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The use of colors, animations and auralizations in room acoustics

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ABSTRACT

The use of computer models for acoustical design of auditoria takes advantage of visualization and auralization for several purposes, some of which will be presented. The sound absorption characteristics of materials can be visualized by the use of colors of surfaces in a 3D room model. Calculation results displayed as color maps in a grid can give a quick overview of complicated conditions of sound distribution, including the display of acoustical parameters for noise level, sound strength, clarity, echo etc. The dynamic picture of a wave front with thousands of balls emitted from a source and reflected in a room has proven to be a useful tool to understand complicated conditions of sound reflection. Using auralization dynamic phenomena like reverberance, echo, and flutter echo can be auralized by listening to a hand clap. Coloration is another phenomenon that may be auralized by listening to white noise. The multisource auralization of a symphony orchestra where each single instrument has been modeled and auralized is a new technique which has opened for a detailed evaluation of the balance and blend due to reflecting surfaces near the orchestra.

Keywords: Room acoustics, auralization, visualization

1. INTRODUCTION

Visualization and auralization play important roles in room acoustic design, particularly as a means to communicate acoustical conditions to non-acousticians like architects and building owners. Early examples of visualization are the use of various physical models, primarily to analyse the first reflections in a two dimensional section of a room [1]. Either wave fronts or rays could be modelled. One method first reported in 1913 is the use of ultrasonic sound waves generated by an electric spark and Schlieren photography in a 2D scale model with smoke-filled air. An example is shown in Figure 1. Another early technique applicable to 2D sections of a room is to send light through shallow water waves generated by a mechanical vibrator.

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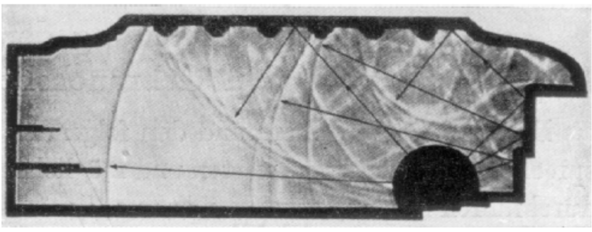

Figure 1 – Example of Schlieren photography showing reflections in a section of a concert hall. (Teddington ca. 1920, from [1]).

With microphones it became possible to take recordings of sound in scale models, and from the beginning the purpose was to perform listening tests, i.e. what today is called ‘auralization’. The first report on this technique for subjective evaluation by listening goes back to Spandöck in 1934 (ref. from [1]). He used a 1:5 scale model and a wax drum to record and replay the sound.

However, the early methods had serious limitations; the visualization methods were normally only for 2D sections, and only the early reflections could be modeled. It was not possible to derive more precise acoustic parameters. The early attempts to auralize room acoustical properties had so severe technical problems that the sound quality was unacceptable and the idea was soon given up; only to be reborn much later with the new possibilities that has come with computer modeling. In the following some examples are given on the possibilities for visualization and auralization with a state-of-the-art room acoustic computer modeling. The ODEON room acoustics software has been applied.

2. VISUALIZATION IN ROOM ACOUSTICS

2.1 Acoustic colors and acoustic material properties

The idea of acoustic colors to visually represent the sound absorption properties of surfaces in a room model was first presented in 2001 [2]. When a digital room model is viewed in OpenGL the colors are controlled by the three basic colors red, green, and blue (RGB). With an analogy to the wavelength of colors in light, the red represents the low frequencies, green the middle, and blue the high frequencies.

The intensity of the RGB colors is calculated from the average reflectance in three frequency bands, namely the eight octave bands 63 Hz to 8000 Hz divided into three bands. Thus the reflectances related to the three colors are:

$$r_{\text{Red}} = 1 - \left(\tfrac{3}{8}\cdot\alpha_{63Hz} + \tfrac{3}{8}\cdot\alpha_{125Hz} + \tfrac{2}{8}\cdot\alpha_{250Hz}\right) \tag{1a}$$

$$r_{\text{Green}} = 1 - \left(\tfrac{1}{8}\cdot\alpha_{250Hz} + \tfrac{3}{8}\cdot\alpha_{500Hz} + \tfrac{3}{8}\cdot\alpha_{1000Hz} + \tfrac{1}{8}\cdot\alpha_{2000Hz}\right) \tag{1b}$$

$$r_{\text{Blue}} = 1 - \left(\tfrac{2}{8}\cdot\alpha_{2000Hz} + \tfrac{3}{8}\cdot\alpha_{4000Hz} + \tfrac{3}{8}\cdot\alpha_{8000Hz}\right) \tag{1c}$$

The acoustic colors have the following features: A totally reflecting surface is white, a totally absorbing surface is black, a surface with equal absorption at all frequencies is gray, a surface with high frequency absorption is red or brown, a resonator with mid-frequency absorption is purple, and a panel with absorption mainly at low frequencies is light blue. A few examples are shown in Figure 2. See also the room model shown in Figure 10.

