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Acoustical Treatments in Architectural Design

Ishita Thakur[1], Ketan Jain[2]
[1]*Fourth Year Student, Department of Architecture, SDPS Women's College, Indore, India*
[2]*Assistant Professor, Department of Architecture, SDPS Women's College, Indore, India*

***Abstract*: Designing a space which corresponds to all the senses of human is necessary to get an overall good experience. Sound is not taken into account while designing spaces like offices, classrooms, restaurants, whereas, for places like studios and auditoriums, the fundamentals aren't applied to precision. Therefore, architects and designers need to study the fundamentals of acoustics and apply them in the initial stages of design. This research paper studies the basics of sound, its mechanism, how it propagates in a space and how it can be treated. Guidelines are formulated for offices, classrooms, restaurants, studios, and auditoriums which will prove to be handy while designing these spaces. At last, Problems were formulated of a college auditorium, a small-scale office, and a restaurant to get a better understanding of how to apply the basics of acoustics by calculating reverberation time and providing viable suggestions.**

***Keywords*: Sound and its mechanism, acoustical treatments, Sound propagation in different shapes, Acoustical materials, reverberation time.**

1. Introduction

In Architecture, we talk about the form and space, we talk about the experience and meaning a building brings to us. All the qualities of a building are the sensory experience of light, touch, smell, and sound. Often, this experience is designed without considering the effect of sound. It is time to start designing for the ears.

Architectural acoustics can be understood as a science of achieving enhanced auditory experience in architectural spaces. The acoustic encounter of diverse spaces has a significant effect on the standard of life, communal behavior, health and efficiency of the people involved.

A better acoustic experience can increase the efficiency of a worker in offices, make the experience in the concert hall more enjoyable, improve the speed of recovery of patients in hospitals, increase the grasping power of students in classrooms and may increase the market value of the apartment. Currently, noise pollution is affecting humans in all areas of the urban lifestyle and spaces are being compromised to provide good sound quality, problems arise when the cost of consulting an acoustician is avoided. And while designing, the science of sound is ignored.

Efficient and economical acoustic solutions are needed to improve the qualitative aspects of any architectural space.

2. Related work

A. Literature review

1. Auditorium acoustics from past to present (Kabir Maishanu); 2017

Paper identifies how the acoustics were generally achieved in auditoriums based on method, technics, and material used. For the present scenario, the problem of loudspeaker system arises, which was not considered while planning most of the auditoriums in the '90s. It can be solved by using flat panel innovation. From past to present, the criteria of the shape of the auditorium, it's seating and its slope have been the same, the material differs at present. Using concrete floors and walls have proved horrible for sound quality.

2. Average sound absorption per person at octave band frequencies (Chagok, Nmd Domtau, Ld Agoyi); 2013

The resulting values are useful for establishing the most favorable reverberation time for effective communication in any type of enclosed space. Occupied enclosed spaces generated a shorter reverberation time than the unoccupied ones. Within the frequency range of 125-4000 Hz, the sound absorption power per person increases with frequency.

Frequency (Hz)	Average Sound Absorption per person
125	0.29
250	0.43
500	0.51
1000	0.68
2000	0.71
4000	0.73

3. Classroom Acoustics: The Problem, Impact, And Solution (Fredrick S. Berg, James C. Blair, Peggy V. Benson); 2000

The paper throws light on the basic problems caused by poor classroom acoustics and its impact on teaching and learning in schools. The classroom design should have a balance of surfaces reflecting, absorbing and diffusing sound. Without using any amplification system, these things can be done to improve acoustics in a classroom;

i. Making surfaces that do not provide useful reflection absorbent.
ii. Making ceiling and side walls reflective.
iii. Installing carpet on the floor to cover the useless reflecting surface and reduce noise.
iv. Echoes and reverberation are prevented when sound

absorbents are placed on the back wall.

B. Case study

1. A case study of philharmonic hall, New York

After studying the acoustics of this hall, certain facts were noted about the design of the space, which are:

The received amount of intensity of sound is mainly a result of the initial time delay gap. The surfaces need to be closer to the source but should not interfere with the sound's direct path to the receiver. Panels reflecting sound are hung from ceiling at an angle so that sound would project into the audience.

3. Scope of study

The main intent of the study is to be able to design spaces that contribute to the psychological, physical and general well-being of humans that are negatively affected by the increment in noise pollution over time.

