Methods for Designing Room Acoustics in the Past and in the Future

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ABSTRACT - After a short overview of common practices in the design of room acoustics, a new method is introduced. This method is based on an inverse-approach of the modelling process, called the Energy Decay Curve (EDC) fitting, and provides a straightforward tool in optimising the treatment of surfaces or even the geometry that is needed for the required room parameters. The conventional and the new method is applied to the geometry of Studio 6 of the Hungarian Radio.

1. Introduction

The basics of modern room acoustics is said to be laid by Sabine [1], who assumed in his simple model of reverberation an ideally diffuse field in large, fairly reverberant (i.e. not "dead") rooms. From that time, the reverberation time (RT) for the -60dB attenuation of the received energy became one of the most important criterion for designing a room acoustically. It is obvious, since this phenomenon is perceived and measured easily, and Sabine's work showed a simple way of calculating this measure approximatively beforehand.

However, his famous formula was refined several times [2] and with the developing technology other parameters could be measured. Of course, it was necessary, because in the real world applications new parameters were needed that describe the perceived quality of a sound field better in rooms that are small or even treated with highly absorbing surfaces.

Usually the task of a room acoustician is to design a room to achieve the required subjective quality that is expressed in objective parameters. In this paper the conventional design process is described, and a new method is introduced afterwards. Finally, these methods are applied to a recording room that was designed by György Békésy.

2. The conventional approach - an overview

2.1. Formulating the objective criteria

Having the geometry and the arrangement i.e. the position and type of the source and listener in a room ready, the objective criteria have to be specified. The collection of the objective parameters and their limit values depend largely on the purpose of the room. Without going into detail, the most of the parameters are calculated from the impulse responses (IR) of the room. It is evident, because if the room is assumed to be a linear and time invariant system, the IR gives all the information needed to characterise the behaviour of a room between two of its points.

But what parameters should be used and what are the ideal values? Typically, those parameters are used, which describe the temporal distribution of the received energy directly or weighted by time or direction, but their values are the topic of several experiments even today, and only some parameter types (RT_{60}, C_{80}, D_{50}, etc.) and value ranges are agreed and accepted internationally.

2.2. Approximating the criteria in the design

Reverberation times are usually the first ones to design for. Statistical formulas can be calculated even manually and can give a first approximation of what surface types (absorption coefficients) should be used. Nevertheless, apart from some basic rules, it was the only tool available before some decade.

In the next step, some modelling has to be carried out in order to see a more detailed behaviour of the room in question. Traditionally, scale models were built to get those results, but building such models is more expensive and circuitous nowadays than running a computer simulation, so scale models are only the last phase.

Modelling can help to verify the results and calculate other parameters or their spatial distribution, so if the results are not satisfactory, the design must be refined. This cycle should continue until the predicted results are not sufficient.

Finally, the new ready built room is measured extensively, subjective tests are carried out in it, and if there are still problems, the room can be modified further if necessary with acoustical treatment of the surfaces, furniture, and so on.

The full "circle of room acoustics" with these steps would look like in Figure 1.

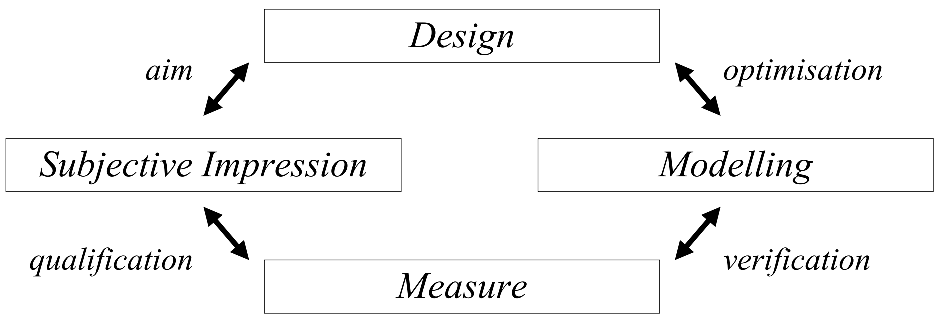

Figure 1. The design-model-test-measure circle

2.3. Problems of the conventional approach

The approach outlined above, can result in a poor design in practice, because:

- usually no modelling possibilities are available, only the experience and the basic formulas help the design;
- the acoustician is not aware of the limitations and possibilities of the modelling methods;

- it is impossible to achieve the required parameters because of other considerations (aesthetics, geometry, etc.), so the acoustician has to make compromises.

3. Modelling

The most promising way of predicting parameters is computer aided engineering (CAE), because running the models on a computer is inexpensive, flexible, and spectacular for the customer. There are two main methods of CAE in room acoustics.

3.1. Modelling methods

Numerical methods like FEM, BEM, etc. give solutions of the wave equation by introducing discretisation of time (finite differences), space (finite elements) or surfaces (boundary elements). Results can be calculated in frequency- or in time-domain, and their accuracy is limited only by computational time.