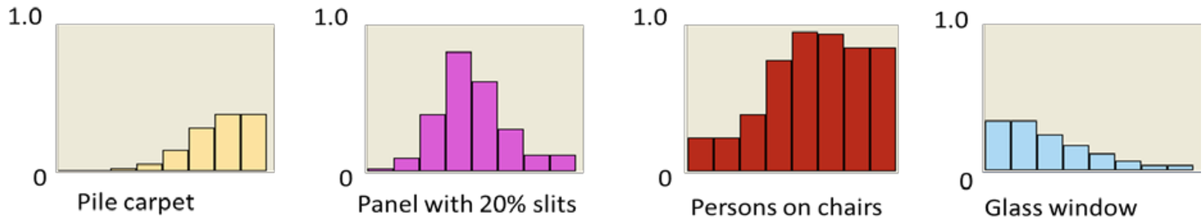

Figure 2 – Examples showing the absorption coefficients in eight octave bands (63 Hz to 8000 Hz) of four materials and the associated acoustic colors.

2.2 3D reflector coverage

With a room acoustic computer model it is possible to visualize the sound reflections in many ways. One option is to define a sound source and select a number of surfaces as interesting reflectors; then the reflection points can be displayed as in the example in Figure 3. When more than one reflector is studied at the same time, it is useful to apply colors to distinguish between the reflectors and the associated reflection points. The method can be extended to show higher order reflections

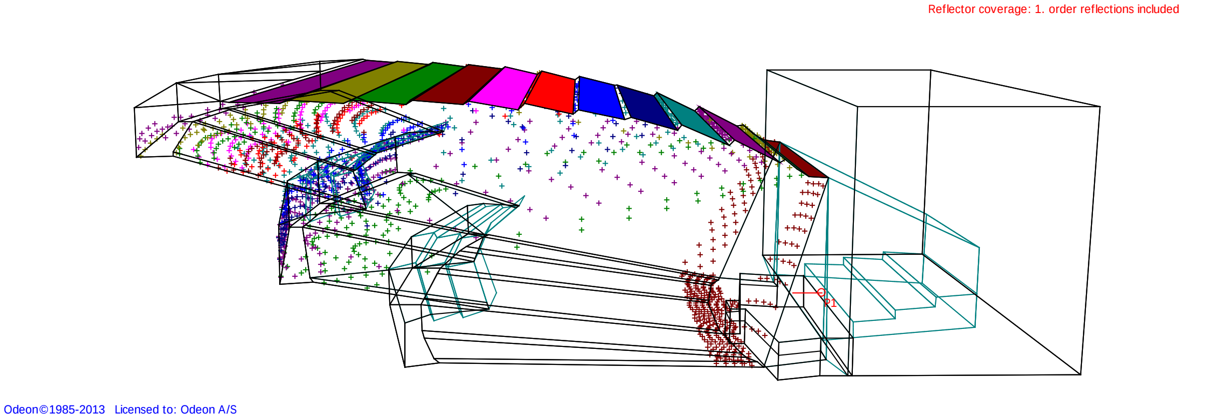

Figure 3 – First order reflections from a number of selected surfaces shown as colored marks on the surfaces in a large auditorium.

2.3 Grid maps to visualize acoustical properties in a space

Grid maps are very efficient tools to visualize the spatial distribution of room acoustic parameters. In an auditorium it is possible to select a grid size that approximately equals the size of the seats. In this way the weak spots can easily be identified, and the improvements of a suggested new design can be clearly demonstrated. In an auditorium it is obvious to look at the room acoustic parameters defined in ISO 3382-1 [3], but other parameters that can be very useful when displayed in a grid map include echo-parameters and the Speech Transmission Index, STI.

