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Casa da Musica, a new concert hall for Porto, Portugal

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ABSTRACT
In Porto a new concert hall is under construction. The new hall will be shoebox shaped with specific solutions to ensure sufficient strong lateral reflections. Acoustically, the main challenge is the front and back walls being entirely made of glass, to give the feeling that the rooms are open to the city. As well as keeping out noise from exterior sources, these transparent walls have to be designed such that they contribute to the sound distribution within the hall. With these considerations in mind, the glass walls of the Casa da Música's concert halls will have horizontally waved structures. The acoustical quality of the hall has been studied by using a simulation model and a scale model.

Introduction
The architectural development of the Main Auditorium of the Casa da Música raised acoustical questions to be answered. The main tool to control the acoustical quality of the concert hall during the design process is a computer simulation program. Despite of the positive experience with the reliability of these programs extra certainty is always needed. An important change in the design was the intersection in the concert hall of the building part related to the small auditorium. The architect wanted to take out this intersection. The consequence was a slightly increased volume and reduction of lateral reflection generating surfaces. But what would be the effect on the acoustics of the hall? Also the corrugated glass windows in the hall are acoustically hard to understand surfaces with respect to their spectral reflection behaviour. The last but not least questions to be solved was the construction and position of the canopy in the concert hall and the sound insulation of the transparent walls.

Architectural concept
In the words of the architect, the Casa da Música will have 'an expressive, rock-like shape'. It has been projected near the Rotunda da Boavista, a square just outside Porto's historic city centre. In addition to two concert halls, various rehearsal areas, a recording studio and a restaurant, the design provides for a music shop, a café, a roof terrace and facilities for education and 'cyber-music'.

The program for the Casa da Música focuses on a main auditorium with a capacity of approximately 1400 seating. The auditorium is mainly meant for symphonic music, but also opera and musical theatre should be possible. The consequence of this choice implies variable acoustics and a lot of technical solutions like a moving catwalk or technical bridge and light bridges above the ceiling.

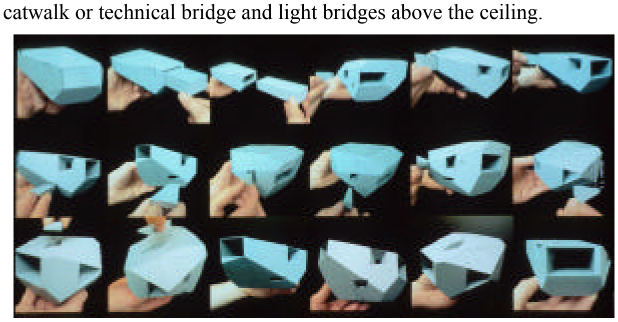


Figure1: In the architectural concept the building is like a big rock holding together all different functions.

In figure 1 the architectural concept is elucidated: the building is like a big rock (or diamond) in which the specific functions are brought in like drawers. The giant rock will have a height of approximately 40 m and will rise up out of parking and will dominate the whole environment. The building will be constructed in white concrete. The real diamond in the building will be the main auditorium. Figure 2 illustrates the concept for the main auditorium in the competition phase. The hall is thought like a big shoebox with transparent rear and back wall. The audience is seated in one raked surface so that they can look out to the Rotunda da Boavista. Musicians can see part of Porto behind the audience. The shape of the auditorium is a logic continuation of the design concept. The width of the hall will be 22 m, the hall is approximately 53 m deep and will have a height of 17,5 m. The volume of the hall is calculated to be 17.500 m^3.

Figure 2: Interior of the hall as thought by the architect

Room acoustical computer simulations

For the room acoustical simulations CATT-acoustics has been used. One of the questions to be answered was the magnitude of detail necessary to get reliable answers. Because the hall is also meant for musical theatre performances all kind of technical arrangements will be introduced. As a consequence we had to deal with technical bridges above the ceiling. The computer program has the possibility to define the diffuse reflection of surfaces. For the corrugated glass it was of interest to study the necessity of detailing the surface or just attribute a factor to this surface. For this goal different geometric models are constructed and compared.

