Acoustics Studies of Lecture Hall

Introduction

Acoustics in a lecture hall is a very important aspect to consider during the design process. With the proper acoustics, the occupants can clearly hear the speaker and therefore have a much more productive time when using that space. In order to optimize the acoustics of a space, one must examine the reverberation time of the room in relationship to the materials used and its sound absorption ability. In spaces such as lecture halls, speeches create high frequency, low-energy phonemes. With this in mind, the reverberation time of the room should be kept to a minimum to ensure the ear's undistorted reception of these phonemes. This acoustical study of the lecture hall will examine the use of different materials in the interior of the room and how they affect the acoustics of the room. If the existing design of the room provides poor acoustics, a new design suggestion will be made to improve such deficit.

Existing Conditions

Lecture Hall 1210 features 85 seats with long wood tables on a stepped floor. The shape of the room is rectangular with the approximate dimensions of 8.7m by 14.2m (28.5 ft by 46.6ft). This lecture room is mainly used for lectures in the university level, and occasional audio-visual presentations. Therefore, we can assume that the age of the audience in the lecture hall to be mostly in their twenties. The ceiling of the lecture hall is dropped in the middle of the room, forming a cove opening around the entire perimeter of the room. The walls of the lecture hall are constructed with gypsum board painted with flat paint. The floor is covered with heavy carpet on concrete. The nine rows of desks and the two doors of the lecture hall are constructed of solid wood with a varnished finish. Last but not least, the sides of the two doors are constructed with glass (See Table 9.1 for material list).

Main Materials	
1. 	**Varnished Wood** Location: desks, doors
2.	**Glass** Location: part of doorframe
3.	**Gypsum board** Location: Walls, ceiling
4. 	**Carpet** Location: Floor

