RECENT EXPERIENCES IN USING ROOM ACOUSTIC SCALE MODELS

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1 INTRODUCTION

As acoustic advisor for the Danish Radio Concert Hall and as acoustic designer for the new Drama theatre for the Royal Theatre, both currently under construction in Copenhagen, the author has had some resent - and very different - experiences in the use of acoustic scale models.

In the case of the Danish Radio the task was to check the design (carried out by Nagata Acoustics) regarding fulfilment of acoustic specifications set up in the brief. However, this exercise was also a fine opportunity to check the performance of scale model measurements against computer simulations, which were also carried out during this project.

In the case of the Drama Theatre, for which the acoustic design is carried out by Gade & Mortensen Akustik in cooperation with Arup Acoustics, an acoustic model representing only a limited part of a curved auditorium wall was built in order to test wether diffusion treatment was adequate to avoid focusing of the sound.

In the following these two modelling experiences are described leading to thoughts about the applicability of scale models in this era of still better and faster computer models.

The purpose of room acoustic modeling is of course to be able too predict and evaluate the acoustic behavior of the room before it is built. Therefore, ideally we would like the technique to handle all [1]physical phenomena of importance for the result including room shape and volume, source/receiver characteristics and positions, surface properties: absorption, diffraction (due to surface size rel. wavelength) and scatter from surfaces not modeled in geometrical detail. Physical scale modeling has been applied as a prediction tool for more than 75 years, but over the last four decades, computer simulation in virtual models has offered a still more convincing alternative to physical scale model measurements[1]. The main differences between the two techniques are essentially the basic difference between simulation and measurement: whilst the former tries to describe nature through mathematical models, the latter monitors the actual physical phenomena.

Both techniques are subject to obvious sources of error – besides the accuracy in the building of the virtual or physical model subject to investigation. Simulation accuracy is limited by the simplifications in the theories and algorithms used to describe the physical reality: not least those associated with diffraction and diffusion properties (often causing too few and often too loud specular reflection components) but also interference and angle dependant absorption phenomena (e.g. grazing incidence attenuation over audience surfaces) are not accurately described by algorithms treating sound as energy. In scale model measurements scaling of the signal frequency according to the model ratio, 1:M causes problems with compensation for increased air absorption at high frequencies, and it is also difficult to find materials and constructions for building the model having absorption characteristics versus fxM matching the absorption versus f of the materials to be used in the real room. This latter issue becomes even more complicated if the materials are not locally reacting or have complex surface impedance influenced by structural vibration.

For auralization, physical scale models often provide a too limited dynamic range due to need to equalize a non ideal spectrum of the source , high noise floor in microphones with small membrane area or due to a calculated compensation for the air absorption. In computersimulations, a harsh sound is sometimes found due to ill represented (too few and too loud) individual early reflection components in the calculated impulse response.

In practice, the most serious problems related to accuracy of each of the two techniques are limited treatment of frequency/direction dependant diffraction and scattering in simulations and limited frequency and dynamic ranges in the scale models (which become more severe the large the scale ratio. In both techniques, problems regarding correct absorption versus frequency are normally treated by adjusting the absorption properties of secondary surfaces so that the reverberation time match the desired result! In other words, the main purpose of modeling a complex room is seldom to check reverberation time, but rather to investigate phenomena related to the reflection sequences generated in the room, i.e. calculation of ISO 3382 (or other) parameters and visual inspection or auralizations of impulse responses – not least to check for echoes.

The main acoustic virtues of simulations are quick and automatic analysis of a large number of positions/parameters including a full record of transmission paths for individual reflections (be careful not to drown in the overwhelming information!), whereas the main advantage of scale models would be its precise representation of diffusion and diffraction (if appropriate geometrical detailing is provided by the scale model).

Besides the issues of quality and quantity of the acoustic information, also other differences between the two techniques are worth mentioning. Simulation offers fast model building and analysis (i.e. it is cheap), erquires no special lab facilities, and auralization is easy. On the other hand, scale models offer high visualization value for architects and other partners working on the project the fact that they can be used to promote the project towards press and potential sponsors can sometimes compensate for them being expensive and time consuming to build and analyze.