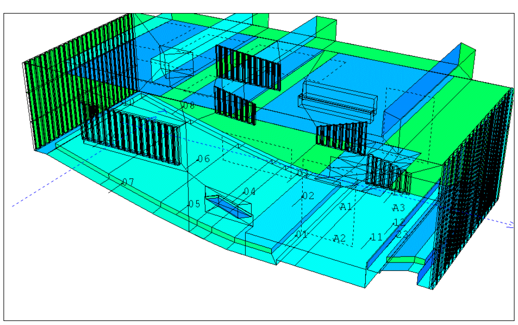


Fig 3a. Geometric model with maximum detail

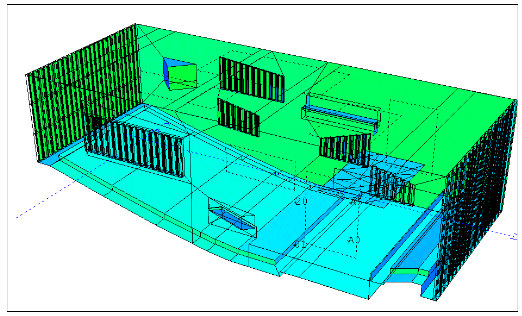


fig 3b. Geometric model with simplified ceiling

Point of discussion was the reliability of the reverberation time calculated with the model and the influence of the diffusitivity of the lateral walls. The next graphs show the differences between calculations with non-diffuse (specular reflecting) lateral walls (a) and fully diffuse lateral walls (b) on the reverberation time. With current computer ray-tracing techniques the detailed build-up and decay response can be simulated and used as a basis for perceived reverberation time analysis. Geometric effects will strongly influence this last prediction method. Generally it is believed that a good concert hall has a high reflection density and, after a plateau with early reflections, a statistical decay of the reverberant sound. In situations where this is the case, the statistical predicted reverberation time, and the value obtained from ray tracing will have a close match.

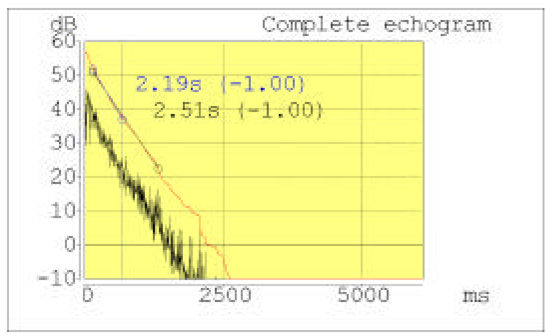


Figure 4a: estimated echogram in case of non-diffuse lateral wall finishing.

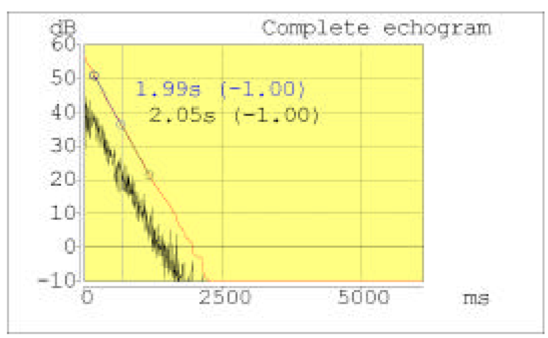


Figure 4b: estimated echogram in case fully diffuse lateral wall finishing.

With the fully diffuse lateral walls the difference between the calculated T_{sabine} and T_{30} almost disappears while there is a big difference in the situation with non-diffuse lateral walls. The graphs show that in case of non-diffuse lateral walls the computer program adds energy in the tail of the reverberation curve.