Table 9.1 – Material list

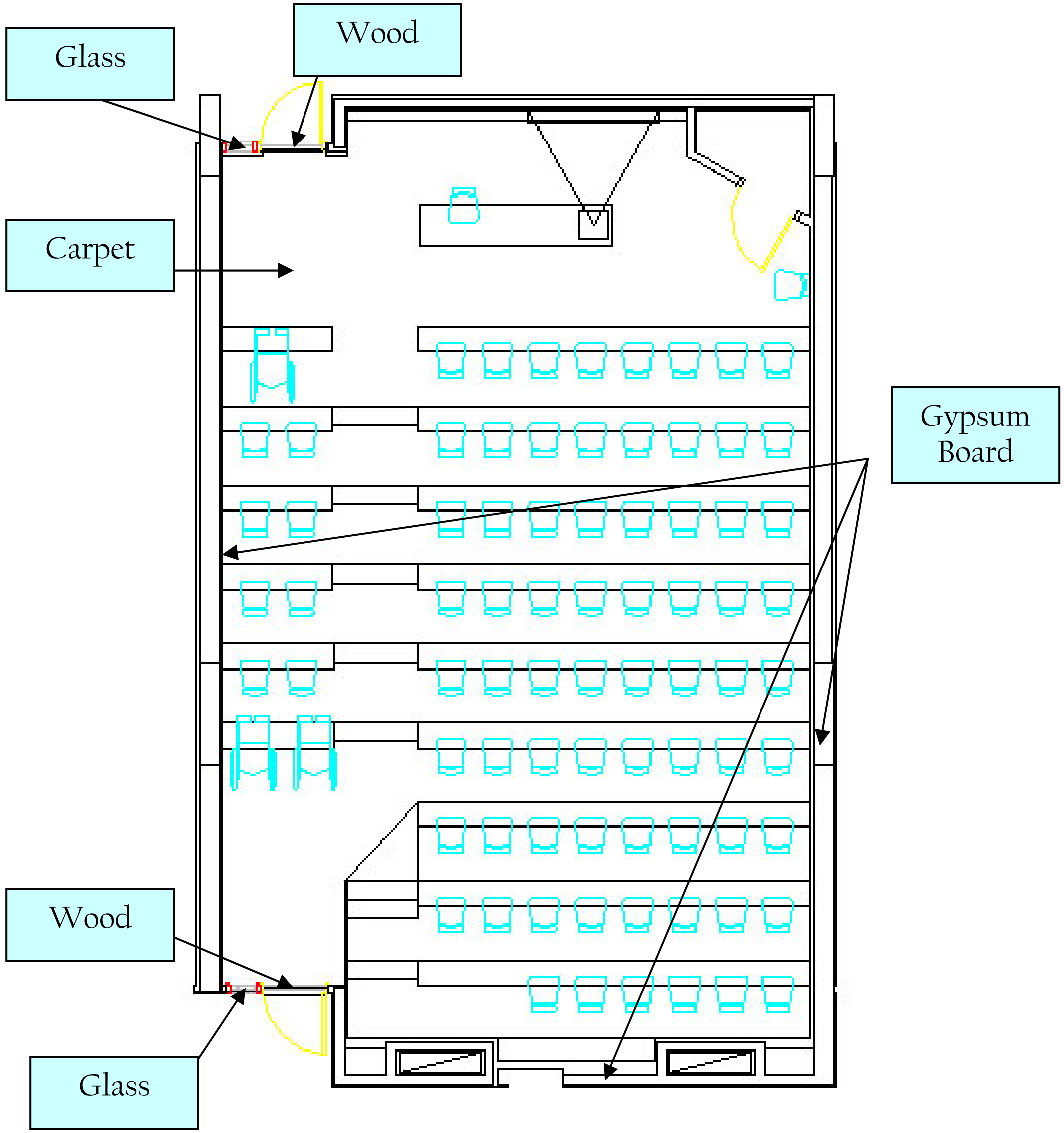

Figure 9.1 ~ Lecture Hall 1210 Layout

Reverberation Time Analysis

The time required for an amount of sound to decay to a value one millionth of its original intensity is known as the reverberation time. The value of the reverberation time in a space depends on the absorption coefficient of the materials, the surface areas in the room, and the volume of the room. The equation of reverberation is given as follow:

$$T_{60} = 0.05 * V/a \quad \text{(in IP units)}$$

or

$$T_{60} = 0.16 * V/a \quad \text{(in Metric units)}$$

Where T_{60} = Reverberation time (unit is seconds)
V = Volume of the room
a = Total room absorption

And the total absorption (a) of the room can be defined as:

$$a = \text{Sum of } (S * \alpha)$$

Where S = surface area of the material (m^2 or ft^2)
α = absorption coefficient of the material

Materials with alpha values of grater than 0.5 are considered as an absorptive materials, and value of less than 0.5 are considered as a reflective materials. Absorption of a material is mainly affected by the physical properties, such as thickness, density, porosity and orientation, of the material. Changes in the absorptive material will no doubt affect the amount of sound it can absorb, which directly affects how well the occupants of the space can hear.

$\Delta\alpha < 0.10$ is not noticeable
$\Delta\alpha = 0.10$ to 0.40 is noticeable
$\Delta\alpha > 0.40$ is considerable

The range of reverberation time criterion for a lecture room at 500 Hz ranges from 0.7 to 1.1 (values obtained from Figure 27.16 of *Mechanical and Electrical Equipment for Building*, Stein & Reynolds). Therefore the preferred, also known as central value at 500 Hz, reverb time would be **0.9** seconds.

If the reverberation time is longer than the optimum value, the sound in the room will sound too lively and boomy. This could give the listeners a difficult time in deciphering the words the speaker is saying. On the other hand, if the speech reverberation time is shorter than the optimum value, the sound in the room will sound dead and flat.

In order to see if the acoustics in the current lecture hall satisfies the optimum reverberation time for speech making, a calculation of the existing reverberation time is performed below in Table 9.2:

Room Volume = **390.068** m^3

	Absorption Coefficients (alpha)								Sabins (Area*alpha)					
Material	**Area (m^2)**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**NRC**	**125**	**250**	**500**	**1000**	**2000**	**4000**
Walls	142.55	0.10	0.08	0.05	0.03	0.03	0.03	0.05	14.3	11.4	7.13	4.277	4.277	4.277
Carpet, on concrete	131.6	0.02	0.06	0.14	0.37	0.60	0.65	0.29	2.63	7.9	18.4	48.69	78.96	85.54
Door	5.9456	0.15	0.11	0.1	0.07	0.06	0.07	0.10	0.89	0.65	0.59	0.416	0.357	0.416
students sitting in chairs	80.12	0.3	0.42	0.5	0.85	0.85	0.84	0.55	24	33.7	40.1	68.1	68.1	67.3
Ceiling	85.846	0.10	0.08	0.05	0.03	0.03	0.03	0.05	8.58	6.87	4.29	2.575	2.575	2.575
Desks (wood)	52.212	0.15	0.11	0.1	0.07	0.06	0.07	0.10	7.83	5.74	5.22	3.655	3.133	3.655
Openings (ceiling cove)	26.961	1.00	1.00	1.00	1.00	1.00	1.00	1.00	27	27	27	26.96	26.96	26.96
Glass	1.562	0.35	0.25	0.18	0.12	0.07	0.04	0.15	0.55	0.39	0.28	0.187	0.109	0.062
								Total Sabins	85.7	93.6	103	154.9	184.5	190.8
								Reverb Time	0.73	0.67	0.61	0.403	0.338	0.327

**General Building Material and Furnishings data courtesy of Owens-Corning Fiberglass*

<u>Table 9.2 ~ Reverberation time calculation of existing conditions of Lecture Hall 1210</u>

Some important values in this calculation are the volume of the room (390.068 m^3), and the absorption coefficients of different materials which can be obtained from material manufacturers. The calculated reverberation time of the lecture hall at 500 Hz is 0.61 seconds. This value is much lower than the ideal reverberation time of 0.9 seconds, and therefore the sound in this room may be dead and flat.

