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Architectural Acoustic Design by Means of Computer Modeling Techniques

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Introduction :

Architectural acoustic design is an important aspect in the development of any building project as any other technical aspect of modern construction, it is concerned with providing a satisfactory acoustic environment and good hearing conditions in every building and best serve the functions intended, such as work, sleeping, entertainment .. etc.

If the acoustics of a finished building is found unsatisfactory, it is often too late to do anything without great difficulty or much more expenses.

Good Acoustics Must Be Designed In Advance .

To make a simulation or to predict the acoustic performance of an enclosure during the design stage, the designers can make experimental simulation techniques or models in acoustic labs, this method is usually time-consuming and expensive. In recent years the capabilities of computers in this field have increased and the computer simulation is thus a better alternative for predicting the acoustics of enclosed and open spaces.

This paper illustrates and discuss the possibilities of using computer modeling techniques in the acoustic design which help architects in predicting the acoustic performance of the spaces they design before being constructed and thus preventing the difficulties and expenses of correction afterwards.

1- Traditional methods for acoustic calculation :

All numerical models derived from geometrical acoustics treat sound waves as rays following the same reflection laws as light rays in geometric optics. Thus, concave surfaces concentrate rays and convex surfaces disperse them.

Consequently, wave effects, such as interference, diffraction, refraction, diffusion, are not taken into account, which means that the results are only valid for high frequencies.

The Mirror image source Method (MISM) and ray tracing Method (RTM) are two well Known algorithms and have been applied for several decades.

1/1 *The MISM is a deterministic method, based on the principle that an impulse response at a receiver point, caused by a pulse originating from a sound source within physical boundaries, can be reduced to a free-field condition, (i.e: no boundaries) , with several mirror-images sources, each radiating spherical waves synchronized with the original source.*

1/2 *The RTM has a statistical character and discretizes the energy emitted by the sound source into sound rays, each traveling at the speed of sound and colliding with the physical boundaries, in accordance with the law of specular reflection. Losses due to spherical divergence are included as a result of the increasing separation between the rays as they spread out from the source with increasing time.*

Due to the inaccurate acoustical behavior of the RTM, the MISM is preferred, but its calculation time increase exponentially with the mirror order, while increasing only linearly for the RTM. This explains why the RTM is nevertheless applied when high reflection orders are needed (e. g : in case of hard linings in an enclosure).

Recently new approaches have been brought out, which all originated from the basic question " How can the great computational inefficiency of the MISM algorithms be avoided? "

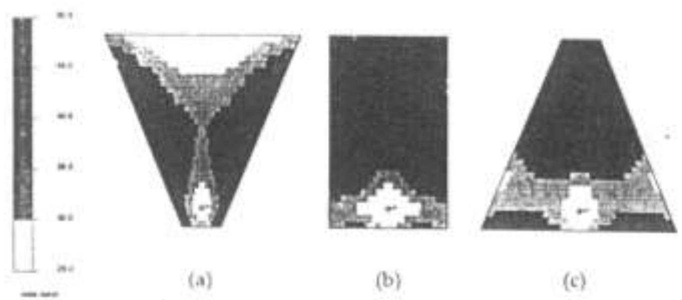
2- Modern computer – aided methods for acoustic calculation :

2/1 RAYNOISE Program :

One of the major breakthroughs in numerical modeling in geometrical acoustics is a method which suggest new MISM/RTM mixtures, combining the advantages of both MISM and RTM in one algorithm. The cone tracing method is where receptor points are touched by cones traveling with the ray in its centers. RAYNOISE is based on this approach based on the Conical Beam Method (CBM).

Raynoise application on a multi-purpose hall :

Due to economic pressures new hall designs have to meet the needs for increasing seating capacity, combined with multi-purpose properties . The main difficulty thereby is that the design criteria are mostly contradictory. A fan shaped plan is ideal in terms of sightlines, but not quite appropriate acoustically, while the rectangular and reverse fan shape is highly appreciated for good sound quality in concert halls. This is illustrated by fig.(1), which displays the computed spatial distributions of the Lateral Efficiency (LEF) [(*)] *in three differently shaped enclosures, The calculations were mode by RAYNOISE, using CBM.*



fan Shape   Rectangular Shape   Reverse fan Shape

Fig. (1) Spatial Distribution of LEF in three Different Shaped Enclousers

Source; Acoustics Today Magazine, Vol.2 July 2006, Issue 3, " Report of the Vision 2010 committee".

The volume of the three enclosures is 75m³. It is shown that the shape is characterized by a large area with low (LEF), this is due to the fact that most of the early reflections from the side walls arrive at the listeners from directions close to that of the direct sound.