4. Fundamentals and basic concept of architectural acoustics

A. Sound and its mechanism

Sound is a vibration of particles that passes on as a perceptible wave of pressure, in solid, liquid, or gases. Vibrations are produced by the source of sound in the medium in which it is present. Sound wave is produced when the source keeps on vibrating and the vibrations move forward in the medium. During this process, sound waves can be reflected, passed on through a surface, or absorbed by a surface. Reflection is sound wave bouncing off, of a surface while preserving the initial energy it started with. The transmission of a sound wave occurs when a wave bends to pass through an obstruction while retaining its original energy. Absorption of sound wave takes place when the sound wave obstructs a barrier and some of its energy is absorbed by its material. The quantity of sound absorption by a material is assessed with the help of its absorption coefficient.

B. Parameters affecting acoustics in architectural space

Echo is the recurrence of sound when sound waves are returned from a surface. When the reflecting surfaces are placed at a distance greater than 17 meters, echoes are bound to happen. When reflecting surface is curved, echoes are more probable to occur.

Reverberation Time is the time required for the rest of the sound to fester. Reverberation is said to take place when sound energy continues to propagate even after the source has stopped generating energy. It is the time required for the complete intensity to drop by a factor of 10^6 or, the intensity of sound decreasing by 60 dB after the source is turned off. Sabine's equation helps in determining reverberation time;

$$t = \frac{0.16\,V}{A}$$

Where,

$t = reverberation\ time\ in\ seconds$
$V = volume\ in\ m^3$
$A = total\ absorbing\ power\ in\ m^2 sabine$

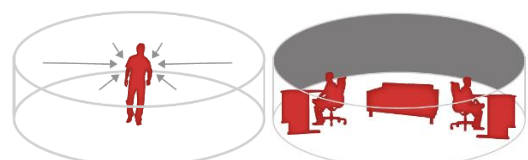
C. Propagation of sound in different shapes

1) Narrow Rooms

Sound absorbents applied at the ceiling will not be as effective as sound absorbers placed very close to the source of sound. Hence, absorbents should be placed on walls first and foremost.

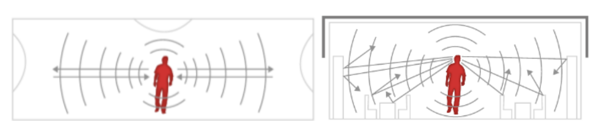
2) Round Rooms

Echoes are created as the sound waves concentrate on the center of construction. This can be solved by applying sound diffusers at the curved surface which will disperse the sound in every direction. The area which will be more crowded should not be put to the center, furniture with high sound diffusing power should rather be placed there.



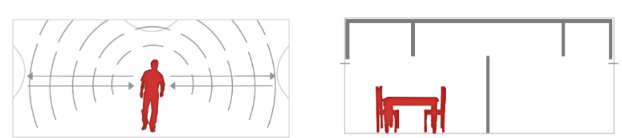
3) Large Rooms with low ceiling

In large rooms, the spreading of sound is a challenge, since the speech can be heard over long distances. The sound should be absorbed and diffused and barriers should be created at the ceiling to obstruct sound.



4) Large Rooms with high ceilings

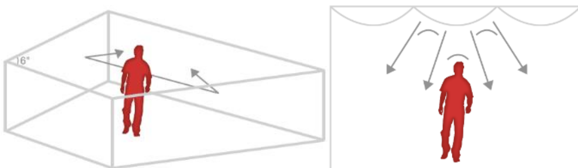
High noise level at such places makes it difficult to concentrate sound. The conversation over short distances is hindered due to the masking of sound by the surrounding noise.



Relevant noise should create a masking effect which can be achieved by appropriately taking down the noise level. Also, the spread of sound should be confined. The surfaces should be furnished with sound absorbents and diffusers. Sound barriers can be created by using furniture, which will not only disperse the sound but also make absorbing better.

5) Inclined Walls

Inclined walls spread and concentrate the sound altogether. When a wall is inclined in proportion to other walls and ceiling, the sound is spread in the desired way. An inclination of more than 6 degrees gives the best diffusive results.

