Analysis of the impact of sound diffusion in the reverberation time of an architectural space - A proposal for the characterization of diffusive surfaces using scale models

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The acoustics quality of architectural spaces has been related directly with the reverberation phenomenon, in order to understand more about sound in architecture, this proposal tries to conclude how diffusion acts on the reverberation time. The fact that architects deal with absorption coefficients and change the reverberation time by playing and designing with materials, opens a door to the possibility of new ways of architectural design, knowing how simple or complex and even natural diffusion surfaces will act in spaces. Several examples of the use of diffusion ad reverberation in architectural spaces can be found in buildings like the Jewish Museum from Daniel Libeskind or the Therme Vals from Peter Zumthor, the use of big surfaces of concrete in the first and uneven surfaces in the second, transform each of these places in one with very interesting sound qualities. To create spaces like these we can take diffusion as a design argument but, how will certain diffusive surfaces influence on the reverberation time of an architectural space? To answer this question it is necessary to experiment with scale models measuring the reverberation time, and not diffusion itself.

1 Introduction

This document proposes the importance that has for architects to know how to use diffusion as an argument of design. Parameters and coefficients had been established, however this information is not useful for architects as it is going to be mentioned later. The necessity to obtain data and instruments that help the architect to have better criteria about sound as a design tool is important.

The first part of the paper refers a reflection about the perception of sound in architectonic spaces, subsequently the concept of sound diffusion is tackled and the paper finishes with the details of the experiment.

The experiment refered in this paper consists in the investigation of the impact of the diffusive surfaces in the reverberation time of architectural spaces, based on the idea that the reverberation time is a parameter more related to architecture.

This research is part of a master thesis degree in course by the first author and guided by the second at the Universidad Autónoma Metropolitana – Azcapotzalco (UAM-A) in Mexico City.

2 What does sound mean to architecture?

It is hard for architects to imagine how an architectural space will sound when there is not enough knowledge of the acoustic parameters; the behavior of materials, the type of space, the dimensions, geometry, all them are fundamental to define the sound characteristics of the space. Since the diffusion started being an object of study, approximately 60 years ago, investigations had been made in this matter, but there is not yet any specific information for architects to be used in the design process. Ji-quing Wang [1] said that the theory and calculation of diffusion concept is still in the initial stage while Trevor Cox and Peter D´Anonio [2] said that in the 30 past years significant contributions had been made in different aspects of diffusion like the theory, design, prediction, optimization, measurement and characterization. But how can architects can understand and use this information? How is the way to simplify all this information and translate it to common methods of the design process?

Many types of studies about acoustics have been done for many years, however there are very few about how a space can bring us to a memorable experience. At the concept stage, architects start always tracing sketches on paper and they make questions like: How is geometrically going to be? How is lighting going to be? Is it going to be natural or artificial light? Which materials? What kind of structure? Is it going to be functional? All these questions solve only the visible aspects of the space, but few architects ask HOW IS IT GOING TO SOUND? How can we be sure that the result will be a pleasant experience?

Architects usually do not have any experience on acoustics; therefore they can not be aware about the acoustic response of the space.

Now a day’s acoustic consultancy can make the difference between a good and a bad acoustics of a space; there is not always an agreement between acousticians and architects and it is difficult to join this two different points of view. The architects usually think in terms of formal and conceptual ideas, on how the space is going to look, however their ideas are not always compatible and an important question is need to be done: Is the acoustical experience depending more of the architecture or is it consequence of the acoustical needs?

We have a lot of examples around the world about how architecture can make beautiful sound experiences in space just only with different materials, the environment and people that will create “music” in it. Francesc Daumal Domenech [3] describes in one article the sound experience in the Barcelona Pavilion, by Mies Van der Rohe (Fig.1), he talks about each room in the Pavilion, how does it sound and a perfect description of the materials and how are they are placed, he also made measurements of the reverberation time and he mentioned the phenomenon of the stationary waves. Finally he calls the Pavilion a “musical instrument”.

