Auditorium Acoustics and Architectural Design

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Abstract
The effectiveness of the acoustic treatment in any auditorium or a performing space has a direct impact on how clearly people can communicate and perform there. This quality is defined by several characteristics in **Acoustical architecture**. This research seeks to clarify the acoustical phenomena and defects that provide the basis for **acoustical designing and material choice**. The paper includes fundamental guidelines and methods for planning auditorium acoustics, as well as fundamental criteria for material selection in relation to the **NRC values** needed in a space. Overall, this research emphasizes the importance of an integrated approach to auditorium design that considers both acoustic and architectural design elements to create optimal auditory experiences for the audience.

Keywords: Acoustic, Auditorium, Noise reduction coefficient, Acoustic material

1. Introduction

The study of sound is known as acoustics, which includes bioacoustics, psychoacoustics, and music in addition to basic physical acoustics. It covers technical areas including noise control, transducer technology, sound recording and reproduction, theatre, and concert hall architecture, and more. Auditoriums are big, air-conditioned spaces with audio-visual equipment that are common in theatres, community centers, and other entertainment venues. To reduce noise pollution, they should have good acoustics, and the reverberation duration should be accurately estimated. This essay focuses on the examination of the acoustics of both new and vintage auditoriums.

History

One of the first authors to examine the subject of the acoustics of performance venues was the Roman architect, mathematician, and scholar Marco Vitruvius, who wrote in the first century BC. Vitruvius defended the requirement for raked seats by claiming that sound propagated curving upwards in addition to horizontally. The fan-shaped Greek theatre, the horseshoe-shaped Baroque theatre, and the surrounding Roman arena were among the geometric designs Vitruvius investigated, according to Michael Barron (1986).

The mechanics of sound in a room have become less of a focus in acoustics over the past 35 years as attention has turned to the impact of sound in the virtual space between the listener's ears. Now, it's best to think of the criteria for effective large performance venues as a four-part system.

Cultural aspects

The auditorium is a representation of the culture of a city and provides a stage for presenting artistic ability and encouraging social interaction. The study of architectural acoustics examines how sounds are reflected in spaces, with indirect sound altering the sound's quality that we perceive.

The quantity of sound absorbed by the room's walls, ceiling, floors, and form and size are the main determinants of sound. The study of sound's creation, manipulation, transmission, reception, and effects is known as acoustics, or the area of physics that deals with sound's physical characteristics.

Broader aspects of auditorium

An auditorium is a multifaceted setting for performances or lectures. Such areas require careful consideration of acoustics since poorly built acoustics can produce unintelligible sounds. The minimum acoustic requirements for an auditorium include a loud enough sound source coming from the speaker, background noise that doesn't distract from the main activity, the auditorium being free of reverberations to prevent masking of different sounds produced one after the other, and defects like echo and late reflections being checked.

The most crucial information is that adverse circumstances for the generation, transmission, and reception of the disturbance must be avoided, and that meticulous surface preparation is required to guarantee that the proper strength of the sound is created at the source.

Additionally, To produce sharp and clear sounds, the transmission line needs to be properly built with sound reflectors and barriers.

Sound propagation in Auditorium

At a speed of 345 m/s, sound waves take 0.01-0.2 seconds to reach the listener. Reverberant sound or late reflection follows early reflection at 50 milliseconds. When a source generates a continuous sound, reverberant sound builds up to an equilibrium level and then gradually fades away until it is no longer audible. Impulsive noises instantly start to degrade.

Direct Sound or Early Reflection

For every twofold increase in propagation distance, direct sound will become 6dB less loud. Within 35 milliseconds, reflection cannot be distinguished from direct sound. Within 35 milliseconds, a further sound appears with spectra and temporal envelopes that are comparable to those of the preceding sound. The precedence effect describes this.