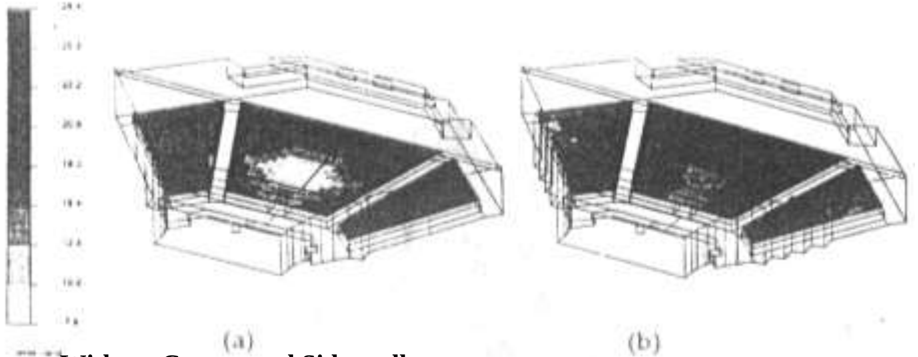
Fig. (2) displays the computed output of the design of a medium sized multi-purpose hall of volume = 5000m³, seat capacity = 800 pers. To insure good sound quality :

(a) an appropriate ceiling design was used to provide strong early reflection across the various audience groups.

(b) Diffusing linings used on the rear wall of the hall to prevent focusing effects and echo.

(c) An average reverberations time of 1.3sec.

(d) To improve the lateralization of the reflected sound, corrugated side walls were used, with alternate elements running parallel to the longitudinal axis of the hall. This approach combines the acoustical advantages of the rectangular shape with the practical advantages of the fan shape.



Without Corrugated Side-walls **With Corrugated Side-walls**

Fig. (2) Spatial Distribution of LEF in a Medium-Size multi – purpose hall

Source; Acoustics Today Magazine, Vol.2 July 2006, Issue 3, " Report of the Vision 2010 committee".

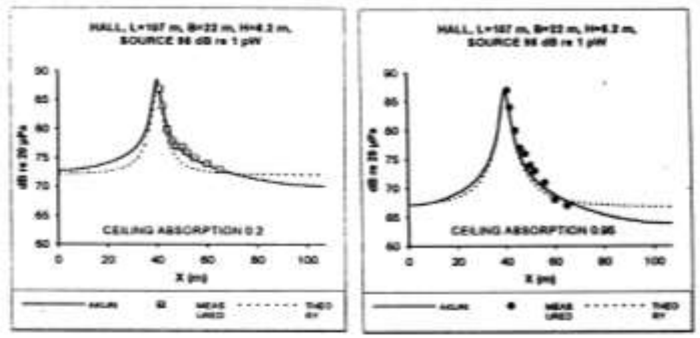
The calculations reached mirror order 40 and the computation time was around 20min. from fig (2), notice the improvement of 4% in the middle of the main floor. The saw-tooth shaped side walls create a more uniform distributed lateralization.

From the Above discussion the RAYNOISE program using the idea of the (CBM), allows the calculation of a complete set of results for the acoustical behavior and quality of an interior or exterior region. The method can be used for room acoustics, industrial noise control and environmental acoustics, such as the computation of noise due to line source, i.e: traffic noise and plane source, i.e : factory noise.

2/2 AKURI Program :

It is a simple acoustical PC-calculation program developed based on the method of images, where the reflecting sound rays are replaced by the acoustical images of the sound sources. The reflecting law of sound rays enables us to construct ray paths between the sound source and any given receiving point without having to calculate and measure angles of reflection .

The advantages of the program is that it is easy to operate and the calculation time is short .



Before and a) b) **After absorption of the Ceiling**

Fig. (3) Calculated and measured sound pressure levels in an empty hall

Source; Acoustics Today Magazine, Vol.2 July 2006, Issue 3, " Report of the Vision 2010 committee".

AKURI application in an industrial interior :

The accuracy of AKURI was tested an a computer model of an empty hall of size 107m x 22m x 6.2 m. The sound source was a speaker located on the floor 40 m from the rear wall at the centre line .

At the first stage the hall linings was quite hard. Then the ceiling of the hall was lined with absorption materials . The sound pressure level measurements, for both cases, were made along the centre line from I m to 25m away from the sound source. Fig. (3) show the results of both measurements.

AKURI is a fast and easy – to – use acoustical PC-programme for architects, layout planners and who are not very skilled in acoustics. The program run many sound field simulations with variable data obtained in a few minutes. The accuracy of AKURI is best in a rectangular hall where the sound sources are small and where there is a full lining of wall or ceiling .

2/3 ECOTECT Program :

Ecotect is the most resent comprehensive building analysis software. It factures a 3D modeling interface fully integrated with a wide performance analysis and simulation functions and acoustics, for any enclosure .