In practice, economy and time often determines the choice - in favor of a computer simulation. However, for prestigious and/or complicated projects (e.g. with complex surface structures) scale models are still often most relevant – but seldom without computer simulation being used as well - as was the situation in both of the modeling tasks described in the following.

2 DANISH RADIO CONCERT HALL MODEL

2.1 The model

For the new Danish Radio concert hall currently under construction in Ørestad, Copenhagen, the design brief requested use of a physical scale model for prediction of the acoustic performance during the design phase. In the discussions with Nagata Acoustics, the acoustic designer chosen by the winning architect Atelier Jean Nouvel, it was decided to build the model in 1:10 scale. The material used for the model is primarily MDF boards and plywood all varnished to avoid unwanted absorption. Due to the complex shape of this wine yard style concert hall, major surfaces of the model were built from layers of MDF-boards each being cut by a computer controlled milling machine programmed to follow horizontal slices in the architects' 3D model of the hall. The model measures roughly 4m x 5m x 2m, and the building costs - including the shed housing it on the site – amounted to about 250.000 Euro. To this should be added the fees to the Acoustic designer and the author for the acoustic testing. Still, the Danish Radio project management is convinced that it was worth the investment, not only because of the value of the acoustic tests; but also because it has helped to visualize and advertise the project towards visitors and contractors bidding on the project. Besides, the model has also been used for lighting design experiments. The photo in Figure 1 shows the model.

Figure 1: The 1:10 scale model of the new Danish Radio concert Hall. View from the organ towards the seat sections in front of the stage. The head of the author's son has been used to indicate the dimensions.

2.2 The acoustic tests

The reason for the acoustic testing being performed both by the acoustic designer and the client's acoustic advisor was that we had different agenda's regarding the use of the model. While the designer primarily wanted to use the model in search for possible echoes and for recording of sound build up functions, the author's measurements primarily aimed at predicting values of the ISO 3382 room acoustic parameters as required in the design brief.

Whereas the Nagata measurements in the model employed filling the model with Nitrogen to avoid excessive air absorption, the author counted on the calculated compensation as found in the Dirac measurement software. The benefit of the latter approach was more free access to the model and choice of measurement positions, but the price was a much reduced signal to noise ratio in the recorded impulse response, which is still adequate for calculation of most of the room acoustic parameters; but which makes the signals unsuitable for convolution with music signals and auralization.

The measurement equipment consisted of an electric spark source, a ¼" microphone (GRAS, type 26CB plus 40BE preamplifier), a 96 kHz sound card (Edirol, UA-5) plus the "Dirac" software running in a portable pc. The Dirac programme performs recording of the signal to disk, conversion of the frequency scale, air absorption compensation, filtering in octaves and calculation of the parameter values. With the single ¼" microphone having omni-directional sensitivity, only the monaural parameters (T, EDT, C, G in audience area and on stage EDT and Support) were calculated.

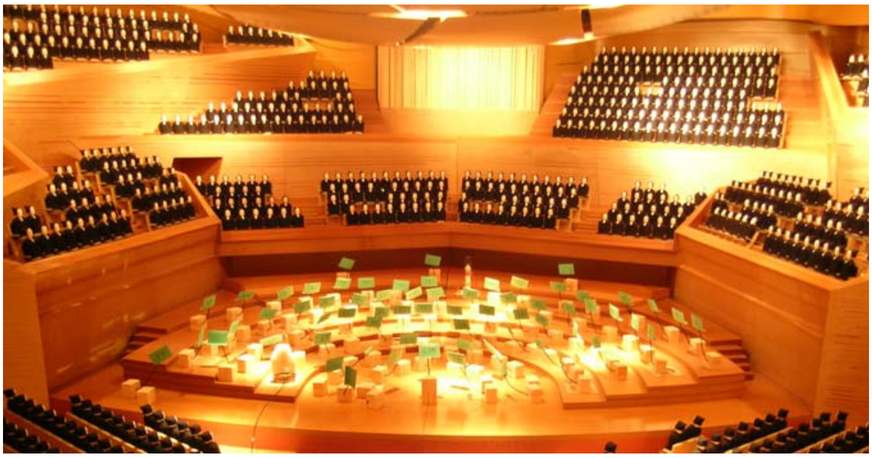

Figure 2:View towards the furnished stage in the 1:10 scale model of the new Danish Radio concert hall.