Methods in the second group assume the validity of geometrical acoustics, therefore they are limited at relatively low frequencies but are easy to use and implement and they can predict the most important time-domain parameters accurately enough. Because of their simplicity, most of the commercially available modelling software are based on these principles.

3.2. Problems of the geometrical methods

With the very simple approximation of modelling sources and reflections, modelling programs utilising the law of geometrical acoustics have the following problems common:

- real, finite size sound sources are modelled only by ideal point-, line- or plane-sources with directional characteristics;
- non-specular phenomena like first- and higher-order diffraction and diffusion are neglected or approximated by empirical or statistical methods only;
- surfaces are described only with a frequency-dependent absorption and statistical diffusion coefficient, their directional and time-domain features are neglected.

Finally, there is often the great problem of what parameter values should be used for a given real-world surface-type or -structure.

4. The inverse approach

The method a room acoustician may eager about and seems more reasonable, goes straightforward instead of just trying and testing different versions. Based on an inverse method [3], from the objective criteria with given geometry and source-listener configuration, the required acoustical properties of the surfaces can be calculated using a geometrical model and the concept of "EDC fitting".

The basic idea behind the Energy Decay Curve (EDC) fitting is, that since the EDC-s are the integrated functions of both the real and the modelled impulse responses in the time domain, they can be directly matched if the parameters of the model are tuned accordingly.

The procedure is shown in Fig. 2. As it is seen, from the timing and the history of a ray-path in the geometrical model, and from the energy decay rate of the band-limited real or the required impulse response, one can calculate easily the amplitudes of each reflection, and so the parameters of the affected surfaces, sources and receivers.

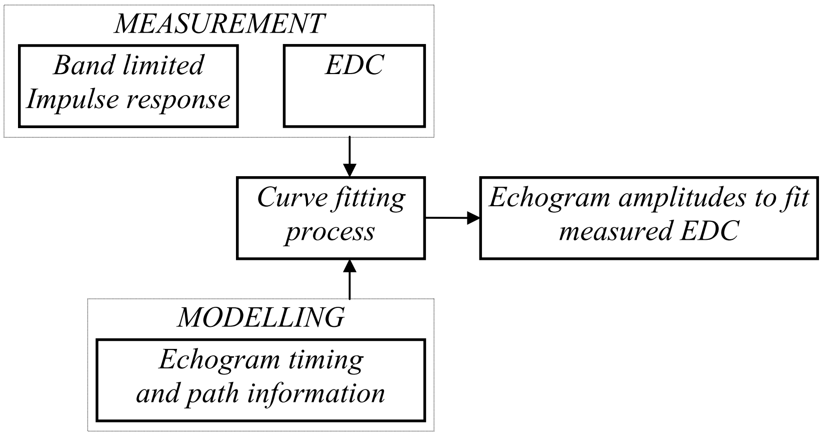

Figure 2. EDC fitting

5. Application

Studio 6 was designed by György Békésy for the Hungarian Radio in 1935 for classical recordings, and its "dry" acoustics is well suited for rehearsal and recording [4].

This room was rebuilt several times, and because its documentation is rather incomplete, the task was to model this room, and examine what kind of materials are applied on the surfaces and to test the inverse method.

5.1. Modelling the room

The layout of the room is shown in Fig. 3. One of the special features in the room is its wall-structure, where a porous-like wallboard is in front of an air gap and different absorptive surfaces (Fig. 4).

