ForumAcusticum 2005

Applications of inverse methods in room acoustics

Andor T. Fürjes
Technical University of Budapest, Department of Telecommunication,
Laboratory of Vibroacoustics, H-1111 Budapest, Magyar Tudósok krt. 2., Hungary, **furjes@hit.bme.hu**,

Traditional design procedures in room acoustics rely heavily on some very basic optimisation formulas and the experience of the designer. On the other hand, conventional modelling methods are helpful simply to predict the effect of the shape and the surface materials of a given room. To discover some of the tendencies, multiple runs of a model are required, which means a time consuming and questionable procedure. The same problem arises when calibrating a computer model to the existing reality, if the surface properties are unknown. The paper presents the application and practical advantages of an inverse modelling approach, introduced earlier by the author. Several validated examples are discussed and analysed also to show the potential of the method.

1 Introduction

Designing acoustics is almost a routine task if a new hall or room is to be built with a conventional shape and if the architectural constraints are loose enough to let acoustical aspects determine ratios, materials, etc. Of course, this is not the case in practice. On the other hand, this would result in just copying existing, well sounding spaces. This approach would not be an acoustical and architectural challenge either.

In reality, however the acoustic design usually meets contradictory architectural constraints and functional requirements. Even if there are several rules of thumbs that can lead the acoustician one has to really go into deep understanding what the visionary room geometry can offer. Or, if a hall has to be renovated, the acoustician has to tell what to preserve and what to omit or what to insert in order to gain an at least equivalent or yet better acoustic conditions.

Computer modeling of acoustics is a tool for analyzing any possible situation without the costs of realization. One provides geometry, material and source selection as inputs and gets room acoustical parameter values as outputs. Sadly there are very limited possibilities to look behind the scenes, i.e. what is really happening between the input and output. In addition, one single calculation sequence can take hours, so a thorough but brute-force trial-and-error scheme requires a tremendous amount of work even though available computing power increases continuously.

This work outlines an alternative approach by first defining the requirements, and then showing the theoretical background of the realization. The goal is to find an algorithmic solution for the practicing room acoustician.

2 Definitions

As mentioned in the introduction, the *traditional approach* means that one provides the geometry, the material selection, the source properties and the receiver properties as the inputs, which make the *model parameter*s. By setting the features of the calculation (typically the number of rays/beams), one provides the *modeling parameter*s. Following from these one can start calculations running. In the end one gets the output, the *modeling result*s. The output is usually a set of values equivalent to existing room acoustical parameters. In better situations the software provides some insight for the user by displaying statistics on distribution, sound paths, or can provide detailed assignments between sound paths and echograms.

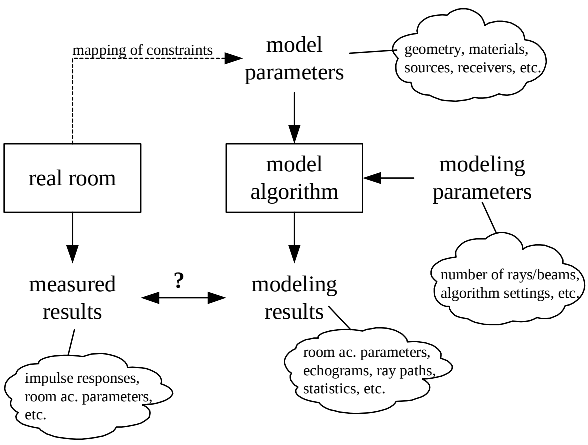

Figure 1: Interactions between elements of the traditional approach in room acoustic design and analysis.

However, there is no way to display instantly how for example a single change on material properties will change quality at a receiver or the distribution in general. Neither there is a way to display how much a part of the geometry limits or affects the possibilities of certain aspects of acoustic conditions.

In addition there is a rather loose connection between measurements and modeling results, hence it is hard to compare the two. Usually some spatially averaged room acoustical parameters such as reverberation time or clarity are shown vs. frequency.

Figure 1 illustrates the above findings.

3 Assumptions and Requirements

First of all one has to realize that a room acoustic model is not an exact simulation of reality (and never it can be), but a reasonably simplified mapping of physical phenomena. In no way does it mean of course, that the model shall be a 'black box', since our goal is to understand the correspondence between model parameters and model results.

Model results are more sensitive to the model parameters (geometry spatial resolution, absorption coefficients, diffuse coefficients, source directivity, etc. together) than to the calculation algorithm itself. It means that the correct selection and interpretation of model parameters is a fundamental factor.

On the other hand the required solution shall be as insensitive as possible to changes of the modeling parameters. It means, that a well-designed algorithm shall provide unequivocally converging results, if higher precision is required.