In Figure 4 is seen an example of a parameter displayed in a grid map using a color scale with eight steps and smoothing the colors to give a very graduated grid map.

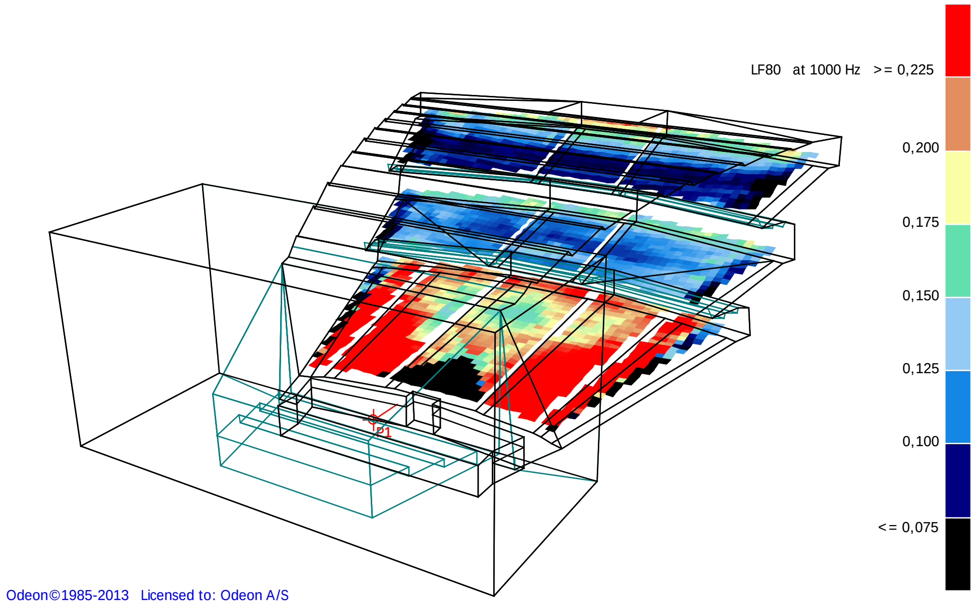

Figure 4 – Grid presentation of results using smoothing of colors. The example shows the lateral energy fraction LF_{80} in a large fan-shaped auditorium.

The example shown in Figure 5 is a grid map with STI, where the a special color scale has applied in order to follow the qualification bands for STI results as recommended in the latest version of the standard IEC 60268-16:2011[4, Figure F.1]. There are 12 bands denoted with letters from A+ to U, and in this case the smoothing between colors is not used in order to separate the qualification bands.

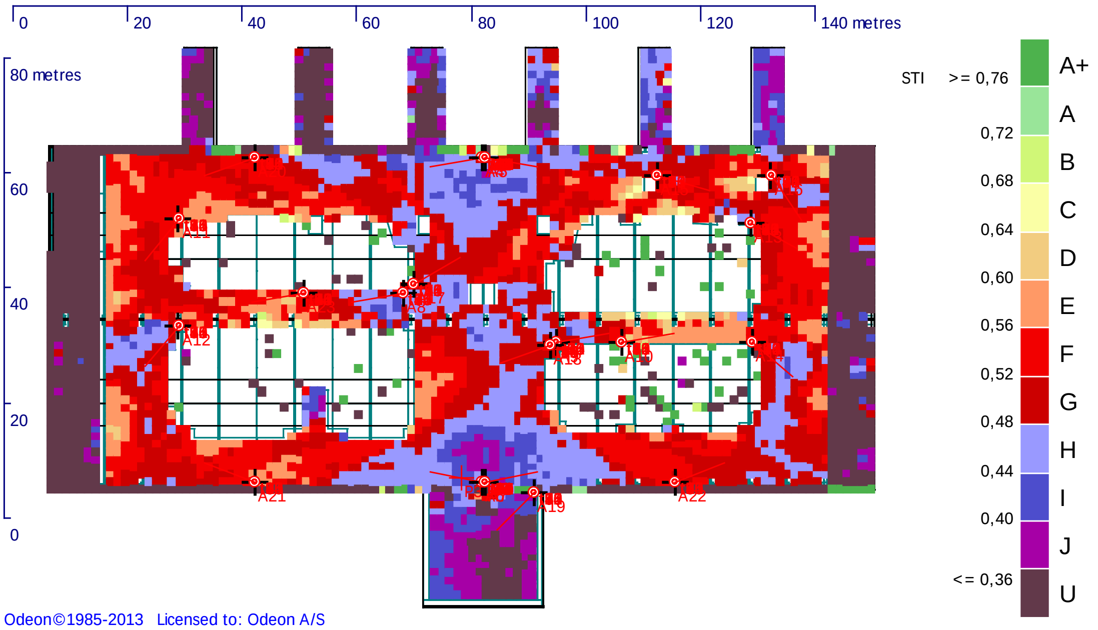

Figure 5 – Grid presentation of results using sharp separation of colors. The example shows the Speech Transmission Index calculated for a PA system in a railway station, applying the qualification bands as recommended in the standard.