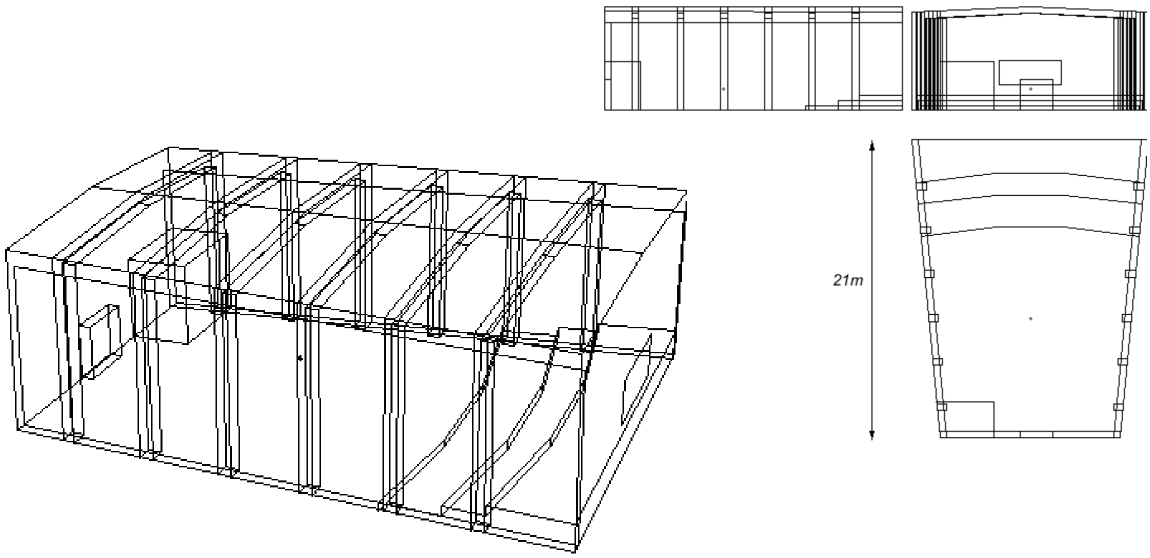

Figure 3. Layout and geometry of Studio 6 in the model

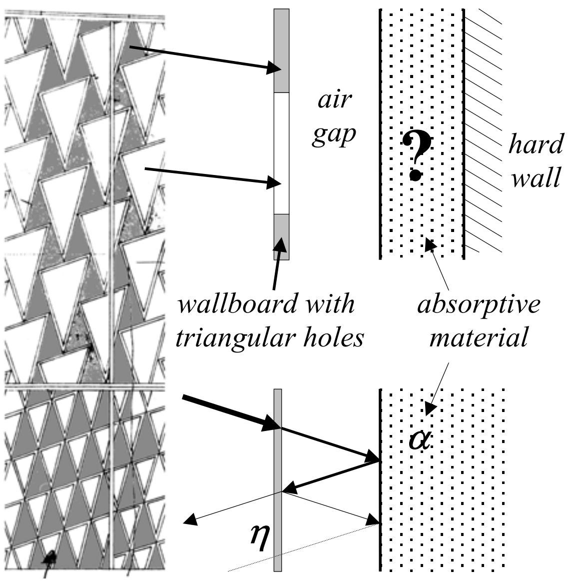

Figure 4. Structure of side wall and its model before and after the EDC fitting

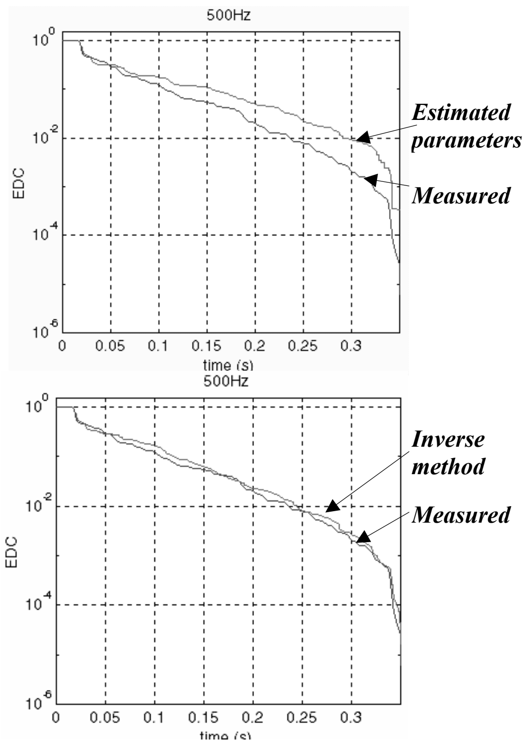

Figure 5. Measured and predicted results

It is not reasonable to model the structure in full detail, so the wall structure is modelled with a statistical approach. The wallboard has also a transparency number η. This tells us the probability of letting through the incident energy.

This is true from both sides of the wall, so the structure gives several reflections from one incident (E_i) wave:

$$E_r(t) = E_i(t)\cdot(1-\eta) + \eta^2(1-\alpha)\cdot\sum_{n=1}^{\infty} E_i(t - n\cdot\Delta\tau)\left[(1-\eta)(1-\alpha)\right]^n \qquad (1)$$

where $\Delta\tau$ is for the time for the wave propagation in the air gap and the wallboard is assumed to be a perfect reflector.

This simple model is rather coarse. However, it explains the behaviour of the structure well, and why there are no distinct and disturbing echoes perceived.

6. Results

The model with special settings for the chairs, the wallboard and the cover of the lighting was run first with estimated parameters from tables. Then, from the measured IR-s, the required parameters were calculated with the inverse method. The two results are compared on the EDC-s in Fig. 5.

7. Conclusions

The inverse method is a promising new way of verification, measurement and prediction using the simple geometrical models.

By introducing the ideal EDC, the design of room acoustics can be straightforward. It means, that from a given geometry and source-receiver configuration, one can calculate where and what to put on the surfaces to achieve the required objective quality. This method can show also if it is possible to achieve that quality; and if not, where is the problem?

First of all, to investigate the possibilities of this approach, one has to define the parameters and their values to design for, and this is the goal of several subjective tests in the future.

References

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[3] A. T. Fürjes, É. Arató-Borsi, F. Augusztinovicz, P. Tamás, “Evaluation and Modelling of Small Rooms”, proc. Forum Acusticum ‘99, Berlin (1999)

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