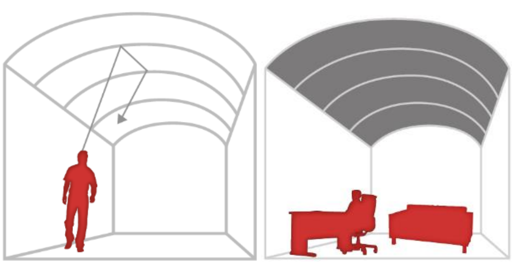


6) Convex Ceilings

Convex ceilings are sound diffusers as they spread the sound. In places where spreading of sound is required (concert halls) providing a convex ceiling is a good option. Curves can be furnished with either sound absorbents or sound diffusive materials.

7) Vaulted Ceilings

Vaulted ceilings concentrate the sound intensity at the center of construction. For the sound to be spread in all directions, sound diffusers are placed at the curved surfaces as the sound movements are intensified at curves. Putting less diffusive elements at the center will not create desired effects. Hence, at the center, it is advised to put sound diffusive elements. To prevent the spread of sound, obstructions should be placed along the curve.



D. Treatment of sound

1) Sound absorption

Absorption is the attribute of a surface by which sound energy gets transformed into another form of energy. The extent to which a surface can absorb sound energy is called its absorption coefficient. Frequency of the sound wave is the main factor for deciding the value of the absorption coefficient.

Classification of sound absorbing materials:

a) Porous Absorbents:

Sound waves, when hits a porous surface, either get reflected or gets into the pores, where it releases heat energy as a result of friction. With the increase in resistance caused by friction, the ability to absorb increases. Some examples are Slagwool, glass wool, wood wool, asbestos fiber spray, foamed plastic, and perforated fibreboards. For high-frequency sounds, opting for porous material will be a good decision.

b) Resonant Absorbents:

In this system, the absorbent material is fixed on sound framing (usually timber) with an air space left out between the framing and the wall at the back. These types of absorbents work well for low-frequency sounds. Sound waves of a specific frequency cause resonance in the panel. When the resonating vibrations dampen, sound absorption occurs.

c) Cavity Resonators:

In cavity resonators, the resonance of air occurs when sound waves travel through it. The air is confined in a chamber with an opening. Such an arrangement can act effectively over a single selected frequency. Application of cavity resonator is normally restricted to absorption from individual machine or in similar cases.

d) Composite type of absorbents:

A cavity is created between the panel and wall by mounting the panels on battens. The panels may be of metal, wood (plywood) hardboard, plasterboard, etc. 10-20% of the total area of the panel should be used for holes. The resonance of air in the cavity causes the sound to dampen when sound passes through the hole. If a porous material is placed in the cavity, its performance will increase. This arrangement works well for a wide range of frequencies and turns out to be economical too.

E. Sound insulation

When there is a reduction in the level of sound when it passes through an obstruction, the phenomenon is known as sound insulation. The factors such as the increase in population densities, change in habits of the community, improvement in building construction practices, etc., have made the attention given to sound insulation necessary.

Hard materials are in general are good sound insulators. The insulation of sound is measured in the adjoining space rather than the space where the sound is produced.

5. Acoustic design guidelines

A. General guidelines

- Sound reflections should be paid more attention to. The straight, flat spaces tend to reflect or echo sound.
- The sound coming from other building systems like HVAC should be kept in mind.
- No obstructions should be present in the direct sound path for optimum clarity.
- Furniture placed in the room should be given a good thought as it will absorb or reflect sound.
- The sound that is leaking should be dampened.
- Floor materials affect the acoustics of the room to a large extent.
- Customized design for ceilings and walls will improve the acoustics of theatres and concert halls.

B. Classrooms

- Schools need to be designed or modified to reduce the occupies classroom noise levels to less than 50 dB

- Make all surface areas that do not provide useful reflection absorbent, and, conversely, do not cover any useful reflective surface.
- Make the ceiling and side walls reflective surfaces to increase signal intensity.
- Install carpet on the floor to cover a useless reflecting surface and reduce noise.
- Place absorbent panels on the back wall to prevent echoes and reduce reverberation.
- An ideal reverberation time of 0.4 to 1.0 seconds is advised depending on the size of the classroom.