2.4 3D reflection paths

Sound reflections can be visualized as reflection paths in a 3D room model. In Figure 6 is shown a single reflection, which can be traced to identify the surfaces that create the reflection.

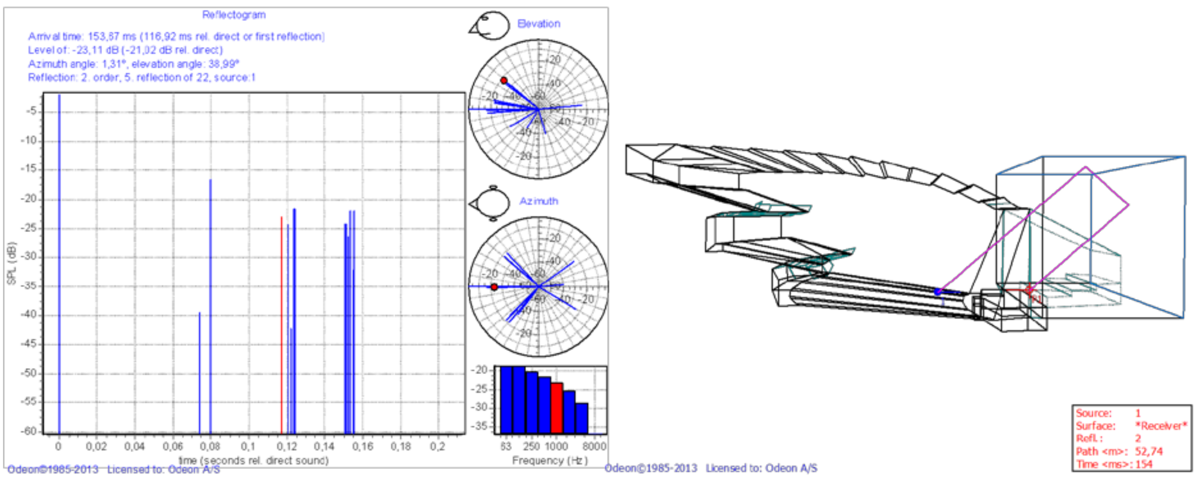

Figure 6 – Visualization of a sound reflection, left side as a line in a reflectogram and right side as a reflection path from source to receiver.

The reflection path of all reflections up to a certain reflection order can also be displayed as shown in the example in Figure 7.

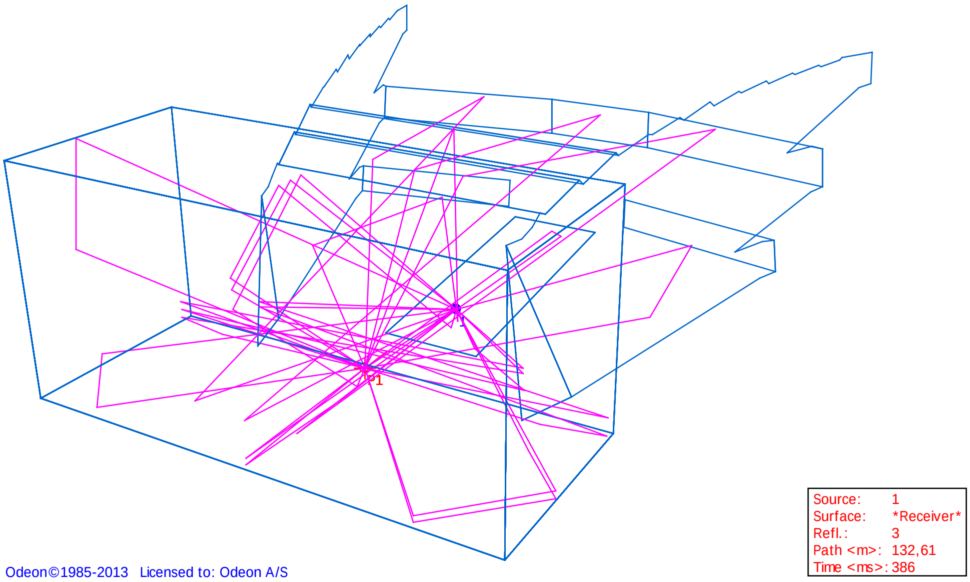

Figure 7 – Visualization of the reflection path from source to receiver of all reflections up to third order. Only the room surfaces creating reflections are shown here.