Lecture Hall Acoustics Redesign

In order to correct this acoustics problem in the lecture hall, the reverberation time must be increased close to the desired 0.9 seconds. To increase the reverberation time of the lecture hall, materials with higher sound reflective properties will need to replace some of the existing interior materials of the space. The original carpeted floor will be replaced with hardwood floor, in combination with closing the gap of the ceiling cove around the perimeter of the room. This will contribute greatly to the increase reverberation time because the walls helps reflect the sound back into the room, instead of the sound wave escaping through the cove opening and the noise being trapped above the ceiling. The resulting reverberation time for the new interior design is listed in Table 9.3, with a reverberation time of 0.87 seconds at the central frequency of 500 Hz. This value is much closer to the optimum reverberation time of lecture hall than the existing value of 0.61 seconds. The new interior design of the lecture hall will be considered as satisfactory since the new reverberation time value is close enough to the optimum reverberation time value (which is only a suggested range),

	Absorption Coefficients (alpha)								Sabins (Area*alpha)					
Material	Area (m^2)	125	250	500	1000	2000	4000	NRC	125	250	500	1000	2000	4000
Walls	142.55	0.10	0.08	0.05	0.03	0.03	0.03	0.05	14.3	11.4	7.13	4.277	4.277	4.277
Hardwood Floor	131.6	0.15	0.11	0.1	0.07	0.06	0.07	0.10	19.7	14.5	13.2	9.212	7.896	9.212
Door	5.9456	0.15	0.11	0.1	0.07	0.06	0.07	0.10	0.89	0.65	0.59	0.416	0.357	0.416
students sitting in chairs	80.12	0.3	0.42	0.5	0.85	0.85	0.84	-	24	33.7	40.1	68.1	68.1	67.3
Ceiling	85.846	0.10	0.08	0.05	0.03	0.03	0.03	0.05	8.58	6.87	4.29	2.575	2.575	2.575
Desks (wood)	52.212	0.15	0.11	0.1	0.07	0.06	0.07	0.10	7.83	5.74	5.22	3.655	3.133	3.655
Cove (closed)	26.961	0.10	0.08	0.05	0.03	0.03	0.03	0.05	2.7	2.16	1.35	0.809	0.809	0.809
Glass	1.562	0.35	0.25	0.18	0.12	0.07	0.04	0.15	0.55	0.39	0.28	0.187	0.109	0.062
								Total Sabins	78.6	75.3	72.1	89.23	87.26	88.31
								Reverb Time	0.79	0.83	0.87	0.699	0.715	0.707

**General Building Material and Furnishing data courtesy of Owens-Corning Fiberglass*

Table 9.3 ~ Reverberation time calculation of new interior condition of Lecture Hall 1210

Alternative to new interior design

Even though the new interior design of the room helps improve the reverberation time to close to the optimum value, some of the major architectural elements of the lecture hall, such as the cove around the perimeter of the room, were taken out. This may affect some of the other designs of the space, especially in the lighting discipline. By closing off the cove opening around the perimeter of the room, one of the major lighting elements of the room (cove lights along the two sides of the lecture hall) will be lost.

An alternative to solving this problem of the cove would be to hang an angled reflector panel above the speaker in the lecture hall (see Figure 9.2 below). A panel will be placed directly above the speaker, in an angle so that it would reflect the sound waves deeper into the back of the lecture hall. This panel will be constructed of material that is highly reflective which will aid in the reflecting of the sound waves. The same effect of the angled hanging reflecting panel can be accomplished by actually constructing a ceiling that is angled. The angled ceiling will reflect the angle deep into the room just as the angled reflector panel can. The only problem with this idea is that it may require a new design of the structural system to support the ceiling, which may involve many other new architectural issues.