The algorithm shall be completely open, in order to gain instant recalculation of any parameter when model parameters are changed.

Additionally the algorithm shall provide some analysis on sensitivity against model parameter changes. This feature is necessary to help the acoustician being effective on surface and material selection.

There shall be a connection between measured and modeled results, as direct as possible. This feature would help to align model parameters to match measured results during a renovation analysis, or to check the validity of the model.

4 Modeling Theory

An important finding is that most of the observed room acoustically relevant and physically measurable parameters are based on energetic and integrated features. It means that the model shall emphasize energetic processes primarily. Hence the principal condition is that the model shall discover and trace all possible energy transfer paths between the source, the room and the receiver, including specular, non-specular and diffracted components. This part of the modeling sequence requires the most computational power. If all these paths are known and recorded, the results can be quickly recalculated if any theoretical details change.

Some algorithms require recalculation if any material property changes. Even more advanced software require recalculation if diffuse properties are changed. To overcome this problem, a new approach is utilized. This is based on the assumption, that as soon as a part of the incident energy reflects in a non-specular way, it will be added to a diffuse tank, which distributes diffuse energy equally to all reradiating surfaces. This way the energy path is calculated only once, incident (and reradiating) points are recorded, and the diffuse part of the response is calculated separately from the specular part.

The energetic balance at any time in an enclosed space is:

$$E_{\text{input}} = E_{\text{absorbed}} + \left(E_{\text{diff}} + E_{\text{spec}}\right)_{\text{reverb}} \qquad (1)$$

where E_{input} is the initial energy used for the excitation, E_{absorbed} is the total energy absorbed from the initial energy by the air and the absorbing materials, and E_{reverb} is the remaining energy reverberating in the closed space, which is the sum of the specularly reverberating energy (E_{spec}) and the diffuse energy (E_{diff}). Figure 2 illustrates the theory.

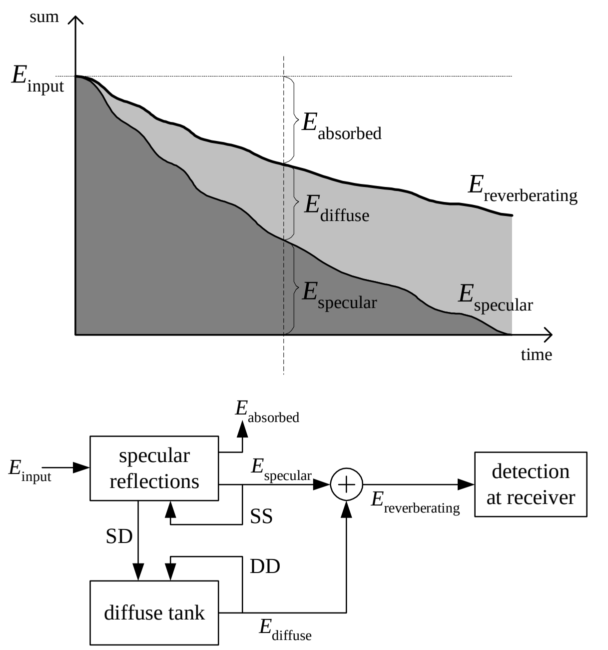

Figure 2: The 'diffuse tank' approach.

The idea is very similar to the one utilized in artificial reverberators (this is where the term 'diffuse tank' came from) [1]. Global handling of the diffuse part is substantially easier, while local diffuse features are well modeled by using only the specular-to-diffuse (SD) transitions, neglecting diffuse-to specular (DS) and diffuse-to-diffuse (DD) transitions [2]. Anyway, at both extremities (completely specular or diffuse field) the model will reflect theoretical and analytical results, and provides the very important diffuse tails after each specular reflection.

Except of the handling of the diffuse part, other parts of the modeling algorithm can be considered traditional. The interaction between certain model parameters and model results are shown in Figure 3.

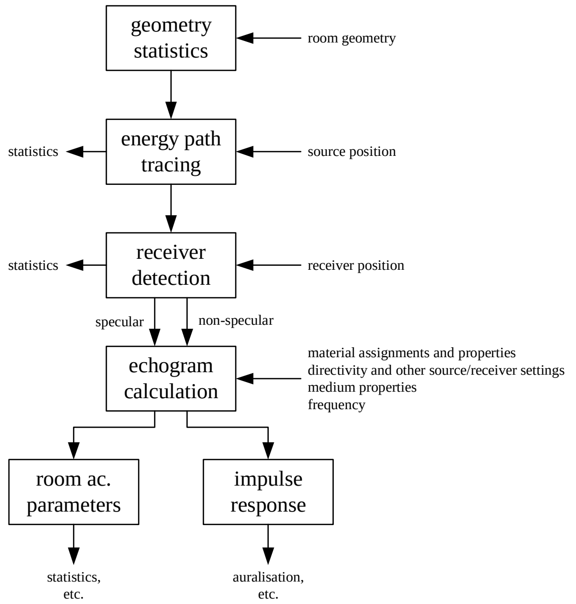

Figure 3: Interactions between certain model parameters and model results using the new approach.