Scale model measurements

As a design and verification tool for the acoustical consulting of large concert halls, research in a scale-model is also important and often used. Such a model is mainly used to detect strong late reflections and the distribution of energy in the concert hall. In this specific project the need of scale model measurements was important because of:

- The shape of the hall
- The behaviour of corrugated glass
- The treatment of the wall surfaces
- Position and number of diffusers
- Change in design (intersection, number and shape of balconies)
- Canopy position

In the next photos the scale model is illustrated as it is built and prepared for the measurements with test equipment

Figure 5: Interior scale model, view to stage

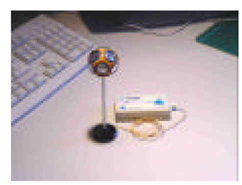
Figure 6: Interior scale model, view from stage

The scale of these models varies normally between 1:20 and 1:8. For the Casa da Música a model has been built on a scale of 1:10. Not only the physical size has to be one-tenth of the original hall, but also the ‘acoustical dimensions’ have to have the same scale. The model has been constructed of 12 mm MDF, the audience is simulated by egg cartons on foam, also the organ surface and galleries are simulated by sound absorbing material, the canopy is made of thin transparent material and the corrugated glass surfaces are also on scale as were the QRD diffusers.

In the measurements with a loudspeaker as the source, the noise signal used is a MLS-signal (stands for Maximum Length Sequence), which is scaled to a frequency range of 800 to 48000 Hz. This is ten times higher than the ‘normal’ frequency range in which most audible frequencies for human beings lie. The MLS-signal is a so-called pseudo-random noise signal, which is an optimised excitation signal for correlation based impulse response measurements. With the derived impulse response a reliable overview of the reflection pattern in the room can be produced. The measured impulse response makes it also possible to derive room acoustic parameters such as reverberation time, early decay time and clarity, etc.. With this correlation-based measurement a certain amount of background noise suppression is achieved resulting in a better dynamic range and less sensitivity for disturbing signals.

The sound source used for the emitting of the MLS-signal was an omni-directional loudspeaker that has been built on a scale of one-tenth of an original decahedron as is used for room acoustical measurements. The spectrum shape of the sound source was measured under free field conditions. The impulse responses have been measured by using a spark (high voltage electric bridge)

The spectrum of the omni directional sound source is illustrated in figure 7a. In figure 7b the spectrum of the spark is given.



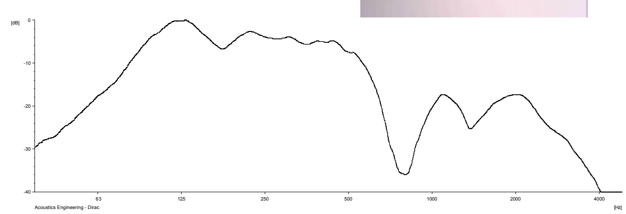
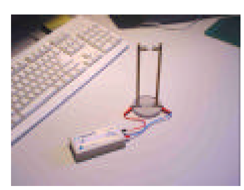


Figure 7a: Spectrum of the omni directional sound source as used.



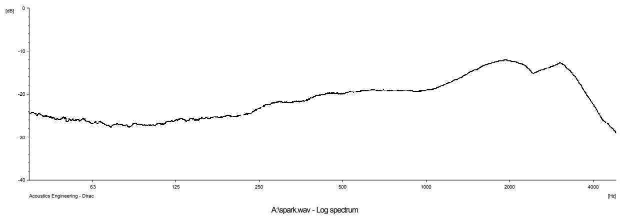


Figure 7b: Spectrum of the spark.

With the sound source a short pulse is generated and recorded with the 1/8" microphone making use of the Dirac software tool. The measured impulse responses are saved as standard Windows .WAV files that include information for unambiguous identification and interpretation.

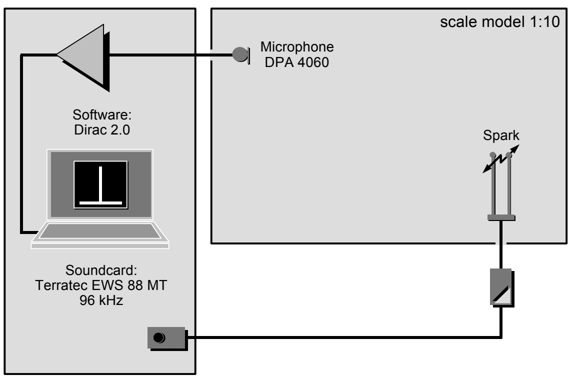


Figure 8. Measurement set-up.