2.5 3D billiard animation of sound reflections

Sound reflections can be visualized as wave fronts by displaying a large number of points that represent sound particles propagation in all directions from a sound source. The view is very diffuse when 3D propagation is applied, so a visualization with only 2D propagation is preferred for clarity, see the example in Figure 8.

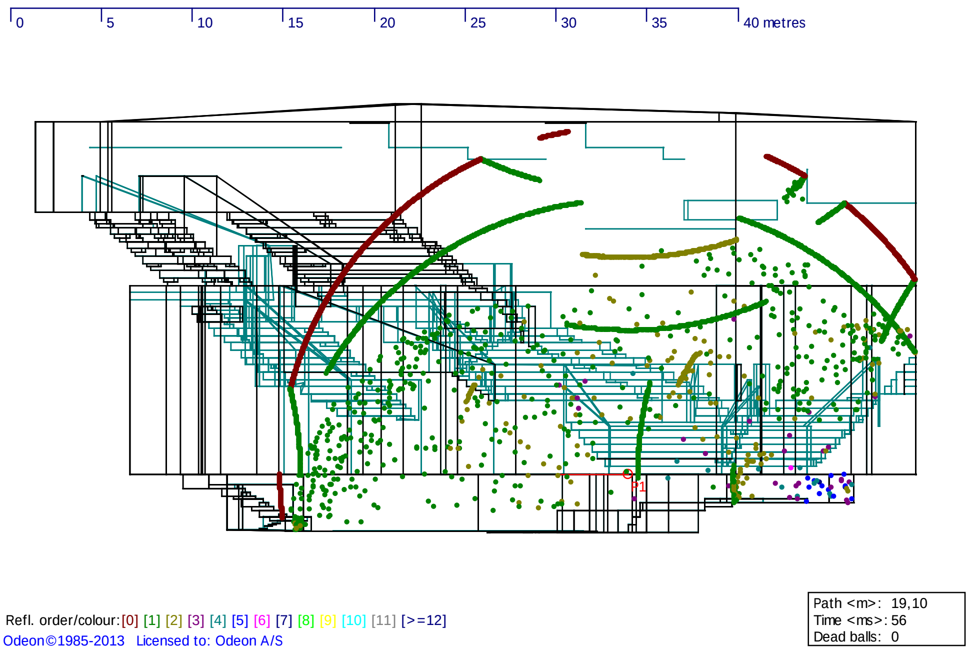

Figure 8 – Visualization of sound reflections as a large number of simultaneously emitted particles from a point source. The example shows a section in a concert hall.

2.6 Visualizing relative importance of noise sources for noise control

In a case with many noise sources, e.g. an industrial hall, a very useful tool for noise control is the visualization of the contribution of each active noise to the total SPL in a receiver point, see Figure 9. The upper part of the figure shows the relative A-weighted sound energy in octave bands, and it is easy to identify the sources with the highest contribution. A click on the gray area in the 1000 Hz bar brings up the information about source number and its contribution.