C. *Restaurants*

- Exterior walls treated with sound-insulating material.
- Placing quieter areas away from the source of the noise.
- Placing a louder space between quieter space and source as a buffer.
- Addition of soundproofing materials between spaces.
- Using flooring underlayment with acoustic properties at dining spaces.
- Using mass loaded vinyl as an absorbent between restaurant spaces.
- Use hanging baffles to absorb the low-frequency noise.
- Use acoustic or fabric-wrapped panels to absorb noises.
- Install a soundproof door between the kitchen and dining room.
- Use sound-absorbing partitions around noisy stations.

D. *Offices*

- Typical reverberation time is between 0.4 to 1.0 seconds.
- Absorptive materials will be most likely required for the ceilings.
- Standing waves are borne to occur if two parallel surfaces are reflective. So, two non-parallel surfaces should be made absorbent.
- Noise level should not be more than 25-35 dB
- The places with a quieter environment should be placed where they can be accessed more otherwise, they will be useless.
- Rooms requiring confidentiality should be placed away from working areas.
- Working stations should be designed with absorbing panels at low heights.
- Crowding of space should be avoided. The maximum allowance should be 8-10 people per meter squares.
- Acoustic treatments to be implied:
  - Perforated ceilings with sound absorptive insulation.
  - Absorptive panels directly fixed to ceilings or soffits.
  - Absorptive panels hanging vertically as baffles or horizontally as clouds.
  - Freestanding screens.
  - Workstation panels.
  - Absorptive treatments to building soffits where there is no suspended acoustic ceiling.

E. *Studios*

- 20-30 dB is the maximum allowable noise level.
- Echoes should be eliminated in the design of studios.
- The finish on the outside surfaces of the building should be of sound reflecting material.
- Resonance and reverberation should be prevented by making exterior and partition walls rigid.
- To reduce reverberation time inside the studio, make the interior surfaces absorbing in nature.
- The provision of windows in the studio should be minimum to prevent the transfer of noise from outside to the inside of the building.
- If there is more than one studio in the same building, it is preferable to locate all of them on the same floor. In no case, the studios should be located one above the other. There should be minimum space of one floor between two consecutive studios in elevation.
- Heavy curtain and draperies may be used with the advantage to control the time of reverberation in the studio.
- The arrangements of hinged panels in walls or rotatable cylinders in the ceilings are made to control the acoustical condition of the room.

F. *Auditoriums*

Volume: The hall should have enough volume. It should be decided while keeping in view the intensities of sounds likely to be developed in the hall.

- An average of 0.60-0.90 square meters per person should be used for calculating floor area.
- The average height varies from 6m for small halls to 7.50m for larger halls.
- Recommended volumes for different types of auditoriums are:

Cinema or Theatres	$4.0 - 5.0\ m^3$ *per person*
Musical Halls	$4.0 - 5.5\ m^3$ *per person*
Public Lecture Halls	$3.5 - 4.5\ m^3$ *per person*

Shape: This is an important consideration in the acoustic design of an auditorium and it involves the geometrical aspect of the hall.

- Concave walls concentrate sound and hence aren't considered good for acoustics.
- Plain walls are better.
- Convex walls are excellent since they reduce the possibility of echoes to the minimum extent.
- Fan-shaped floor plan gives better performance. An

arrangement should be made for sidewalls such that their angle doesn't increase more than 100 degrees curtain line.

Sound Absorption: To control reverberation, sufficient absorbing surfaces should be provided in the hall.

- The surface from which the sound is likely to be reflected should be so designed to assist the distribution of sound.
- The areas likely to cause objectionable sound reflections should be sorted out for the treatment with sound absorbents.

Site Selection: If the site is not present in a quiet place, heavy and costly implementations will have to be made to have an acoustically good hall.

- The orientation of doors and windows should be kept such that the external noise is permitted to the minimum possible extent.
- 40-45 dB is the maximum allowable noise level within the hall.

Seats and Seating arrangement: Seating arrangement should follow arcs from concentric circles.

- Seats are arranged in a zig-zag pattern so that each seat gets a clear path to receive sound and it is not obstructed by the person sitting at the front.
- In successive rows, the end to end distance of chairs should be 450 mm which can be extended to 1000 mm.
- The line of sight and horizontal should not have an angle of more than 30 degrees.
- The angle of eyesight from the horizontal of the front-most observer should not exceed 30 degrees to view the highest object on the stage.
- The distance of the first-row workouts to about 4.5m for cinema and 3.6m for theatre.
- The rise in the level of seats may be between 80mm to 120mm per row.
- Width of seats should be between 450mm to 600mm.