The measurements on stage were of special interest to the author, as he had participated in renovating the stage at the present Danish Radio concert hall in 1989 with the purpose of improving the ensemble conditions for the musicians[2] and so was aware of the resident orchestra's concern about this issue. For the stage acoustic tests, the stage was furnishing with chairs and music stands as seen in Figure 2 mainly to provide realistic scatter of the stage sound and to avoid unrealistic reflections from the curved stage riser fronts. Furnishing the stage also made it possible to compare the stage acoustics with our large data base of stage acoustics data from existing concert halls measured under similar conditions.

As earlier in the project acoustic computer modeling of the hall had been carried out (using the Odeon 7.0 software), it was possible to compare the results obtained by the computer and the physical scale model techniques.

Thus, using the Odeon data as reference, the results regarding reverberation time obtained in the scale model are shown in Figure 3. The Figure shows three graphs originating from three different sets of scale model data:

1) results from Dirac obtained from spark impulse recordings and air absorption compensation,

2) Dirac calculations (with air compensation switched off) using the impulse responses recorded by Nagata in the model with MLS technique emitted by a model dodecahedron loudspeaker and a Nitrogen atmosphere in the model, and finally

3) the T values both measured and calculated by Nagata.

It is seen that the differences are quite small in the mid frequency octaves 500 and 1000 Hz; but all scale model data are lower than the Odeon prediction at low frequencies, and already at 2 kHz (20 kHz in the model) there seems to be a deviation in the Dirac data obtained with calculated air absorption compensation. As the two data sets obtained from impulse responses recorded in Nitrogen atmosphere (and calculated by Nagata and Dirac respectively) are both closer to the Odeon reference, this is likely to indicate inaccuracy in the calculated air absorption compensation (although in this case temperature and humidity in the model had been thoroughly checked and entered into the programme.)

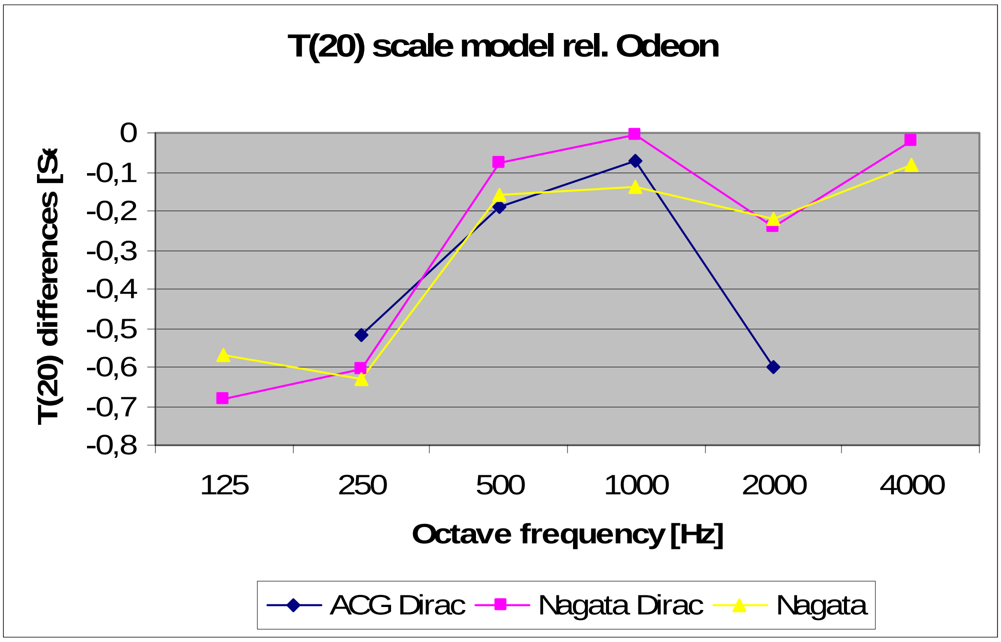

Figure 3: differences between position averaged values of Reverberation Time data derived from different scale model measurements and from Odeon simulation of the new Danish Radio concert hall.

