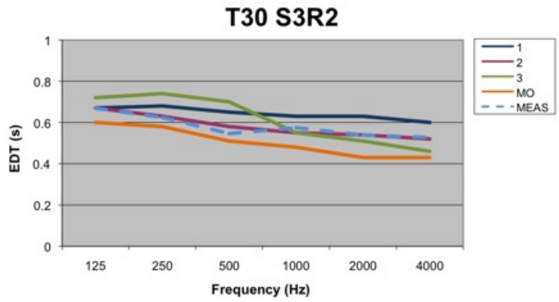

Figure 13b. T30 with source on floor above receiver.

Important parameters related to intelligibility are Definition (D50) and Speech Intelligibility Index (STI). Looking at the D50 in figure 14 a clear difference of +/- 0.4 is shown between the source and receiver pairs S1R2 and S3R2. Again most groups were able to model this trend well.

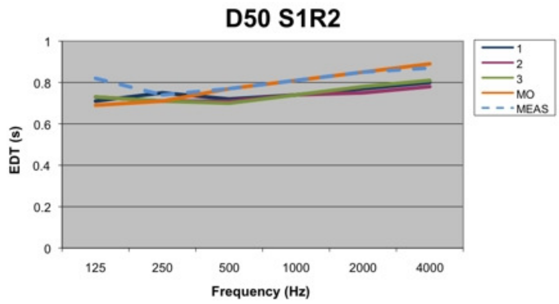

Figure 14a. D50 with source on receiver floor.

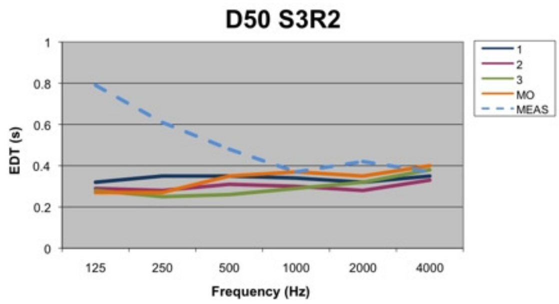

Figure 14b. D50 with source on floor above receiver.

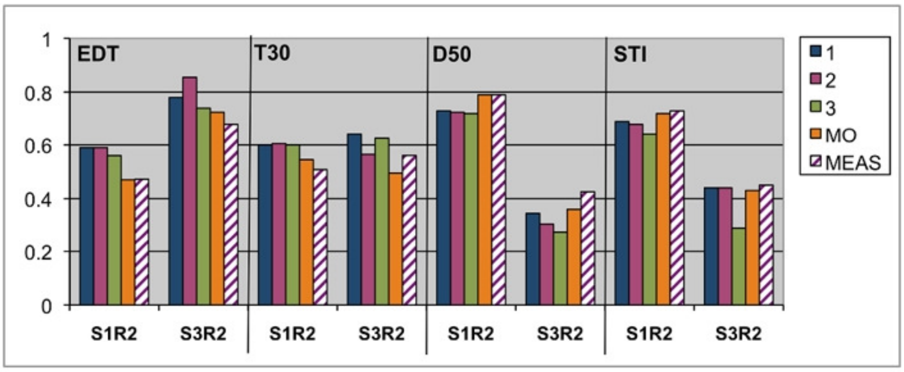

Figure 15. Comparison of all parameters EDT, T30 and D50 single number rating (average 500 – 1000 Hz) and STI with background noise.

For source and receiver pair S3R2 there is a large difference between the measured and calculated D50 at low frequencies.

Looking at the STI in figure 15, a clear difference of +/- 0.2 is shown between the source and receiver pairs S1R2 and S3R2. The STI seems to be predicted well by most groups. Again, the trend between different source positions is clear in measured as well as calculated results.

Figure 15 also shows the single number rating in accordance with ISO 3382-1 [1] for the three parameters EDT, T30 and D50. In general, it is shown that the different groups following the workshop were able to calibrate the model to the measurement results reasonably well.

Auralisation (part 3)

The auralisations made by the participants were collected from the four models. During the final presentation of the results of the different groups, all auralisations were played back and discussed. All of the groups managed to make an auralisation of the assigned scenario with background noise. Judging the different group auralisations, most sounded comparable. When comparing the modelled auralisation to the auralisation derived from the measurements, a large difference was audible in sound spectrum and quality making comparison difficult.

CONCLUSIONS

It is shown that,

- different approaches are used by different experienced room acoustic modelers to make a room acoustic prediction model;
- uncertainty about material properties may result in large deviations of room acoustic parameters;
- after calibration of the model to the measurement results of the reverberation time, trends in room acoustic parameters have been predicted well by all modelling groups;
- for most participants of the workshop auralisation seemed like a promising tool to judge room acoustic predictions. However, it seemed difficult to really judge room acoustics by ear (only).

The response of the participants and the experience of the master showed that a workshop is an indispensible part of master classes in the field of room acoustics.

FUTURE IMPROVEMENTS

Participants were asked to give feedback for future improvements of the master class and workshop in a questionnaire.

Some of the following may be considered to improve or extend the workshop:

- add group discussions in between and during different workshop parts;
- take more time for the geometric modelling during part 1;
- save a separate model version of every part of the workshop, to be able to see results before and after calibration of the model.

REFERENCES

1 ISO 3382-1:2009, Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces