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The role of sound diffusing surfaces in the quality of the architectural space

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ABSTRACT

Architects usually do not consider sound as an important element in architectural design. However there is no doubt that sound is a key factor in space perception. By simply closing our eyes we realize the importance of sound, compared to using our sight only. Visual aspects such as light, materials, textures and colors are generally the elements that guide architects creative ideas. Today diffusion surfaces in concert halls are widely used, contributing to the improvement of music programs acoustic quality and to the improvement of the visual aspects of halls. This means that sound diffusers can significantly improve the architectural quality of any space by incorporating sound quality design as well as visual features. This paper presents the authors research on the diffusion of sound in surfaces and the impact these have on the reverberation time of an architectural space using a scale model approach and a real space comparison. We take into account that reverberation is understood through various parameters of the acoustic quality of the architectural space. This analysis has been developed from the architectural point of view, considering the use of sound diffusion as an architectural design concept. Inside this paper the development of the experiment done and the results of it are reported.

INTRODUCTION

One of the problems facing architectural design today is the lack of an integral vision of space that includes all aspects involved in its perception.

This paper is part of a research made by the authors regarding the integration of acoustics as a design element to be included through the architect's daily work. The perceived disjoint between acoustics and architecture, due to the difference between professions and the disciplines that support them, has caused architects throughout times, to not use sound as a fundamental element of design.

In search to find the acoustic elements that can give us an answer to the question about the quality of the architectural space, we choose the concept of sound diffusion since there are recent concert hall developments that include it in their conception with very interesting visual results. From this point of departure we did two experiments to find the impact that different sound diffusive surfaces have on the quality of an architectural space by looking for parameters that could be quality indicators. The first one was an experiment done with a scale-model comparing different diffusive surfaces, and the second one was focused on the comparison of the sound quality of two auditoriums; one of which has diffusive surfaces.

SOUND AND ARCHITECTURAL DESIGN

Usually architects turn their attention solely to the visual aspects of design leaving aside other aspects that enable people to have an all-encompassing perception of space. Specifically we refer to the fact that sound is not usually an influencing issue in the architectural design process. Although it is true that architects designing theaters, auditoriums and concert halls do take acoustics into consideration, we are still yet to find this practice in the design of non-acoustic specialized spaces.

Sound and space perception in architecture

Space perception is a concept that includes the use of all human senses. Sight and hearing are the two most important ones. The other minor senses of smell, touch and taste are involved in a secondary way when experiencing a space.

According to Pallasmaa [1]:

> "Sight isolates whereas sound incorporates; vision is directional, whereas sound is omnidirectional. The sense of sight implies exteriority, but sound creates an experience of interiority. I regard an object, but sound approaches me; the eye reaches but the ear receives. Buildings do not react to our gaze, but they do return our sounds back to our ears".

This thought, makes us understand the importance of sound in the perception of space. Without it, it would not be possible to have a complete experience of space. If we simply close our ears, we quickly realize this.

The relationship between the visual and the auditory is a matter that must be considered as a whole, since they are complementary concepts in the spatial experience. From our point of view, the architectural character of a space is defined precisely by these two aspects: the visual and the auditory. It is hence very important that the acoustics of a space can be felt from the visual and the materials and forms can be felt on the auditory.

Therefore to talk about the quality of an architectural space means talking about the quality of the visual and auditory, without neglecting the aspects of touch, smell and taste.

Acoustic quality of the architectural space

The acoustic quality of an architectural space is related, on one hand, with the ability of carrying out the activities for which a space has been designed, and on the other, with not having noise problems such as those related to reverberation and isolation.

However, sound quality cannot be reduced merely to functionality. The sound present in the architectural space needs to create an acoustic environment, and this acoustic environment needs to be part of the architectural environment of the space. Therefore, it is important that independently from fulfilling its functional needs to take into account the acoustic quality of space as a consequence of its mere architecture.

Besides common acoustic environments, expressive environments can be designed; this lead to an artistic intention that can be inserted into the acoustic environment of an architectural space. With this idea, we have an architectural space that can be seen from an acoustic point of view, and whose character can go from the functional to the expressive, passing through the environmental [2].