(Fig. 1, Barcelona Pavilion [4])

(Fig. 1.1, Barcelona Pavilion [4])

Another example in where the interaction between people and the space is very successful is the Jewish Museum in Berlin by Daniel Libeskind (Fig. 2). The museum can create specific sensations in each part of it, the small corridors that arrive to enormous spaces where the architecture creates a change in the perception of sound, and force people to stop and feel; even more they speak lower and walk slowly, any simple sound can grow considerably because of the reflecting surfaces of the room.

(Fig. 2, Jewish Museum)

We can finally established that sound represents a key factor for experiencing space at any place. We cannot stop hearing, as with sight and smell. Any space can create emotions that will make us either love or hate the experience of being in a crowded or quiet place. We cannot forget that the experience is made by the architecture and the people; the inherent relation between these elements forces the architect to think in a space coherent with what we see and what we hear. Michael Vorländer and Esam Abou-Elleal [5] made an experiment where people had to associate a sound (dry or reverberant) with the space (close, semi-closed or opened) where a very reverberant opened environment will cause confusion and vice versa and the conclusion was that people need to hear what they see.

3 Is sound diffusion an element related to the acoustic comfort?

As mentioned in section two, diffusion has been studied since many years ago and it is known that a diffuse field will give the sensation of a bigger space and the spatial impression is created due to the first lateral reflections where the quality of sound is improved due to the diffusion and scattering properties of surfaces.

Sometimes it is difficult to qualify the quality of a space because of subjectivity since we all know that everybody has personal preferences. From this point of view acoustic comfort parameters need to be more generalized. But the quality of sound implies the application of subjective preference tests to a wide group of people that will result in an important data classification for better acoustic comfort knowledge.

4 Sound Diffusion and Architecture

Diffusion is important for the sound quality in architecture, but how do architects can use these element to design spaces? Although there are two norms that have different processes to characterize diffusion the ISO 17497 [6] and the AES-4id-2001 [7] the data obtained from it is not useful for architects, unless they use some of the computer simulation programs that take diffusion coefficient into account.

According to Angelo Farina the ISO scattering coefficient can differ significantly from the diffusion uniformity coefficient [8] and the Mommertz/Vorländer method could be unstable, with the disadvantage that the experiment needs large samples of the surfaces and any mistake on the edges could change considerably the results [9].

For this reason is important to find which are the indicators that are useful for architects in terms of sound diffusion.

5 What does sound diffusion mean to Architecture?

Research in acoustics at the Universidad Autónoma Metropolitana -Azcapotzalco (UAM-A) is focusing on the diffusion, and how architects can design or use this type of surfaces to improve the designed spaces in terms of acoustic comfort. Experiments are designed but still in process to be done.

One of the objectives of this experimentation at the UAM-A is that architectural students have the option to learn more about acoustics and how to design with it, as well as an understanding of the fundamental concepts to clarify how sound reacts in different spaces with the use of different materials and geometric elements. This work is intended to make understandable how diffusion acts on the reverberation time.

6 Proposal for the characterization

One of the ways to understand sound diffusion in the architectural spaces is through computer acoustic simulation models, it is established that there are problems in the characterization of sound diffusion due to different forms of measuring it and the processes are not completely validated yet.

In the other hand there is one method of simulation in scaled models, this method according to Oguchi Keiji [10] is more reliable because it uses real sound to excite the space, in difference of the computer models that try to simulate sound by mathematic equations.

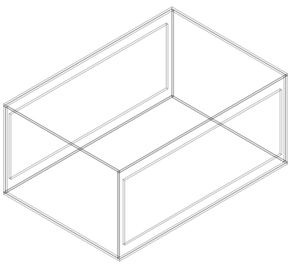
For this reazon in the UAM-A has been developed a laboratory in order to characterize diffusion in scaled models which are more sympathetic with architects. For that, it has been built a semianechoic chamber that allows to make sound measurements without the influence of the outside environment.

