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Simulation of the reverberation time of an existing architectural space using a 1:10 scale model

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Recently the science of acoustics has been reconsidered and valued more than just a tool concerning physics, telecommunications, and music. It is now an important topic of research for the acoustic comfort of places where people work and live, and it is also considered as an essential issue for the physical and mental health of human beings. Sound has to be integrated as a design concept in architecture, but architects need tools for the better understanding of the way to reach not only good acoustics but also good architectural design. It has been proven that physical scale models are very useful for the prediction of the acoustical behaviour of rooms, therefore this process is analyzed and studied at the Acoustic Design and Analysis Laboratory (LADAc) of the Universidad Autonoma Metropolitana (UAM-A) in Mexico city, in order to promote further investigations that provide useful data for the design of architectural spaces as well as the design of sound control devices. This paper shows the work of a master's degree thesis, the main objective of which is to present the results of the measurements of reverberation time taken in an existing room compared with those taken in the physical scale model of the same room.

1 Introduction

Nowadays it is very important to know the way architectural spaces react to different conditions, so as to predict, even during the design phase, their response. To manage this, it is convenient to use some sort of model to simulate or represent different situations. These simulation models are representations of the reality and can be generated either by mathematics, computer programs or physical scale models.

There are many areas within architectural, industrial design and construction that must be assesed by specialists, but designers and architects can prove, with the aid of different kinds of models, the design efficiency and make sure that the special intervention of a consultant will consist only in detailing, specifying, and calculating the scheme [1].

In room acoustics, the main objective is to study the behaviour of sound waves inside architectural spaces and tests can be taken place at acoustic laboratories. Physical scale models have been used for more than 100 years to serve this purpose. Designers and architects are used to work with physical scale models to visualize many design issues, so the approach of acoustic consideration and design can be better understood with these acquainted tools.

This paper adresses the work of a master's degree thesis, the objective of which is to present the acoustic measurement procedure that has been used to obtain important room acoustic parameters in a 1:10 physical scale model of the Academic Council Hall at the Design School of the UAM-A.

2 Laboratory characteristics

Inside the hemianechoic chamber of the LADAc at the Design School of the Azcapotzalco campus of the UAM-A, tests and measurements are made in order to anticipate the acoustic performance of architectural spaces using physical scale models to determine the acoustic qualities of rooms as to guarantee the correct function, in terms of sound comfort, the activities that take place inside them.

The existing hemianechoic chamber is a controlled environment where acoustic measurements can be done under "free field" conditions and with low levels of backround noise. The working area is 6.20 x 2.90 m (fig. 1) with a height of 2.92 m in the upmost part and 2.29 m in the lowest (fig. 2).

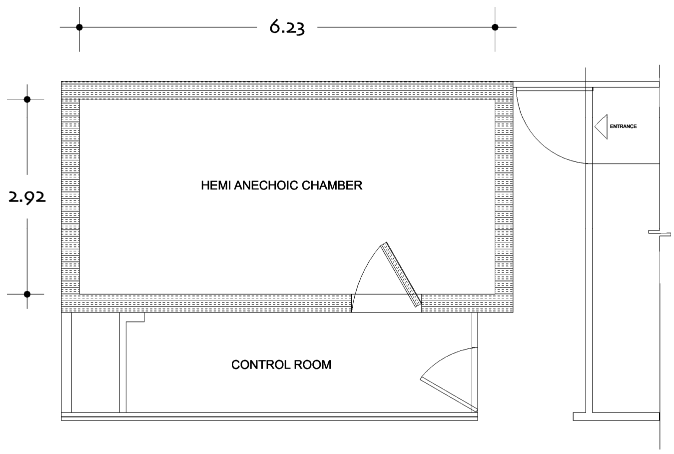

Fig. 1 Floor section of the hemi-anechoic chamber

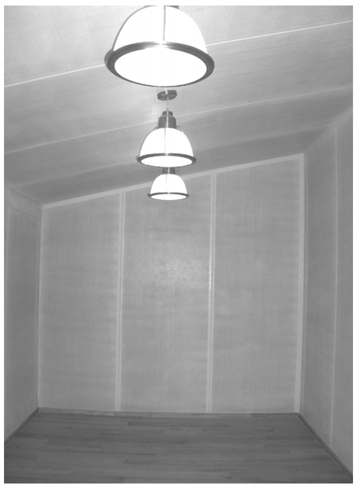

Fig. 2 Interior of the hemi-anechoic chamber

3 Case study

The chosen existing room for this work of investigation and whose conditions were simulated, was the Academic Council Hall (fig.3), located at the top of a three-storey building at the Design School of the UAM-A.