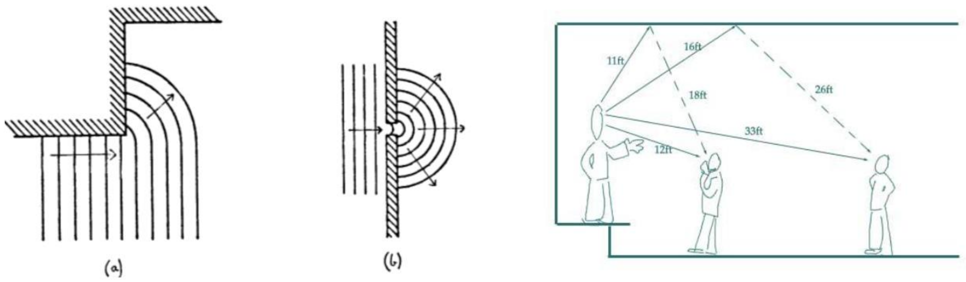


Figure 2. precedence effect

Source – www.auditoriumsinfo.org

Reflection of Sound

From the edges of a room, sound waves are reflected, some of which are absorbed by the surface and some of which are transmitted through it. It seems as if a new source of sound were being created when reflected sound strikes a hard, flat, and smooth surface. In the construction of auditoriums, convex surfaces spread sound and make the space safer, whereas concave surfaces concentrate sound and make the space unsafe. Concave surfaces produce reflections that sound like echoes when the focal point is near to the audience or performers.

Diffraction of Sound

Due to diffraction, which enables sound to bend around corners, obstacles don't completely block off sound. While shorter wavelengths and higher frequencies won't, longer wavelengths and low frequencies will diffract around a border. Outside of the boundaries, not much of this sound will be audible.

Reverberation

The persistence of sound after it has been generated is known as reverberation. Some of the energy of sound waves is absorbed when they come into contact with a room's border surfaces, while the remaining energy is reflected. The amount of sound absorption, how frequently it happens, the size of the room, and the decay time all affect how long it takes for a sound to die.

Propagation of Sound in a Room

To determine the direct sound route and the dispersion of the first few reflections, sound waves can be examined. However, after the first one or two reflections, it is impossible to calculate their courses since they have already reflected off of objects.

Design Factors to Consider When Designing Rooms for Music:

Inverse Square Law

According to Parkin et al. (1969), the inverse square law can be stated as follows:

"As distance from the source increases, the loudness of the direct sound decreases due to the spreading of the sound."

Parkin et al. (1969) estimates that due to the inverse square law, the loudness of the direct sound will be cut in half for every time the distance triples.

The inverse square law causes a reduction in the volume of direct sound that passes lightly over the heads of the audience. Raking the seats is the most effective treatment to lessen grazing incidence loss. It is recommended to keep hall lengths as short as possible since longer halls cause the rear rows to lose definition. The quality and loudness may be improved in big halls with a capacity of more than 1500 people by utilising the initial reflections to amplify direct sound. To do this, a shaped reflector can be placed over the performers to direct sound in that direction.

The availability of reflecting surfaces near this aspect has a significant impact on the stage and its dimensions. The audience will hear sound coming from wildly different directions if the stage is too large. The mix will lose some value as a result of this. (1969) Parkin et al.

Acoustical materials

Acoustics is a property of all construction materials that affect sound absorption, reflection, or transmission. Sound is partially reflected, partially absorbed, and partially transferred to the next room when it hits a room's border. The two most significant events in room acoustics—sound absorption and reflection—can be induced to happen by choosing materials that are appropriate for the environment.

When sound causes a stiff but not entirely rigid system to move, absorption through resonance happens. If the system's inherent frequency matches the frequency of the incoming sound, it will absorb and distribute the energy.

The following materials are examples of porous absorbers: glass fibre, mineral fibre, fibreboard, acoustical ceiling tile, cotton, pressed wood shavings, cotton, carpet, drapes, velour, felt, aerated plaster, and open-celled foams. The best low-frequency sound absorbers are panels, however because they reflect sound at high frequencies, porous absorbers must be installed to reduce this impact. In order to absorb a broader frequency range, resonant absorbers—which operate on the Helmholtz resonator mechanism—can be paired with panel absorbers.