7 Experiment

To perform the experiment it was thought in the possibility to use a scaled parallelepipedic shape model 1:10, in which a comparison between different surfaces will be done. These surfaces are from absorbent to diffusive, going through a reflective space.

To validate the reverberation time obtained from the use of the diffusive surfaces it has been thought in a comparison with a virtual model constructed in CATT-ACOUSTICS program that includes the diffusion information for the known diffuser, concretely from RPGinc the diffuser QRD734 was chosen.

For the construction of the parallelepipedic space (Fig. 3) is important to take into account the "Bolt Area", so the resonant room modes will not interfere with the measuring process. Another aspect is that the volume of the space has to be enough that the reverberation time will be significant, because of this reason, a volume of more than 200 m^3.



(Fig. 3, parallelepipedic model)

The model is a 9mm acrylic box, the dimensions scale 1:10 are 40 cm x 60 cm x 88 cm.

The mode calculations were not more than 2217 hertz that does not get into the range of study of 5000 to 20000 hertz, according to Rayleigh formula.

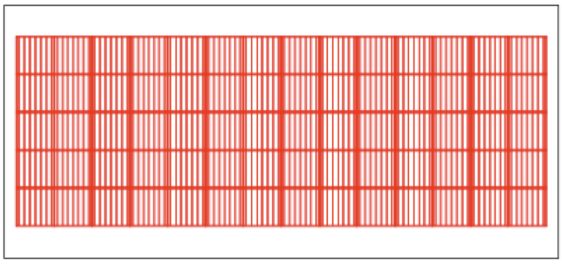
The maximum frequency in which the mode calculations do not have any influence is 4957 hertz.

The total volume of the box is 211 m^3 scale 1:1, and 0.211 m^3, scale 1:10.

The two openings in the large walls will be necessary to set the different diffusive surfaces.

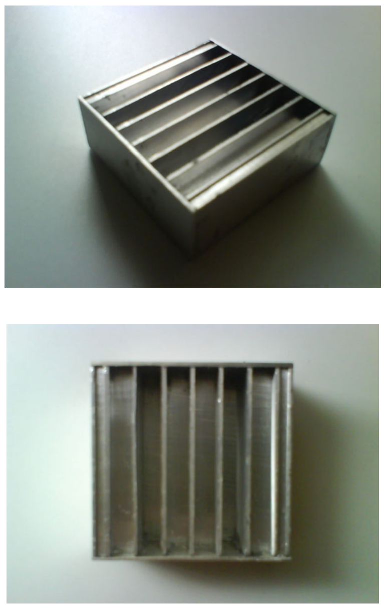
The density of covered surface is 42.56% of the total lateral walls, and is based on ideas from Murray Hodgson [11] where if the density of the volume of diffuse surfaces becomes sufficiently high, the sound becomes "trapped" and will not reach the room surfaces, another example of this ideas is the Jing Yong Jeong, Sung Chan Lee and Michael Vorländer [12] experiments, where they prove how much diffusion is enough to get the maximum coefficient, they conclude that the 30% of density in semi-spheres and 50% of square shapes are enough.

In this case the experiment will allow having the 42.56% of covered area (Fig. 4) that are exactly 140 QRD734 diffusers with a 1D organization. The QRD734 was proposed because the bandwidth of diffuse coefficient is optimum for the range of study and the application of them are commonly used in learning spaces.