6. Problem formulation

A. SDPS college auditorium

On measuring the office area, the following values were obtained;

$length = 20.3\ m$

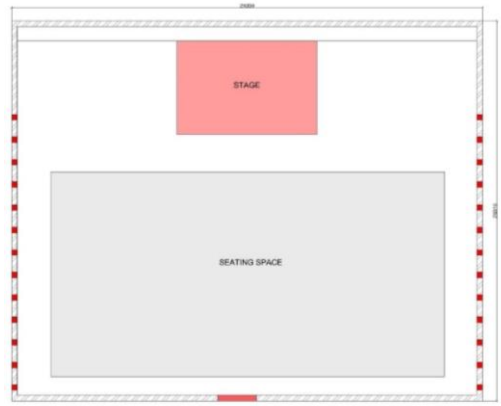
$breadth = 25.2\ m$

$height = 7.5\ m$

$Approximate\ Occupancy = 200\ (maximum)$

$Area\ of\ Plaster = 657\ m^2$

$Area\ of\ flooring = 512\ m^2$



Now calculation of the number of absorbing units and the time of reverberation is done in below-mentioned cases;

- When occupancy is zero
- When occupancy is 50
- When occupancy is 100
- When occupancy is 150
- When occupancy is 200

The absorption coefficient for various surface and its absorption units is tabulated as follows:

SURFACE	AREA OR NO. In m^2	ABSORPTION COEFFICIENT $per\ m^2\ or\ per\ no.$	ABSORPTION UNITS $In\ m^2 - sabine$
Plaster	657	0.02	13.14
Flooring	512	0.03	15.35
Furniture	200	0.02	4
		Total=	32.50

Now, the absorption of an adult $= 0.46\ m^2 - sabine$

Hence, the net increase in the absorptive power of the room due to the presence of one person is obtained by deducting the absorption power of the seat from that person.

So, the net increase in absorption power per person$= 0.46 - 0.02 = 0.44$

The absorption units of office with different strength of people will be as follows:

STRENGTH	ABSORPTION UNIT WHEN OFFICE IS EMPTY	ABSORPTION UNITS OF AUDIENCE	TOTAL ABSORPTION UNITS $In\ m^2 - sabine$
NIL	32.50	0	32.50
50	32.50	22	54.50
100	32.50	44	76.50
150	32.50	66	98.50
200	32.50	88	120.50

Now, volume of office= $lenght \times breadth \times height = 3836.7\ m^3$

The time of reverberation for different strength of crowd can be worked out by applying Sabin's equation:

$$T = \frac{0.16V}{A}$$

For no crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 3836.7}{32.50} = 18\ seconds$$

For 50 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 3836.7}{54.50} = 11\ seconds$$

For 100 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 3836.7}{76.50} = 8\ seconds$$

For 150 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 3836.7}{98.50} = 6\ seconds$$

For 200 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 3836.7}{120.50} = 5\ seconds$$

Thus, we see that the reverberation time of the auditorium is very high in every case.

Usually, the strength of the auditorium crowd is about 100 so absorption units required so as to get reverberation time of 2.0 seconds when the strength of the crowd is 100.

$$A = \frac{0.16V}{T} = \frac{0.16 \times 3836.7}{2} = 306.93$$

But, absorption of the room when the strength of crowd is, is 76.50 $m^2 - sabine$

So, extra absorption unit comes out to be 230.44 $m^2 - sabine$

Coefficient of absorbing material if the absorbing material is fixed on the flooring and two opposite walls of the auditorium, Total area to be covered with absorptive materials

$$= 816.06\ m^2$$

$Absorption\ coefficient\ required\ of\ the\ material,$ μ

$$= \frac{extra\ absorption}{area\ to\ be\ covered} = \frac{230.44}{816.06} = 0.28$$

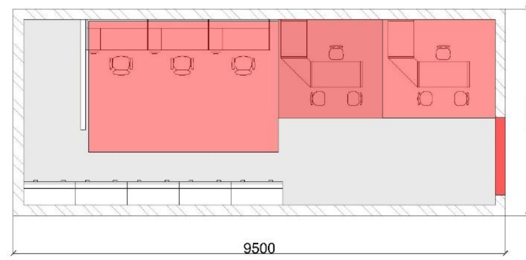
Acoustical Treatments advised:

- Since the auditorium is already constructed, it is not possible to do flooring underlayment, so absorptive carpet should be installed.
- Absorptive fabric-covered foam panels on the longer walls will absorb the low-frequency sounds.
- The addition of acoustic tiles on the ceiling will further improve the overall experience.