The room has an area of 142.1 m^2 and a volume of 588.3 m^3. Its maximum height is 6.5 m, and the lowest, is 3.5 m. The ceiling has a truncated piramid form, which gives the room special acoustical features. The vertical elements are concrete columns, gypsum drywall panels, and plywood elements, as well as 6 mm glass for the windows, and 3 vinyl folding doors. The floor is made of ceramic tile (66 m^2) and carpet (74 m^2) in its central part. The ceiling is made of gypsum drywall and the furniture consists of wooden desks and synthetic-upholstery chairs.

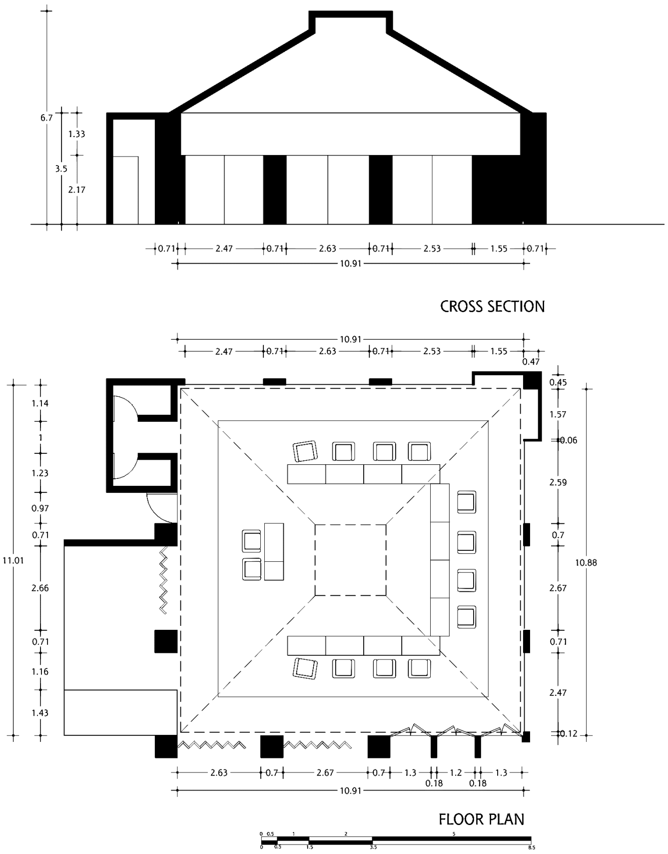

Fig . 3 Floor plan and section of the Academic Council Hall, Design School of the UAM-A

4 Physical scale model

As we know, the principle of scale model experimentation used for acoustical purposes, is that all dimensions involved are transposed to the same scale factor, including the dimensions of the room, the frequencies of interest and the absorption coefficients of the materials used in the model [2]. The scale used to build the physical scale model for the LADAc will be determined by some important factors, like the interior size of the hemianechoic chamber, the characteristics of the measurement instruments, the attributes and physical properties of the materials, and the capacity to reproduce them at a certain scale factor.

It was decided to use the 1:10 scale factor in order to reduce problems associated with high frequencies, being air absorption, the restraints of the equipment, as well as the lack of published information concerning absorption coefficients for building materials at these frequencies. In addition, changes in the model at this scale are easy to make.

The floor, walls and ceiling of the model were built from 6 mm MDF (medium density fiberboard) and 3 mm for the furniture, and varnished to reduce the small pores, the doors and windows were made of 3 mm acrylic membrane. The folding doors were modeled using 20 pts. estirene and polypropilene membranes, and the chairs were made of fenolic foam. The most important element of absorption is the area covered in carpet, and it was modeled using thin cloth and thick felt cloth.

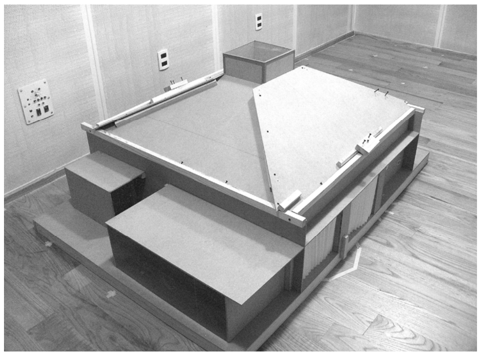

Fig. 4 Physical scale model

Fig. 5 Interior of the physical scale model

5 Measurements

It was decided to use the same measurement procedure as described in ISO 3382:1997 [3] to validate the measurement process in order to obtain reverberation time values for both the real room and the scale model and to compare them to verify this simulation technique. The parameters that can be obtained at the LADAc are the ones that directly depend upon reverberation time , being T_{20}, T_{30}, EDT, clarity, etc.

Two source and four receiver positions were established, considering the possible locations of both the sound sources during sessions in the Hall and the most important places of seating (fig. 6). For each position 3 measurements were made and averaged, so 24 values were obtained.

First, the measurements in the real hall were made, and values for T_{20} and T_{30} in 500 Hz and 1000 Hz were obtained, after averaging the results in each position.