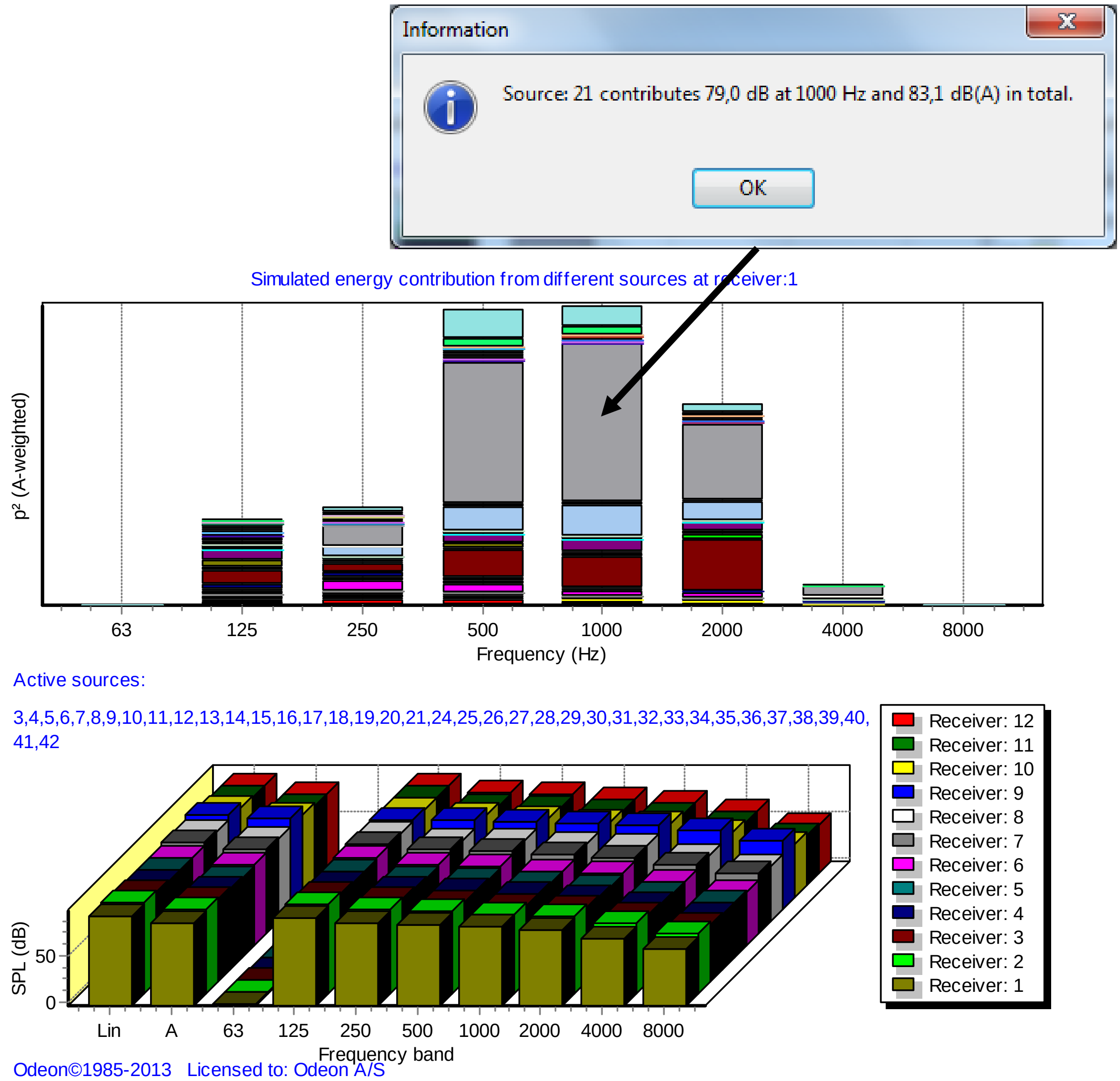

Figure 9 – Example of visualization of the relative contribution of many noise sources in a selected receiver point in a large industrial hall.

In the lower part of Figure 9 is seen the total SPL linear, A-weighted and in octave bands for each receiver point. This graph is helpful for the selection of which receiver points to use for the analysis. In the middle of the figure is a list of active sources in the current calculation.

3. AURALIZATION OF ROOM ACOUSTIC PROPERTIES

3.1 Principle

An impulse response in a room is related to one receiver position and at least one source position. Auralization means that an impulse response is convolved with a sound signal (preferably anechoic) in order to create the sound in the listener position. In the most common case of binaural listening (with headphones) the impulse response is in fact a two channel function, since the impulse response is split into the two ears signals by means of a head related transfer function (HRTF).

The sound signal that is used for the auralization should be selected carefully in accordance with the purpose of the auralization. Some examples of this are discussed in the following.