Sound diffusion and the architectural quality of space

Numerous concert halls such as the Philharmonie de Paris, the Copenhagen Concert Hall, and the Walt Disney Concert Hall, have recently been designed including the idea of visual acoustics. This is visible through elements of sound diffusion on walls and ceilings. These elements have been considered, from the architectural point of view and not exclusively from the acoustic one.

Sound diffusion is an opportunity that architects can take to make acoustics visible contributing by this way to the architectural quality of space.

Although sound diffusion elements have only been used in concert halls, radio and television studios and similar spaces, it is important to find the way to integrate them into an architectural language that can be used at any space.

Traditionally sound diffusion according to the above mentioned ideas has been used in spaces where music is the main activity, but it is important to consider its impact in other activities, just as an architectural design concept.

Sound diffusion as an architectural design concept

Architectural spaces are usually designed surrounded by smooth, hard and flat surfaces and the impact they have on the acoustic environment is not often considered. Moreover, when designing a space with acoustic elements to control sound, such as sound absorption areas, these are commonly proposed as additional elements not fully integrated into the original design.

Although sound diffusion can be integrated as an additional element to a given space, it has a greater impact when it is integrated into the original architectural design. What we need to know is what kinds of surfaces are diffusive and the impact they have on the acoustic environment of an architectural space.

From the acoustic point of view, sound environment is characterized by reverberation time. This is a concept that traditionally is present in architecture as a sound quality standard. That is why it is very important to make a research about the impact that different diffusive surfaces have on the reverberation time of an architectural space.

PROBLEM

Much of the technical information used in the field of architectural acoustics is far from the scope of architecture. Therefore it is important to make a gradual translation of acoustic concepts to those more related with architecture without avoiding the use of one or the others.

There is a very little knowledge in architecture about the concept of sound diffusion because this is a highly specialized concept. To link this concept with the reverberation time of a space can help to increase its understanding in terms nearer to architects.

The research problem that rises in this experiment is to establish the impact of sound diffusion surfaces on the acoustic environment of a space. In order to do this we decided to find out the impact that diffusion surfaces have on the reverberation time. We were set to find the relationship of these results with the sound quality parameters traditionally used in the field of room acoustics.

DEVELOPMENT OF THE EXPERIMENT

The proposed objectives for this experiment were:

1. To make a comparison of the reverberation time in a given space with the presence of different diffusing surfaces.
   - To accomplish this objective we set out a procedure to measure the RT in a scale model according to the ISO3382:97 standard [3].

2. To make a comparison of the reverberation time of two real spaces with the presence of diffusing surfaces in one of them obtaining their acoustic quality parameters.
   - To accomplish this objective we set out two procedures:
     - The measuring of RT in real spaces according to the ISO3382:97 standard [3].
     - The modeling of real spaces through the acoustic simulation program CATT-Acoustic.

To carry out this experiment which was developed as a Master Design Degree Thesis [4] with the guidance of Prof. Rodriguez-Manzo, the following stages took place:

- Definition of the space
- Definition of diffusive surfaces
- Validation of the experiment
- Acoustic measurements in the physical scale model

1. Definition of space

The proposed space is a physical shoe box scale model (Figure 1) with proportions of 1:1.5:2.2 corresponding to a space of 4 m x 6 m x 8.8 m, at real scale and of 0.4 m x 0.6 m x 0.88 m at 1:10 scale, its volume correspond to 211 m^3, and at 1:10 scale, 0.211 $m^{3.}$ Proper modes of vibration were reviewed to avoid acoustic faults.

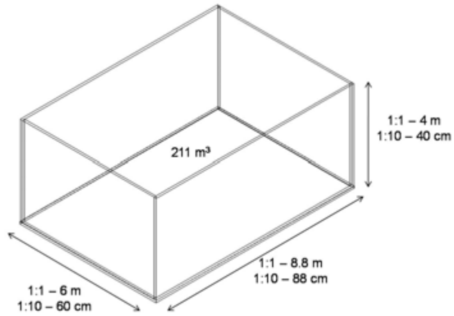

Figure 1. Definition of the space.

2. Definition of diffusive surfaces

Four types of scaled surfaces were compared (Figure 2):

- A surface based in QRD 734® diffusers, made of aluminum.
- A natural surface with rocks made of natural stones.
- A reflective surface made of acrylic.
- A designed surface based in different types of curves called architectural surface, made of wood.

Figure 2. Surfaces used in the scale model.