The same measurement method was used during the tests applied in the physical scale model. A ¼" microphone was used as the receiver and a miniature loudspeaker (fig. 7) was used as a noise source. This miniature loudspeaker was specially built for this test, trying to follow some of the characteristics mentioned by K. Oguchi [4,5]. Tests were made in the physical scale model obtaining values for T_{20} and T_{30} in the corresponding scaled frequencies of 5,000 Hz and 10,000 Hz.

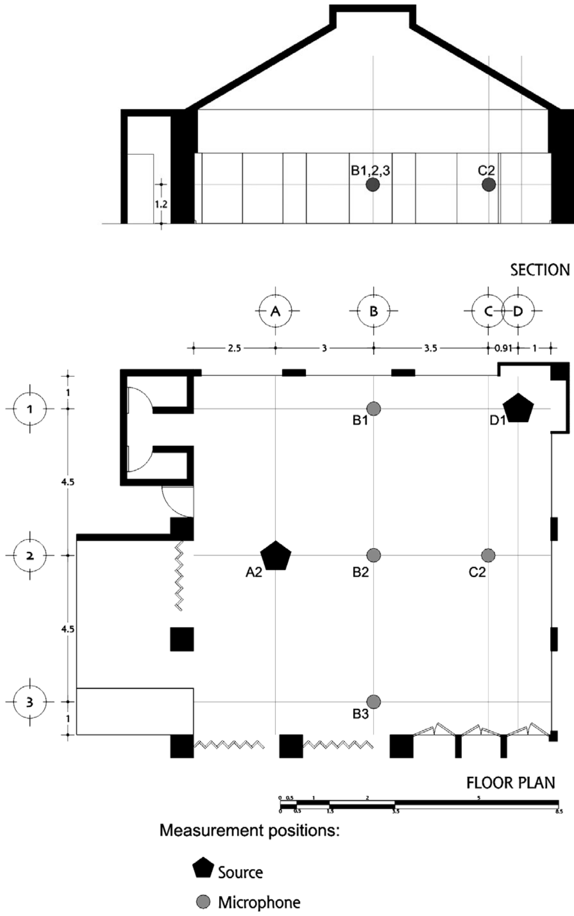

Fig. 6 Sound source and microphone positions for the measurements

Fig. 7 Miniature loudspeaker used in the physical scale model

All tests made in the physical scale model included the addition of more layers of varnish applied over all the surfaces as well as changes on the material that simulated the carpet (from a thin cloth to thick felt cloth), a shift that modified the original results.

At last, RT values in the physical scale model were obtained and compared to those of the existing room, as well as those obtained both from Sabine´s reverberation equation Eq.(1) and the equation for $TR_{mid.}$ Eq.(2)

$$TR = 0.161 \times (V/A) \quad (1)$$

where: V = Volume in m^3
A = Total absorption of the surfaces, in m^2.

$$RT_{mid} = \frac{RT\ (500\ Hz) + RT\ (1\ kHz)}{2} \quad (2)$$

where: RT_{mid}= Reverberation Time at mid-frequencies

Finally, 5 different values were obtained (table 1). They all differ from each other with a minimum variance, which can be justified due to the lack of absorption coefficient data for the materials used in the physical model as well as the difference in the directivity patterns between the sound sources used, although the miniature loudspeaker was placed in such a position as to emulate the behaviour of the hemi-dodecaedron loudspeaker, which has an omni-directional pattern.

	Sabine's Reverberation Formula. Physical scale model	RT in the physical scale model	RT_{mid} of the physical scale model	RT in the real Hall	RT_{mid} in the real Hall
s	0.14	0.16	0.14	1.3	1.2

Table 1. Comparison of values of the RT

5 Conclusion

The objective of the experiment, from the election of the scale factor for the construction of the physical scale model, to the selection of the materials to build it, was to obtain the RT value in order to compare it with the one acquired at an existing architectural space using a valid and proven method.

Satisfactory results were obtained in the physical scale model which comprise different steps including the addition of more layers of varnish and a change in the thickness of the absorbent material of the model.

Results of T_{20} and T_{30} have been presented and small differences are shown, from 0.1 to 0.4 sec. Results show that differences in the results are bigger at mid frequencies (500 Hz and 5,000 Hz in the scale model), than those at high frequencies (1000 Hz and 10, 000 Hz), which are relatively small. Even with these small differences, it can be proven that the results obtained from tests validate the experimental process.

Although the advances in computer simulation are evident, physical scale models are still popular and useful, as results are obtained with some amount of certainty. Michael Barron [5] suggests that the best decision is to run parallel tests on more than one simulation technique in order to get more reliable results. The benefit in the use of these models by designers and architects is the consideration of sound as an important design element and applies directly to the achievement of acoustical qualities of rooms in architectural design.

Acknowledgments

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