3.2 Auralization of basic room acoustic properties using hand claps

Any experienced acoustician knows that a great deal of information about the acoustics of a room can be captured by listening to a simple hand clap. Similarly, with a room acoustic computer model it can be very informative to generate auralizations with a handclap as the sound source. It is better than listening to the pure impulse response, which may sound unnatural. This kind of quick auralization is useful for the evaluation of reverberation, echoes or flutter echo, i.e. phenomena in the time domain. However, while useful as a tool for the acoustician, this kind of auralization is not so well suited for presentation to architects and other people without acoustical background; speech or music should be used instead, depending on the intended use of the room.

3.3 Auralization of sound coloration

In a room with sufficiently strong early reflections there may be a risk of coloration, i.e. music or speech does not sound natural, but some frequencies are stronger than normal and other frequencies are weak. This is a well-known acoustical defect in some small rooms; it is easy to hear even for an inexperienced listener, but there is no well established, reliable way to detect this by an objective parameter. So, auralization is an obvious means of analyzing a room if there is a risk that coloration can be an issue and for that purpose white noise is a good choice. When listening to and comparing auralization examples with different degrees of coloration it is easy to hear when there is a problem. Listening to speech is also good in order to detect coloration, whereas music cannot be used for this purpose.

3.4 Speech intelligibility

Auralization with speech is the obvious choice for several purposes. In rooms designed for teaching, meetings or other cases where good speech intelligibility is important, the auralization with a speech signal can instantly demonstrate the importance of acoustical treatment. It becomes evident also for non-acousticians what it means when a space is over-reverberant.

For this kind of auralization the source should be modeled with the frequency-dependent directivity, and it is important that the sound level is adjusted to be as realistic and correct as possible. In addition, the combination with realistic background noise is very important, although often neglected. But without background noise the auralized speech can be intelligible at long distances, which is not the case in the real world.

PA (Public address and alarm) systems are another area well suited for evaluation by auralization with speech signals. The transfer function of the loudspeaker units introduces spectral changes to the sound, very typical for PA systems, e.g. in railway stations. Also the possibility of echo-like disturbance to the sound due to the time delay from remote units is most efficiently evaluated by listening to auralizations. By the way; the objective STI parameter does not include disturbance from echoes. Again, it is very important that the typical background noise is included in order to make the auralization as realistic as possible.

3.5 Speech privacy in offices

Auralization is sometimes used for research purposes, by creating a number of acoustical scenarios, which are used for listening tests with a large number of test persons. This has been applied successfully in some projects related to the acoustics of open plan offices. In an early example this technique was applied to shown how speech privacy is related to STI [5].

In a later research project auralization through a multi-channel surround system was used for a test laboratory to examine the effect of office noise and temperature on human perception, comfort and office work performance [6]. The experiment concerned offices of two different sizes with three different acoustical treatments. The sound background was created by the ODEON room acoustic simulation software: I) a real open-plan office; II) an office as (I) but with a reflective ceiling; and III) an office as (I) but with the addition of acoustically absorbent surfaces. A total of 15 subjects were exposed to the conditions and each exposure lasted for 6 hours. The presence of office noise and the type of office environment were found to have a significant effect on office work tasks that involved processing words.

3.6 Quality of verbal communication

In restaurants and other places where many people are gathered for a social event, it is a well-known problem that verbal communication can be very difficult, because the noise from the other people talking is too loud. In order to auralize this kind of acoustical problem the correct signal-to-noise level is most important, but also the influence of the Lombard effect makes this a little tricky. A simulation technique for solving this problem has been presented in 2012 [7].

In order to ‘calibrate’ the different sound signals used for auralization it is found to be useful to apply an A-weighted alignment of the input signals before the actual convolution with the impulse response. This allows adjusting the overall level to be approximately right according to the calculated SPL, but it also makes it easy to adjust the mixing of several auralized signals to the correct signal-to-noise level.

3.7 Single musical instruments

The complicated directivity pattern of musical instruments presents a special problem to auralization. Whereas some sources may be sufficiently represented by a fixed directivity in each octave band, this is not possible for most musical instruments. In order to overcome this problem the multi-channel auralization technique was introduced in 2004 [8-9]. The idea is to record the sound in an anechoic environment with a number of microphones distributed around the source. When applied for auralization the sound source in the simulation must be split into the same number of highly directive sources.

3.8 Orchestra, balance and blend

In a concert hall the sound source is an orchestra which is a large and extremely complicated sound source. In order to improve the realism of auralizations of the sound from an orchestra, the multi-source technique was introduced in 2007-08 [10-11].