3. Validation of the experiment

To validate the experiment the space was modeled with the acoustic simulation program CATT-Acoustic comparing the result of reverberation time with the one obtained at the scale model, using the QRD 734® surfaces in both models (Figure 3).

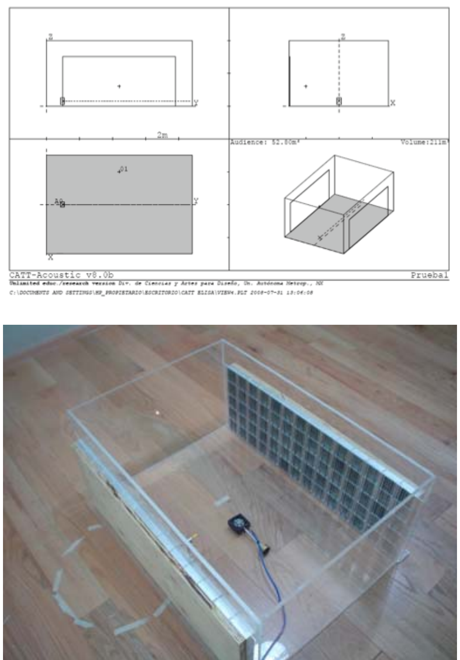

Figure 3. Models with QRD 734® surfaces.

4. Acoustic measurements in the physical scale model

These measurements were made in a hemi anechoic chamber with a reverberation time of 0.06 s, the equipment used was a NOR840 two channel analyzer, a Norsonic portable amplifier, a GRAS ¼" microphone with its ¼" pre-amplifier, and a mini sound source whose sound propagation pattern at 5 kHz y 10 kHz frequencies are shown in Figure 4.

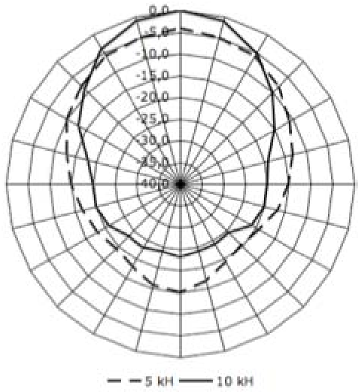

Figure 4. Mini source sound propagation pattern at 5kHz and 10kHz

Measurements were made according to ISO 3382:97 standard with an arrangement of measurement points and source as shown in Figure 5, an example of measurements are shown in the Figure 6.

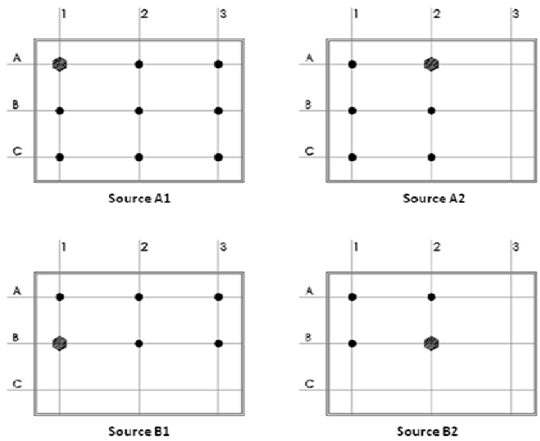

Figure 5. Arrangement of measurement points and the source.

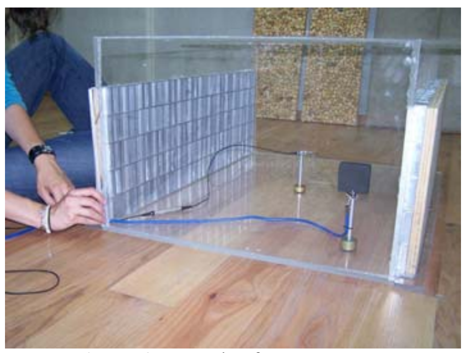

Figure 6. Example of measurements.

Real space measurements

Two similar auditoriums in form and function, shown in Figure 7, were selected with the difference that the first one has no intentional acoustic design with the presence of reflective surfaces, the second one does have an intentional acoustic design based on diffusive surfaces and an orthophonic ceiling.

Figure 7. Left – non acoustic treated auditorium, right – acoustic designed auditorium.

To make these measurements a hemi-dodecahedron NOR275 source, a Norsonic portable amplifier, and a NOR140 analyzer with the options to obtain the reverberation time and measurements of level vs. time.