Requirements for Good Auditoriums Acoustics

Shape

Horseshoe, fan-shaped, and rectangular are the three fundamental forms used in theatre architecture. According to Michael Barron (1993), surround, horseshoe, and rectangle designs have been used in amphitheatre architecture since the dawn of civilization. Acoustically, surround auditoriums are difficult because of barriers and a lack of reflections. The conventional form for opera theatres is a horseshoe, however if the seating is not raked, it might result in a long reverberation period. Since the 19th century, rectangular halls have been the norm; yet, when planning for huge crowds, the quantity of people it pushes away from the stage has been an issue. Due to its shorter length, which brings the majority of the crowd closer to the stage and promotes better homogeneity, the fan-shaped hall has been preferred.

Platform

The platform height shouldn't be less than 0.6 metres or greater than 1.2 metres because doing so will distance the front row seats from the performers. A trade-off between comfort and acoustic requirements is recommended by Michael Barron (1993). According to Grade (1989), the delay of direct sound might make ensemble playing more difficult beyond 8 metres. Suggests adopting the fan form when fullness is only a secondary necessity and definition is the primary one.

Floor material of platform

Because it produces a pleasant tone, wood has traditionally been preferred by musicians as the ideal structure for the platform floor.

Science has made an effort to understand the mechanics underlying this predilection. He discovered that while the wood floor will absorb sound from the air, it will work as a sounding board for low-register instruments in direct contact with the floor. The wood flooring also creates the impression that there are structural vibrations installed in the floor, which improves inter-performer communication.

Because of the loss of connection between the front row seats and the artists, the platform height shouldn't be less than 0.6m or greater than 1.2m. A balance between acoustic requirements and comfort is recommended by Michael Barron (1993)

2.Historical background

According to Michael Barron (1993), historically significant theatres include the Classical Greek Theatre, a platform with an altar in the middle and a sizable audience seated against a hillside to watch plays at the altar.

The Greek theater's resultant acoustics made sure that the audience members heard the direct sound first, which was then followed by a reflection from the front of the horizontal orchestra. The Greek theatre and the Classical Roman Arena were dissimilar in a number of respects. The majority of the theatres were built as standalone structures on flat terrain, with a lower stage level that was 1.5 meters above the ground to provide the senators in the orchestra with clear views.

A higher seating rake of around 30-340 was used to eliminate the need for orchestra reflections, and the seating capacity was virtually cut in half from what Greek theatres could hold. 7000 people could fit in the Roman theatres, with the seat 53 meters from the stage being the furthest distant. The Horseshoe Baroque theatre gained popularity in the 16th century because to its several rows of boxes built on top of one another.

Greek theatres were often built on top of a hill with a stage that dipped downward at a 45-degree angle. Between AD70 and AD81, Roman theatres with a stage house, a raised performing range, embracing wings, and a chorale talked were constructed. The acoustics of these venues were excellent, and the stage was positioned behind the orchestra, less than three meters away. The Amphitheatre, which included a stage house, a raised performing range, encircling wings, and a chorale area, was constructed between AD70 and 81.

Types of auditoriums

The horseshoe shape's suitability for concert halls, according to Parkin et al. (1969), is disputed because of its brief reverberation period. The fan-shaped hall's curving rear wall, balcony front, and seat risers all provide a serious threat of echoing, which is a drawback. Due to the lower likelihood of echoes and cross-reflections between its parallel walls, the rectangular hall has a longer history than the other two designs. The volume, quantity of absorption, and form of the room all affect how long sounds reverberate. According to Michael Barron (1993), because the orchestra and vocalists must both be able to see the conductor, opera houses have the most stringent criteria of all sorts of theatres.