B. *Small scale office*

On carrying out the measurement of the office area, the following values were obtained;

$length = 9.5\ m$
$breadth = 4\ m$
$height = 3\ m$
$Approximate\ Occupancy = 5\ (usual), 20\ (maximum)$
$Area\ of\ Plaster = 80.68\ m^2$
$Area\ of\ flooring = 38\ m^2$



Now calculation of the number of absorbing units and the time of reverberation is done in below-mentioned cases;

- When occupancy is zero
- When occupancy is 5
- When occupancy is 10
- When occupancy is 15
- When occupancy is 20

The absorption coefficient for various surface and its absorption units is tabulated as follows:

SURFACE	AREA OR NO. In m^2	ABSORPTION COEFFICIENT $per\ m^2\ or\ per\ no.$	ABSORPTION UNITS $In\ m^2 - sabine$
Plaster	80.68	0.02	1.61
Flooring	38	0.03	1.14
Furniture	20	0.02	0.4
		Total=	3.15

Now, the absorption of an adult = 0.46 $m^2 - sabine$

Hence, the net increase in the absorptive power of the room due to the presence of one person is obtained by deducting the absorption power of the seat from that person.

So, the net increase in absorption power per person= $0.46 - 0.02 = 0.44$

The absorption units of office with different strength of people will be as follows:

STRENGTH	ABSORPTION UNIT WHEN OFFICE IS EMPTY	ABSORPTION UNITS OF AUDIENCE	TOTAL ABSORPTION UNITS $In\ m^2 - sabine$
NIL	3.15	0	3.15
5	3.15	2.2	5.15
10	3.15	4.4	7.15
15	3.15	6.6	9.15
20	3.15	8.8	11.15

Now, volume of office= $lenght \times breadth \times height = 114\ m^3$

The time of reverberation for different strength of crowd can be worked out by applying Sabin's equation:

$$T = \frac{0.16V}{A}$$

For no crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 114}{3.15} = 5.7\ seconds$$

For 5 people,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 114}{5.15} = 3.4\ seconds$$

For 10 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 114}{7.15} = 2.4\ seconds$$

For 15 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 114}{9.15} = 1.8\ seconds$$

For 20 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 114}{11.15} = 1.5\ \ seconds$$

Thus, we see that the reverberation time of the office is higher than ideal reverberation time.

Usually, the strength of the office crowd is about 10, so absorption units required so as to get reverberation time of 0.6 seconds when the strength of the crowd is 10 people,

$$A = \frac{0.16V}{T} = \frac{0.16 \times 114}{0.6} = 30.4$$

But, absorption of the room when the strength of the crowd is 7, is 7.15 $m^2 - sabine$

So, extra absorption required= 22.28 $m^2 - sabine$

Coefficient of absorbing material if the absorbing material is fixed on the opposite walls and ceiling.

Total area to be covered with absorptive materials

$$= 95\ m^2$$

Absorption coefficient required of material, µ

$$= \frac{extra\ absorption}{area\ to\ be\ covered} = \frac{22.28}{95} = 0.24$$

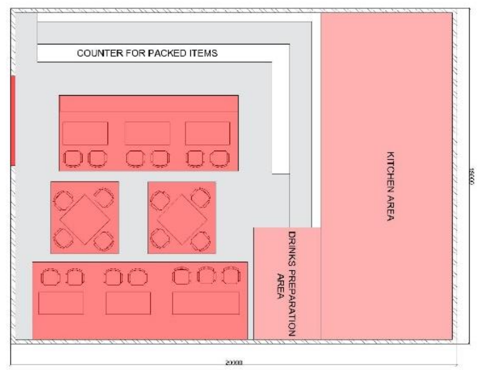
Acoustical Treatments advised:

- Perforated ceilings with sound absorptive insulation.
- Absorptive panels directly fixed to ceilings or soffits.
- Absorptive panels hanging vertically as baffles or horizontally as clouds.
- Freestanding screens.
- Workstation panels.