The procedure to measure the RT in both auditoriums was based on the ISO3382:97 standard, the arrangement of sources and measurement points are shown in Figure 8.

Figure 8. Source and measurement points arrangement.

RESULTS

In the following paragraphs we will analyze the results obtained through the measurements done in the scale model and in the real spaces.

The first part shows the comparison of the reverberation time between different diffusive surfaces in a scale modeled space and in the second part we will see the comparison between two real spaces, the first with diffusive surfaces and the second without them.

Scale model

After measuring the RT in the scale model with the presence of different diffusive surfaces we obtained the following results:

In Figure 9 we can realize that the longest reverberation time was obtained with the reflective surfaces, as expected. The second longest reverberation time was obtained with the presence of the curved surfaces, followed by the QRD 734® and at the end the less reverberated case with the presence of natural rocks. We expected the QRD 734® to be the less reverberated but we found that the natural reliefs and cavities present in the rocks surface contribute to this fact.

On the same graph we can realize that the difference of the reverberation time between the 5 kHz and 10 kHz in each case is reduced as the surfaces are more irregular.

T mid comparison on scale model surfaces

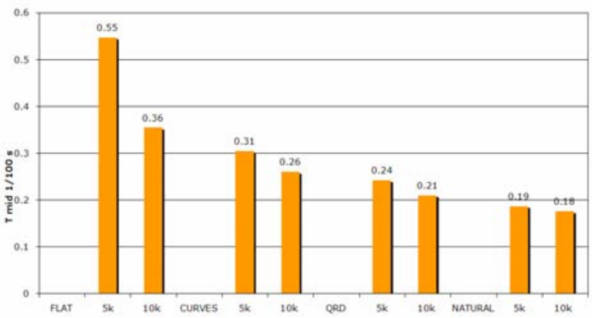

Figure 9. Comparison of RT of the scale model with different diffusive surfaces.

In Figure 10 a comparison between the RT obtained every 1/3 octave frequency band in both, the reflective environment and the diffusive one (QRD 734®) is shown and we can realize that a diffusive surface tends to homologize the RT in all frequencies, and the reflective surfaces tend to vary them.

T mid comparison / flat and QRD surfaces

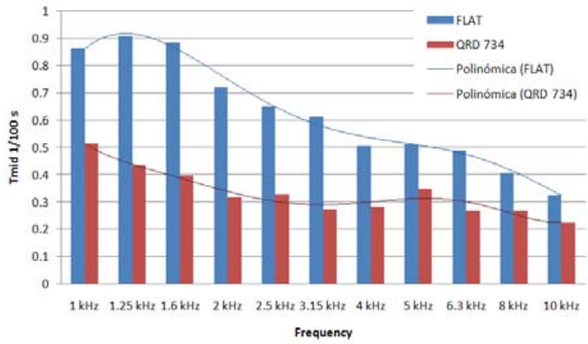

Figure 10. Comparison of RT of reflective and diffusive environments at different frequencies.

From this graphs we can conclude that sound diffusive surfaces tend to reduce and homologize the RT between the different frequencies.

Real space

The RT measurements at the real spaces were done with the objective to confirm if diffusive surfaces tend to improve the acoustic quality of rooms, besides reducing it.

In Table 1 RT results obtained in both auditoriums are shown.

Table 1. RT comparison of the auditoriums.

	T20	T30	RT
T mid K-001	0.6	0.62	**0.61**
T mid F-001	1.05	1.18	**1.11**

The difference between the RT in both spaces is due to the presence of diffusive surfaces in the K-001 auditorium that scatter energy and reduce the RT. However we can feel a still alive space and not a dead one.

In Figure 11 we can see that the RT in the auditorium with diffusive surfaces tends to be homologized in the different octave band frequencies, unlike the auditorium without them.

The difference between maximum value and the minimum one is 0.11 s in the K-001 and 0.37 s in the F-001.