5 Connection between Model and Measurement

Measurements result usually wide-band impulse responses, while models can provide monochromatic echograms. Even band-limited reflectograms are hard to compare with band-limited impulse responses, if there are no characteristic reflections in the response. In most of the cases however, room acoustical parameters are to be compared.

Since energy decay curves (EDC) are the basis where most of the room acoustical parameters come from [Furjes et. al], it is a reasonable choice to use these decay curves for comparisons between modeled and measured results (see Figure 4).

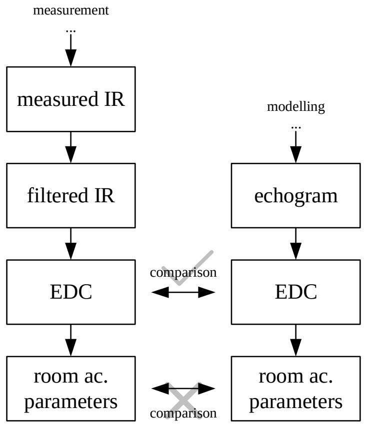

Figure 4: Connections between model results and measurements.

6 Inverse Problem Formulation

The inverse formulation of room acoustical problems basically means that model parameters are derived from model results.

The selection of the EDC as the connection between measurement and models will complete the required scheme. In an earlier paper it has been shown, that the EDC can directly determine the amplitudes of the echograms if the timings of the echoes are known ('EDC fitting') [Furjes et. al].

Mentioning again the connection between room acoustical parameters and the EDC makes the connection between room acoustical parameters and model parameters more clear.

Based on the required room acoustical parameters one can synthesize EDC templates, which then can be used to fit the variable model parameters to according to a set of constraints (priorities and physical constraints, like directivity for example).

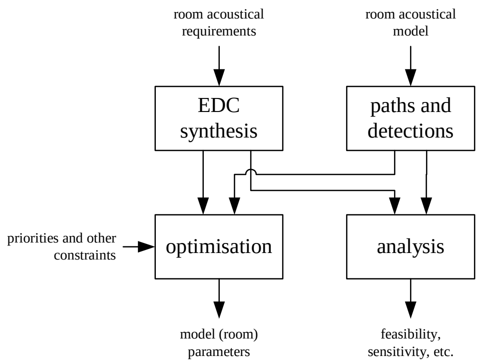

Figure 5: Interaction between elements of the room acoustical modeling and analysis package.

Utilizing these features, the whole system can support both analysis and design in a more handsome and elegant way than available before (see Figure 5).

7 Application Examples

As one can see, using the new features, one is able to answer the following very important questions for example:

- What are the physically available room acoustical parameter values for a given geometry and source-receiver configuration?
- Which surface affects or limits the most a certain room acoustical parameter?
- What are the parameters of the unknown structures and surfaces in an existing room?
- How do model parameters affect model results?
- Is the required room acoustical improvement or objective feasible at given architectural and financial constraints?
- …

Although most of these questions seem fairly simple from the client’s side, only the outlined scheme (or and equivalent) can professionally support the acoustician in complex situations.

From scientific point of view, the most important question that the approach can help to answer is about the validity of the algorithm itself. Since the approach is open to different details in implementation (diffuse reradiation directivity, phase considerations, diffraction paths, low frequency extensions, etc.) it is fairly easy to check which combination gives better, more consistent results, against reality.

8 Conclusions

Based on practically experienced problems with the approach of available tools in designing room acoustics, a new approach has been developed. This new approach will provide the users more insights into the features a given room, source and receiver configuration, etc. can provide. At the same time analytical functions are gained, which help the acoustician to decide in most of the situations, even if the architectural constraints are complex and unique.

Although implementation of some of the algorithms is still under development, the results are promising. During the presentation some application examples will show the potential of the new approach.

References

[1] J. Dattorro: ‘Effect Design, Part 1: Reverberator and Other Filters’. *Journal of AES*, Volume 45 Number 9 pp. 660-684; September, 1997

[2] B. Dalenbäck, M. Kleiner, P. Svensson: ‘A Macroscopic View of Diffuse Reflection’. *Journal of AES*, Volume 42 Number 10 pp. 793-807; October 1994

[3] A. T. Fürjes, É. Arató-Borsi, F. Augusztinovicz, ’A New Method for the Objective Qualification of Rooms’. *Acta Acustica*, vol. 86, pp. 911-918; 2001