Also EDT showed a peculiar behavior by being about 0,4 dB lower than T in the Odeon calculation; but only about 0,1 Sec. lower than T in all scale model measurements. This is likely to be caused by higher (and probably mmore correct) gracing incidence attenuation in the scale models than in the computer model.

On the other hand, the position averaged values for Clarity, C, deviated less than 1 dB from the values found in Odeon, and also Strength, G, showed sensible - and favourable – values predicting highly satisfactory acoustics in the finished hall.

3 MODEL STUDIES FOR THE NEW ROYAL DRAMA THEATRE

3.1 The Model

The new Royal Drama Theatre under construction in Copenhagen is being designed by the Danish architects Lundgaard and Tranberg. The main auditorium will have about 750 seats arranged in stalls, parterre and on two balconies in a room shaped partly like the traditional Italian Baroque theatre. However, rather than being horse shaped, the plan ís almost circular as shown in Figure 4, offering the acoustic designers a challenging job.

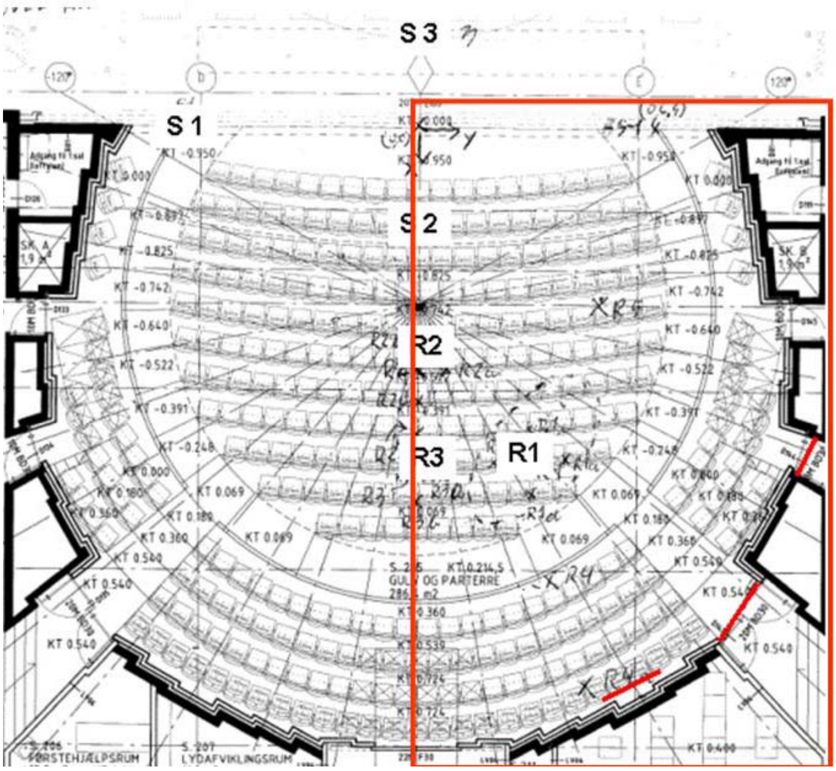

Figure 4: Plan of the main auditorium for the new Royal Danish Drama Theatre in Copenhagen. The red rectangle indicates the section modeled in scale 1:5 for checking the design against focusing of the sound.