T mid comparison / K-001 and F-001

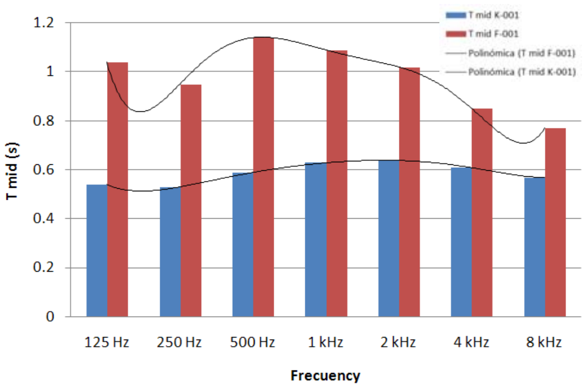

Figure 11. Comparison of RT of the auditoriums in different frequencies.

Figures 12 and 13 show the decay curves at 500 Hz and 1 kHz, and we can see that this curve in K-001 auditorium has a softer decay that the F-001 auditorium, and this is an indicator of the fact that diffusive surfaces tend to avoid acoustic faults.

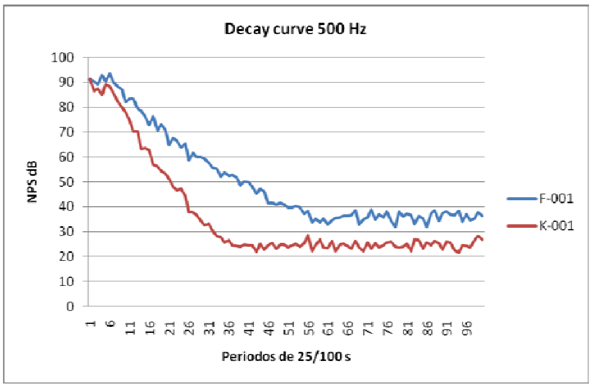

Figure 12. Comparison of decay curves of the auditoriums.

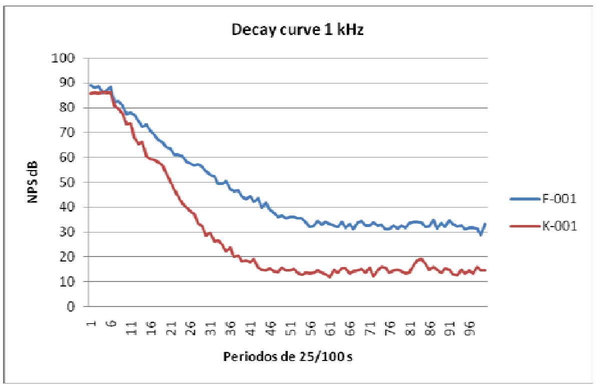

Figure 13. Comparison of decay curves of the auditoriums.

After analyzing the RT measurements of both auditoriums, we sought the significant quality parameters of the architectural space to determine if sound diffusive surfaces can improve them.

Both auditoriums were modeled with the CATT-Acoustic software and through them, after having validated the real vs the virtual; we choose the following indicators to compare the acoustic quality of them: D-50, G, LF and RASTI at 500 Hz.

In Figure 14 we can see that the speech intelligibility of the space evaluated through the D-50 parameter shows that the K-001 auditorium has more upper values and homogeneity than the F-001 auditorium. We have to remember that values over 50% are well suited.

D-50 / 500 Hz

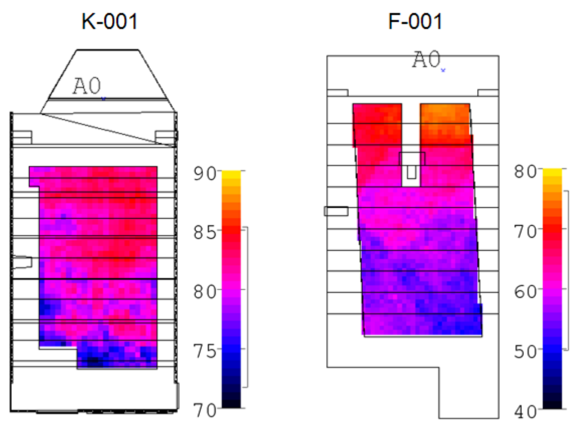

Figure 14. Comparison D-50.

In Figure 15 the strength parameter (G) shows us that both auditoriums are over the recommended values, but in the case of the K-001 auditorium we can see that the presence of the acoustic shell and the orthophonic ceiling have an impact in specific areas of the auditorium.