Dirac (Dual Input Room Acoustics Calculator) is a software tool for field or laboratory acoustics engineers. It measures impulse responses and calculates various room acoustical parameters, according to the ISO 3382 and IEC 60268-16 standards. Dirac supports a wide variety of measurement configurations. Dirac features an automatic soundcard calibration procedure, and supports automatic system calibration in a reverberation room according to ISO 3741. System calibrations only impact post processing, and need not be completed before starting field measurements.

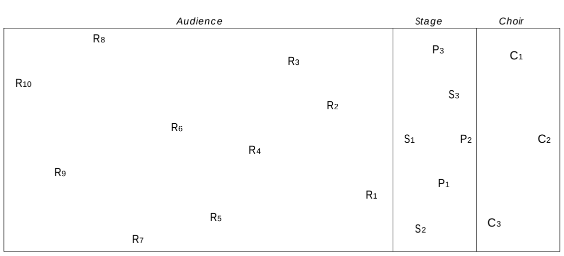


Figure 9 : Source and receiver positions.

The source and receiver positions used in the scale model are the same as used in the computer calculations. With this test set up for all possible source – receiver combinations impulse response have been recorded and analysed. Also all kind of different single number quantities to describe the acoustics quality of the hall are derived (clarity, stage support).

In Figure 10 examples of measured impulse response are shown.
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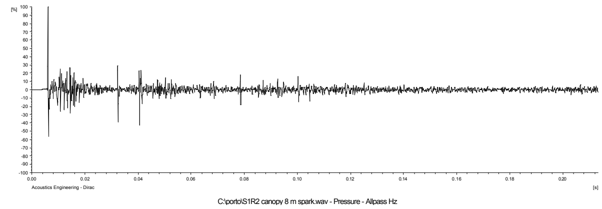

Figure 10a: Impulse response source position 1, receiver position 2., canopy height 8 m

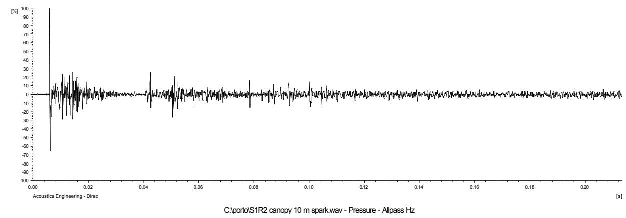

Figure 10b: Impulse response source position 1, receiver position 2., canopy height 10 m

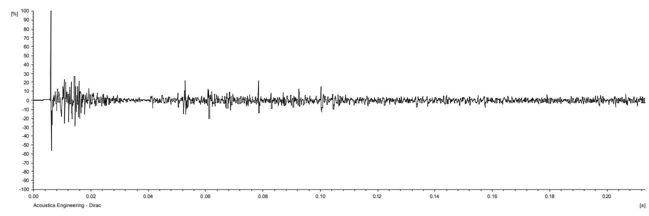

Figure 10c: Impulse response source position 1, receiver position 2., canopy height 12 m

The impulse responses for different receiver positions and source position 2 are used to calculate the energy ratio C50. In figure 11 the mean value for energy ratio C50 with two choir receiver positions and two stage receiver positions indicate the importance of the canopy. Also it is clear that the height should be between 8 and 10 meter.

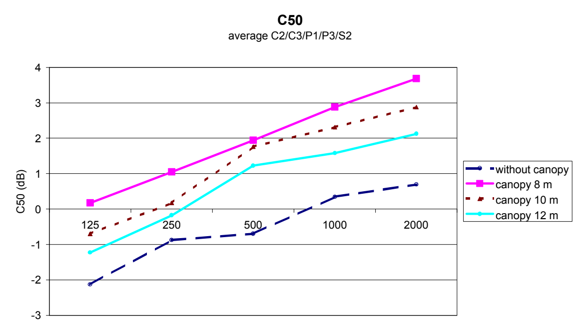

Figure 11: Energy ratio (C50) for the three different canopy heights

From the impulse responses for the different stage positions the energy ratio support is calculated. In figure 12 the mean ST_{early} (over three positions S1-S3) is iven for the three different situations.