C. Restaurant

On carrying out the measurement of the restaurant, the following values were obtained;

$length = 20\ m$
$breadth = 15\ m$
$height = 3.5\ m$
$Maximum\ Occupancy = 55$
$Area\ of\ Plaster = 290\ m^2$
$Area\ of\ flooring = 300\ m^2$



Now calculation of the number of absorbing units and the time of reverberation is done in below-mentioned cases;

- When occupancy is zero
- When occupancy is 15
- When occupancy is 25
- When occupancy is 40
- When occupancy is 55

The absorption coefficient for various surface and its absorption units is tabulated as follows:

SURFACE	AREA OR NO.	ABSORPTION COEFFICIENT $per\ m^2\ or\ per\ no.$	ABSORPTION UNITS $In\ m^2 - sabine$
Plaster	290	0.02	5.8
Flooring	300	0.03	9
Furniture	55	0.02	1.1
		Total	15.9

Now, the absorption of an adult = 0.46 $m^2 - sabine$

Hence, the net increase in the absorptive power of the room due to the presence of one person is obtained by deducting the absorption power of the seat from that person.

So, the net increase in absorption power per person= $0.46 - 0.02 = 0.44$

The absorption units of office with different strength of people will be as follows:

STRENGTH	ABSORPTION UNIT WHEN RESTAURANT IS EMPTY	ABSORPTION UNITS OF AUDIENCE	TOTAL ABSORPTION UNITS $In\ m^2 - sabine$
NIL	15.9	0	15.9
15	15.9	6.6	22.5
25	15.9	11	26.9
40	15.9	17.6	33.5
55	15.9	24.2	40.5

Now, volume of restaurant= $lenght \times breadth \times height = 1050\ m^3$

The time of reverberation for different strength of crowd can be worked out by applying Sabin's equation:

$$T = \frac{0.16V}{A}$$

For no crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 1050}{15.9} = 10.56\ seconds$$

For 15 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 1050}{22.5} = 7.4\ seconds$$

For 25 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 1050}{26.9} = 6.2\ seconds$$

For 40 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 1050}{33.5} = 5\ seconds$$

For 55 people crowd,

$$T = \frac{0.16V}{A} = \frac{0.16 \times 1050}{40.5} = 4.2\ seconds$$

Thus, we see that the reverberation time of the restaurant is higher than the ideal of 1 second.

Usually, the strength of the restaurant crowd is about 25 so absorption units required so as to get reverberation time of 1.0 seconds when the strength of the crowd is 25:

$$A = \frac{0.16V}{T} = \frac{0.16 \times 1050}{1.0} = 168$$

But, absorption of the room when the strength of the crowd is 25, is $26.9\ m^2 - sabine$

So, extra absorption required= $141.1\ m^2 - sabine$

Coefficient of absorbing material if the absorbing material is fixed on the opposite walls and ceiling.

Total area to be covered with absorptive materials

$$= 440\ m^2$$

Absorption coefficient required of material, μ

$$= \frac{extra\ absorption}{area\ to\ be\ covered} = \frac{141.1}{440} = 0.32$$

Acoustical Treatments advised:

- Soundproofing the wall between the dining room and bar.
- Adding mass loaded vinyl as a barrier between restaurant spaces.
- Use hanging baffles to minimize the noise in the dining area.
- Use acoustic or fabric-wrapped panels to cut down on noise in the dining room.
- Install a soundproof door between the kitchen and dining room.
- Use sound-absorbing partitions around noisy stations.

7. Conclusion

Design of space should correspond to all the human senses, but majorly while designing we talk about the form, the space and its visual impact over users.

The acoustics of a space play an important role in the usual psychological, physiological and general well-being of people involved. To make spaces that complement the acoustic needs, we first need to understand how the science of sound works in a building.

To create an acoustically sound space, a balance of reflective and absorptive surfaces is to be achieved.

After studying sound, its mechanism, how it propagates in different shapes of spaces and how sound can be treated; either absorbed or insulated, this report was drafted to give the general guidelines that would help in designing commonly used spaces, like, offices, classrooms, restaurants, studios, and auditoriums.

Three live problems were formulated; a small-scaled office, a restaurant and an auditorium of a college, to get a better understanding of how the fundamentals studied during the research can be implemented by calculating the reverberation time and providing the solutions that can improve the acoustic problems of the then present scenarios.

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