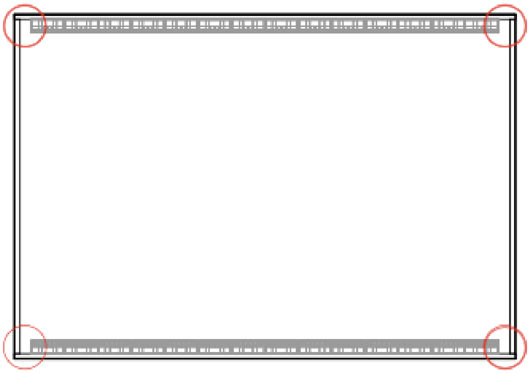
(Fig. 4, QRD734 organization)

Once the number of diffusers are estimated it was thought which material can be used to make the model scale 1:10, the edges need to be done perfectly, that is why wood was not chosen, the best option was aluminum, because of its solidity that allows to have perfectly edges and due to its porosity absence it apparently reflects sound with enough quality (Fig. 5).



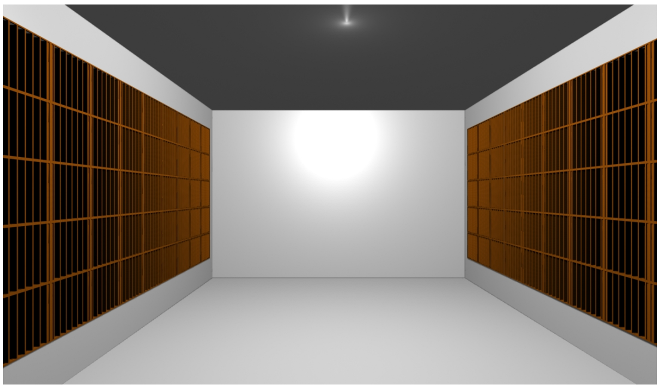
(Fig. 5, QRD734 diffuser at scale 1:10)

The arrangement of the diffusers (Fig. 6) had some resonance problems in the corners; to eliminate the residual spaces that can cause this effect we set the diffusers on a level with the wall (Fig. 7,8). Once the scaled model is made it is important to have the simulation done in the program CATT-ACOUSTICS to count on with the reverberation time data, necessary to compare with the scaled model. This stage of the experiment is still in process.



(Fig. 6, arrangement with resonance problems)

(Fig. 7, arrangement with diffusers on a level with the wall)



(Fig. 8, view of the diffusers in the reverberant chamber)

8 Some ideas about sound diffusion as a design argument

With these experiments what we try to do is to give the new architects a wider vision to create interior, outdoor and urban spaces that can take diffusion and different sound parameters as a concept of design. The object of study to integrate diffusion in the surfaces and see how is going to react in the reverberation time of the sonic space. The reverberation time is predictable if we use Sabine's formula but what happens when the diffusive surface is considerably big and can modify the result? It is said by Jing Yong Jeong, Sung Chan Lee and Michael Vorländer [12] that a diffuser is also an absorber, and any use of these surfaces will reduce the reverberation time. According to Stephen Chiles and Michael Barron "Bartel and Magrab found that rotating diffusing panels significantly reduced the scatter of reverberation time" [13] and Trevor Cox and Peter D´Antonio found that "Diffusers may be favored over absorption because they can deal with the distortion of sound due to reflections without removing energy and reverberance" [14] but we do not know specifically how many seconds or percentages will the diffusion will increase or decrease, and testing a different quantity of surfaces can show us parameters that we can use as architects, including the knowledge of the quality of the space.

Ji-quing Wang [1] said that the "ideal diffuser is non-absorptive, scatters the incident sound in all directions over a significantly wide frequency range" this parameters will give us a complete idea of how the different surfaces react in the reverberation time and we can determine if a certain surface will improve the sound of a space depending on the different typologies and uses of the buildings.

9 Conclusion

A study of the characterization of diffusion has been exposed. This research is still under realization and will give results at the end of this year which will be reported as soon as they are avalaible.

The above proposal tries to be a contribution for a better understanding of architects that will allow them to use this information to create spaces with better quality and comfort.

The use of diffusive surfaces is today a reality. New music spaces are being designed with important proposals in this matter. The sound investigation is still young as we can notice in this paper and there is still a long way to walk.

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