G / 500 Hz

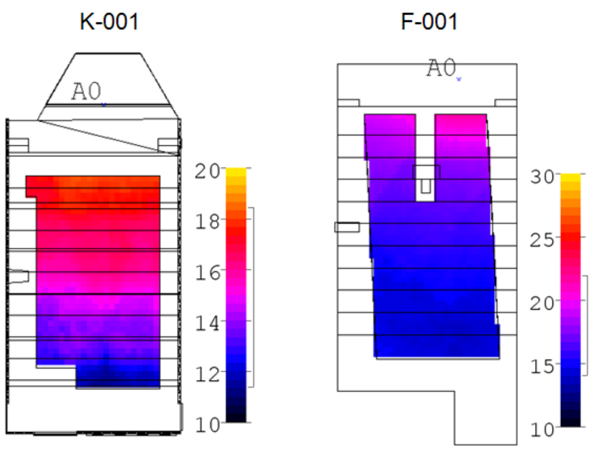

Figure 15. Comparison G.

In Figure 16 the lateral fraction, which is related to the spatial impression, shows us that the K-001 auditorium has wider and homogeneous areas with this kind of quality.

LF / 500 Hz

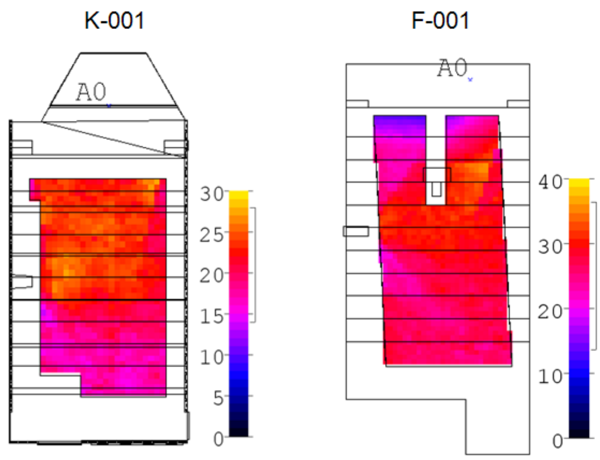

Figure 16. Comparison LF.

Figure 17 confirms us the speech intelligibility quality improvement of the K-001 auditorium due to the presence of diffusive surfaces.

RASTI

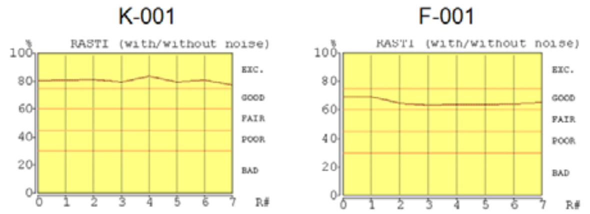

Figure 17. Comparison RASTI.

DISCUSSION

In this research where issues like the sound environment sensation and perception, and their possibilities as architectural quality indicators were taken to conduct an experiment to define the way in which architectural elements like diffusive surfaces can have an impact on the acoustic quality of the architectural space.

The results of this experiment let us made a reflection about the way in which architecture can influence the sound environment by its mere presence.

In the scale model experiment we found that diffusive surfaces tend in one hand to reduce and control the reverberation and on the other to homogenize the frequency response of reverberation time, which means that the sound environment can be improved in two ways: the functional issue and the qualitative.

These aspects are very important because the diffusive elements can be designed to provide the architects with tools for architectural quality space conceptions.

When the comparison between the real auditoriums was done to verify in real life the impact of sound diffusive surfaces in them and to live somehow the experience brought with it, we obtained results that confirm what we found in the scale model experiment and they revealed aspects related with the acoustic quality of the architectural space.

In this last study we experienced the meaning of being immersed in a space with sound diffusive surfaces which allows us to understand that they do not only control reverberation but they also make the space to feel "alive".

With all this elements the discussion about sound diffusion and architectural design is focused in two main aspects: the possibility of the reverberation control of space, that is to reduce problems that reverberation brings to architectural spaces and the possibility to maintain a "live" space from the sound environment point of view and to contribute with that to the architectural quality of the space.

Sound diffusion is able to be designed by using surfaces, being integrated or overlapping in the architectural space, this gives to the architect multiple opportunities to acoustically improve the architectural space design.

Architects need to comprehend the acoustic phenomena and the wide spectrum of opportunities to influence in the sound environment through architectural ideas and concepts.

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