The program offers a number of acoustic analysis options, based on ray tracing techniques, such as :

(a) ***Statistical Reverberation*** *: it uses volumetric and material data to determine the reverberation time (RT) which is considered an objective and quantitative value used to estimate the acoustic response of a space . Fig (4).*

(b) ***Linked Acoustic Rays****: any change to the source position or room geometry it automatically update the predicted sound reflected rays, making the design of acoustic reflectors far simpler and interactive. Fig.(5)*

(c) ***Particle and Ray Analysis :*** *One can view the delay on level at any point and which surfaces are hit or reflected from. Fig (6)*

(d) ***Acoustic Response :*** *This analysis uses existing rays or a set of randomly generated ray paths to determine the RT, mean free path length and average absorption with an enclosure. Such an analysis is vital in determing the range of spatial RT within any auditorium. Fig. (7)*

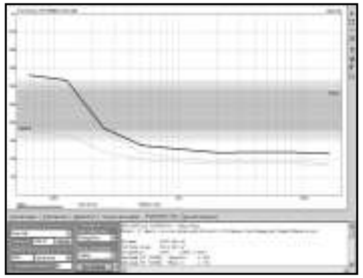


Fig. (4) An output of the statistical reverberation analysis from the Ecotect program

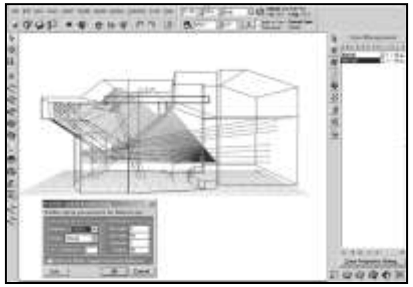


Fig. (5) An output of the Linked Acoustic Rays analysis from the Ecotect program

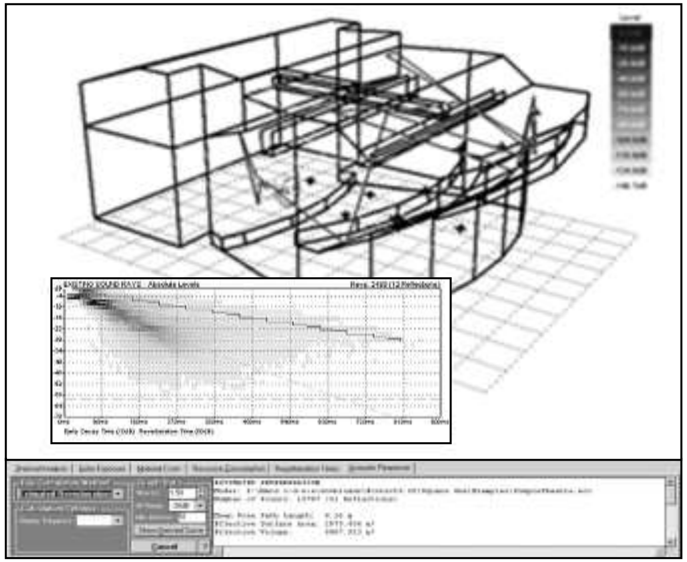


Fig. (7) An output of the Acoustic response, from the Ecotect program analysis

Source; Ecotect V. 5.5 software program.

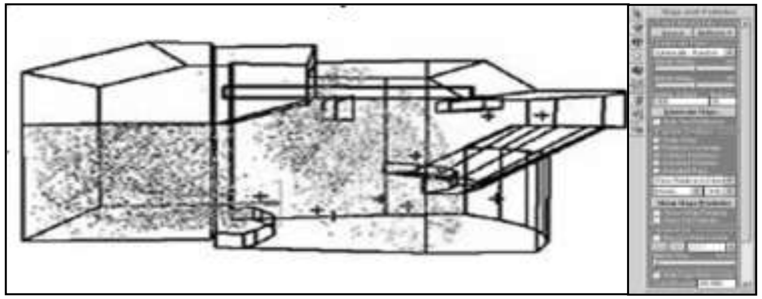


Fig. (6) An output of the particle and ray analysis from the Ecotect program

3- Discussion and conclusion :

Acoustics of buildings, or architectural acoustics, is a field of engineering concerned with providing a satisfactory acoustic environment and good hearing conditions is every building.

Everyone knows that an auditorium needs special attention to acoustics, but few realized that the apartment house, the office building, classrooms … etc. pose equally important and difficult acoustics problems.

Acoustics is as important in the development of any building project as any other technical aspect of modern construction. Available information about architectural acoustics usually permits the design and construction of acoustically satisfactory buildings without need for latter treatments or corrective measures. Thus good acoustics must be planned and designed in advance.

For architect experimental simulation techniques for acoustics are usually time-consuming and expensive, whereas in recent years the power of computer software programs, for acoustics simulation and design, has increased dramatically. Computer simulation is thus an attractive alternative for predicting the acoustics of enclosed and open spaces, giving accurate prediction of the acoustical performance of a space in the early stages of design and planning beside saving time and cost.

In this paper three different computer programs in the field of architectural acoustics, had been illustrated briefly, they are based on the main acoustics design theory methods, The Mirror Image Source Method (MISM) and the ray tracing Method (RTM).

- *The RAYNOISE program based on a mixture of image method and ray-tracing method.*
- *The AKURI – Program based on the method of images .*
- *The ECOTECT- program based on the ray-tracing method.*

Using any of the computer simulation acoustics programs will enable Architects to have good information and prediction about their projects' acoustics performance in the design stage to ensure providing a satisfactory acoustic environment after their construction .

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