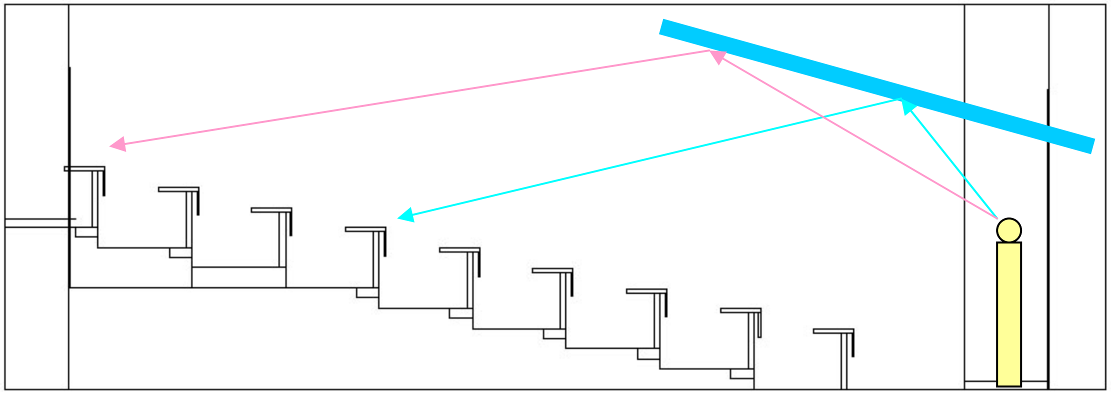

Figure 9.2 ~ Angled reflected panel hanging above speaker in lecture hall to redirect sound

Sound Transmission Class Analysis

Another analysis for the lecture hall will be performed with respect to the ability to isolate sound from one room to another. This analysis will involve the calculation of the Sound Transmission Class (STC), which is a number rating of a building or room element's efficacy in blocking the transmission of sound. The sound transmission class value will then contribute to the analysis for speech privacy between the lecture hall and the adjacent spaces. The speech privacy rating depends on six main factors, which are listed in Table 9.3 on the next pages. These factors all relate to the amount of sound created and the ability of the building material to isolate the noise.

The speech privacy rating for the back wall of the room is to be analyzed, since one side of the wall is the lecture room, and the other side is a hallway. A STC and speech privacy analysis is appropriate for this space because excessive noise transmitted into the lecture hall could be distracting to the students, causing lower productivity in the classroom.

The back wall of the existing lecture hall is constructed of single wood studs that are 16 inches on centers and half inch gypsum board on each side with air cavities. This type of construction is assumed as a basic partition construction, which gives a basic STC rating of 35. With all the other factors accounted for, a speech privacy rating of 7 is calculated for the existing room (see Table 9.4 on next page for calculation details). When this number is referred to the graph on Figure 28.38, of *Mechanical and Electrical Equipment for Building*, Stein & Reynolds, the anticipated response to privacy situation is in the range of **moderate dissatisfaction**. This situation can be improved by changing the composition of the stud wall. One solution is to add a basic partition of double gypsum board on both sides of the stud wall. This will increase the STC value by a value of four to a total new STC value of 39. With the improvement of STC, the speech privacy rating improved to a value of 3 (see Table 9.4), which corresponds to an audience response to privacy of **apparent satisfaction**. This means that the audience inside the lecture hall will not be disturbed by the noise in the hallway even when the hall way is in full occupancy use.

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	Speech Rating	EXISTING DESIGN	IMPROVED DESIGN
1	Speech effort from source room	72	72
2	Source room floor area (A1) - effect of source room absorption = 1416 ft^2 which corresponds to a rating of zero	0	0
3	Privacy alllowance - degree of privacy required	9	9
	Speech rating total	81	81
	Isolating Rating		
4	Sound transmission class (STC) - common barrier	35	39
5	Noise reduction factor (A2/S) -effect of receiving room absorption and barrier size	9	9
6	Adjacent room background noise level (dBA) - masking sound available	30	30
	Isolating Rating Total	74	78
	Speech Privacy Rating Number		
	= (Speech Rating Total) - (Isolating Rating Total)	7	3
	Anticipated Response to Privacy Situation	Moderate Dissatisfaction	Apparent satisfaction (low range)

Table 9.4 - Speech Privacy Rating Calculation

Conclusion

A recommendation for improving the acoustics of Lecture Hall 1210 is to change the material of the floor into a better sound reflective surface (such as hardwood floor). This will improve the reverberation time drastically since the sound will be reflected into the audiences rather than being absorbed by the very porous carpet material. Also, the reverberation time can be improved by not having the cove opening around the perimeter of the room. However, this method involves a large amount of changes to the original architectural features of the room. Therefore a suggestion to use angle sound reflective panels above the speaker, or an angled ceiling in the lecture hall will be more realistic. This is because it enables the room to keep the original architectural features and preserve the integrity of most of the ceiling structure. Another improvement that can be made to the lecture hall is to add extra layers of gypsum board on both sides of the back stud wall. This will improve the STC rating, which will overall improve the ability for that wall to isolate sound coming from the hallway outside the lecture hall.