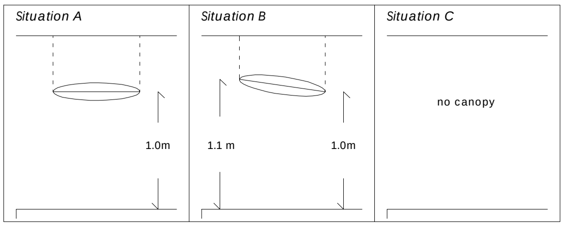

Figure 12. These measurements have been carried out with a spark and a DPA miniature microphone.

A value for the Support (ST_{early}) normally reached in concert halls is about –12 dB. Clearly visible is the effect of the canopy. In situations with the canopy the values for the Support are about 2 dB higher. The difference between situation A and B is less than 1 dB in all octave bands.

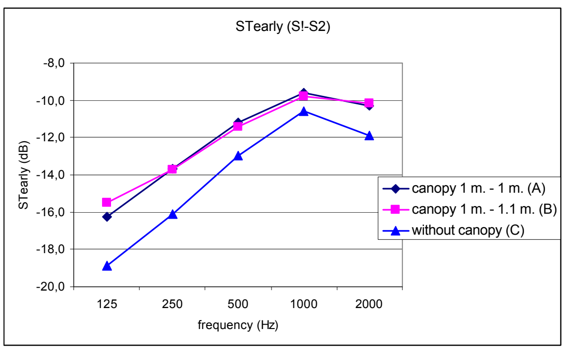

Figure 13: Support for the stage receiver positions

Several different measurements have been carried out to study the influence of the intersection of the small auditorium in the main auditorium.

In chronological order, the following situations have been studied:
- small auditorium intersected in main auditorium;
- small auditorium as a part of the side wall (no intersection. The originating gap is in this situation filled with corrugated glass;
- small auditorium as a part of the side wall, with the corrugated glass replaced by a wooden board.

Conclusions

The evolution of the architectural design of the main auditorium directs to smoother finishing of the walls. Nevertheless the main function of the hall asks for optimal acoustics for symphonic music. In the scale model the necessity of extra diffusion as a consequence of taking out the intersection of the small auditorium has been studied. Also the best position of the canopy is determined.

The measurements in the scale model show not such specific effect on the impulse responses that the intersection of the small auditorium in the main auditorium cannot be compensated. The consequence of this change in the design however is that extra diffusion will be necessary especially in the ceiling area. Therefore some additional diffuser elements have to be introduced.

As well as the small auditorium intersection, balconies are removed from the original design. Because of this, a great part of early lateral sound energy coming from the soffits to the audience is reduced and should be compensated. Additional sound diffusion in the walls or ceiling is considered necessary.

Measurements have been carried out to optimize the acoustic position of the canopy. Three different canopy heights, respectively at approx. 8, 10 and 12 meters above the stage have been studied. Also the inclination of the canopy was point of research. The measurements with the different canopy heights and positions show that the lower position is slightly preferable. The canopy will have to be positioned horizontal. The lower position is also advantageous to prevent unintentionally strong late multiple reflections coming from the walls close to the stage.

The measurements demonstrate clearly the necessity of additional diffusing surface in the ceiling area. For the measurement QRD scale model elements are used. Just like the corrugated glass these elements reflect very directional. As a consequence the QRD elements in the ceiling will have to be divided as randomly as possible. The proposal of the architect for an adapt ceiling plan proved to be the direction to go, however the total area of QRD elements should be increased by at least 30%.

We conclude with stating that the Casa da Música is not a standard hall. To guarantee the acoustical quality of such a hall a lot of research is needed. Acoustical research tools are important and acoustical experiments are necessary. We think we do not exaggerate when we claim that designing a new hall like this one asks a lot of knowledge and creativity, and that every possibility to study part of the acoustics or acoustical phenomena should be used.

References

[1] Committee draft ISO/CD 17497, 21-07-2000.
[2] Mommertz, E., Measurement of scattering coefficients in the reverberation room – Some precision considerations, Note No.43, ISO/CD 17497 working group.