In order to avoid focusing, four different diffusing measures were planned. As seen in Figure 4, the wall would be broken up into smaller saw tooth sections which would be helpful in the frequency range 250 to 1500 Hz. The wall is being build in brick work, so at lower frequencies alternating sections with and without mortar in the vertical joints between the bricks will provide diffusion. At higher frequencies diffusion will be obtained by individual bricks being shifted up to 30 mm in or out relative to the wall surface. At very high frequencies (above 5 kHz) we rely on the large tolerances in the hand made bricks chosen. In spite of these precautions, it was felt necessary to test the overall diffusion properties of the wall geometry in a scale model. In order to be able to model also the shifted brick layers the model was build in scale 1:5 out of layered, hard, foam plastic, which was afterwards spray painted several times. Thus, the thickness of the foam (about 6 mm) was equal to one fifth of the actual brick height including a layer of mortar. As the purpose of the model tests were exclusively to test the sound dispersion from the wall only one half of the auditorium wall from floor and up to the first balcony was built. However, in order to take into consideration the corner reflections also the balcony suffit on top of the wall segment was included. This was regarded sufficient to check the design for any focusing of first order reflections from the wall/suffit.

Before building the entire wall section, a smaller square sample with side length 50 cm was built and tested separately with regard to surface diffusion and absorption. The diffusion characteristics were tested by comparing the level of the specular reflection from this sample with the reflection from a plane, smooth panel of equal dimensions. This diffusion coefficient was subsequently assigned to the wall surfaces in the Odeon model of the auditorium, which was already being used as the main room acoustic design tool during this project.

The absorption of the small sample was checked in a model reverberation chamber, as we wanted to be sure that the hoped lack of focusing would not just be due to absorption by the model wall. The average absorption coefficient was about 0,25.

A detail of the model brick wall is shown in Figure 5 below.

Figure 5: detail of 1:5 scale model brick wall for the main auditorium in the new Royal Drama Theatre in Copenhagen The white cubes in front are "heads" of model audience.

The testing of the entire wall was carried out by means of the equipment already described in section 2. The focusing was checked by identifying and gating the reflections generated by the curved wall and subsequently measuring the standard deviation (STD) of the integrated wall reflection levels among positions distributed in the audience area in front of the wall. Slight modifications in wall geometry were then made until the STD was minimized (indicated by three, small red lines near the wall in Figure 4).

It should be mentioned that the total costs for building and testing this model was less than 15.000 Euro or about 5% of the price for building and testing the Danish Radio model, and an important outcome of the tests was values for the surface scatter which could be directly applied in - and hopefully improve the accuracy of - the Odeon model. It is also worth noticing that building and testing this model was done in two months, whereas the Danish Radio model took about a year to plan, build and test.

4 DISCUSSION

One big source of uncertainty in the use of computer models is how to specify the scatter coefficient which is most often caused by a combination of surface roughness and diffraction around small scale geometries in the room model. In the current version of the Odeon programme (8.0), a new algorithm for treatment of frequency and distance dependant diffraction has been implemented[3], which should make it possible to consider only surface roughness when "guessing" on values for diffusion/scatter coefficients to be entered in this computer simulation programme. This makes it tempting to use very detailed room models for the computer simulation (e.g. imported from the architects' 3D CAD model), as this would reduce the influence of the scatter "guesses" further.

Therefore, as computer models are becoming still more advanced, in particular with respect to handling surface scatter and diffraction phenomena, it is likely that the use of physical scale models for acoustic purposes will decline further. However, the experience from the projects described above has convinced the author that still today physical scale models have a role to play in acoustic design of complex rooms for which the acoustic properties are of major importance for the user. Not least it has been interesting to see, that fairly cheap and fast scale model investigations can help in providing scattering data for specific diffusing structures developed in cooperation with the architect. Hereby the scale model technique can directly support and fill out the weak spots in current state computer models. Perhaps we should use this possibility much more…….

5 REFERENCES

1. J. H. Rindel, “Modelling in auditorium acoustics – from ripple tank and scale models to computer simulations”, Revista de Acústica 2002, Vol. XXXIII No 3-4, p 31-35.
2. N. V. Jordan, J. H. Rindel, A. C. Gade, “The new orchestra platform in the Danish Radio concert hall”’, Proceedings Nordic Acoustic meeting, Luleå, 1990, p. 117-122.
3. C. L. Christensen, J. H. Rindel, “A new scattering method that combines roughness and diffraction effects”. Proceedings of Forum Acusticum, Budapest 2005, p. 2159-2164.