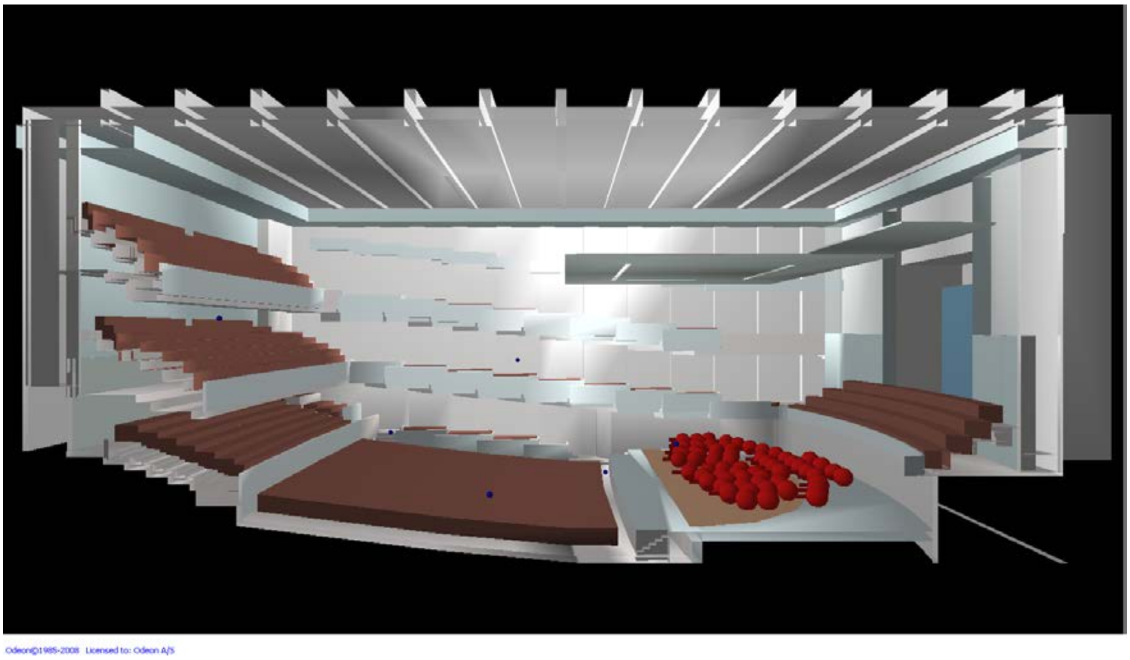

Figure 10 – A concert hall model prepared for auralization of a symphony orchestra using the multi-source technique; every musician is represented as a sound source (the red spots).

The multi-source auralization technique is based on anechoic recordings of each single instrument in the symphony orchestra. Although the accurate synchronization of the instruments cannot be perfect, the advantages of this technique include increased realism in terms of localization and apparent source width, and the possibility to compare different orchestra setups and the interaction between the instruments and the hall. In some concert hall designs with audience seats at the sides or behind the orchestra it is particularly interesting to have the possibility to compare in advance different listener positions; the new suggested method should allow to evaluate the balance and blend in such cases. An example is shown in Figure 10. At present the anechoic recordings of six different symphony orchestra pieces are available for the multi-source auralization, two examples from the Technical University of Denmark, and four examples from Helsinki University of Technology, see link at [12].

4. CONCLUSIONS

Visualization of room acoustic properties has been applied for auditorium design for about a hundred years. However, within the last twenty years or so there has been a strong increase in the possibilities and applications of visualization within all areas of room acoustic analysis and design. With the background of computer modeling it is natural today to analyze realistic 3D models instead of the simplified 2D models that were usual before. Thus the spatial distribution of various acoustic parameters can be displayed in color maps, and the reflection path of single reflections or groups of reflections can easily be studied in the 3D model. The use of colors to visualize the absorption characteristics of the room surfaces is particularly useful during the acoustical design process.

The auralization technique has also developed within the last twenty years or so and again based mainly on room acoustic computer modeling, although auralization is also possible with impulse responses measured in a scale model. The use of different sound signals has been discussed, starting with a simple hand clap and examples of speech intelligibility and verbal communication. The problems related to calibration of the sound level of auralization presentations have also been addressed. Special techniques have been developed in order to overcome the problems related to musical instruments as sound sources; for the single instruments the multi-channel technique has been introduced and for the orchestra the multi-source techniques represents the state-of-the-art.

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