3.Case studies

Case Study 1: Braeburn Auditorium

The Braeburn Theatre can accommodate 416 people on the balconies and 360 people on the first floor. The volume (0.6m x 0.45m x 0.45m) per occupant is 0.1215m3. The auditorium has 10 sides, with the side walls converging towards the stage to create the appearance of a fan-shaped arrangement. The stage is 4 meters distant from the front row of the audience, and the platform is 12 metres long by 8 metres wide. The stage was constructed using reinforced concrete for the back and side walls and parquet wood for the floor. The theatre is 5 metres high from floor to ceiling, and the forestage is 1.04 metres high.

The ideal reverberation duration for the Braeburn auditorium is 1.1 seconds, which falls within the advised range of 1.0-2.2 seconds. This indicates that the space is appropriate for recitals and chamber music as well as light opera, musical comedies, semi-classical concerts, theatre, lectures, and conferences. Currently, the hall serves as a lecture hall for Braeburn's music students and on occasion, the general public rents it out for light opera musical acts.

The suggested range of 1.0-2.2 seconds includes 1.1 seconds as the ideal reverberation duration.

Fig 3: bradeum auditorium

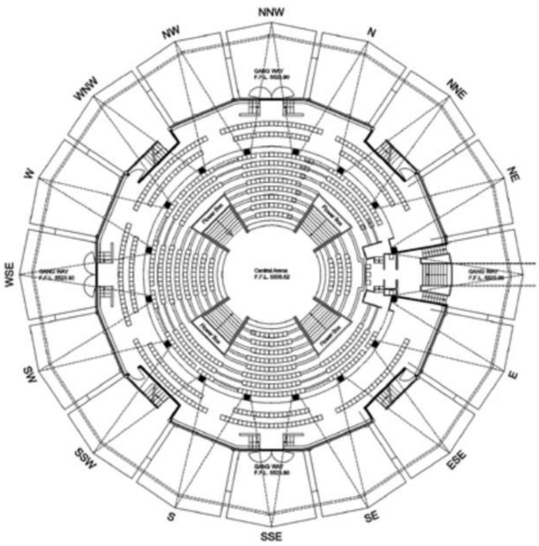
Source – www.bradeumauditorium.com

Case Study 2: KICC Auditorium

The KICC Amphitheatre has a total space of 18,864 m3, a ceiling height of 18 m, and a hut-shaped roof. The total volume occupied by all residents is 76.8m3, or 0.096m3 for each occupant. The 18m floor to ceiling height of the auditorium causes a lot of echoes, which prevents early reflections from reaching the audience in a timely manner.

Due to the numerous diffusers on the ceiling that scatter and disperse late reflections back to the audience, the echo is a little more noticeable in the hall. The KICC auditorium is circular, has a red carpet floor, and is built of wood. It has an 8-meter diameter and a 50-meter2 total floor space.

If each artist occupies 1.6m of stage space, the stage can hold about 31 performers. The only way to transmit sound from the stage is through useful reflections off the ceiling and balcony walls. The layout of the room positions the speaker in the middle, which means that at any given moment, they are facing away from a portion of the audience. The suggested range of 1.0-2.2 seconds includes 1.7 seconds as the ideal reverberation period.



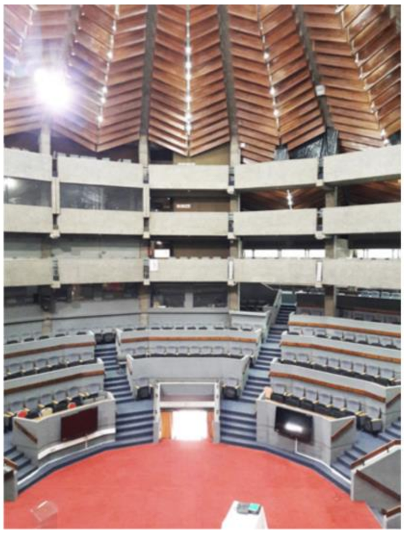
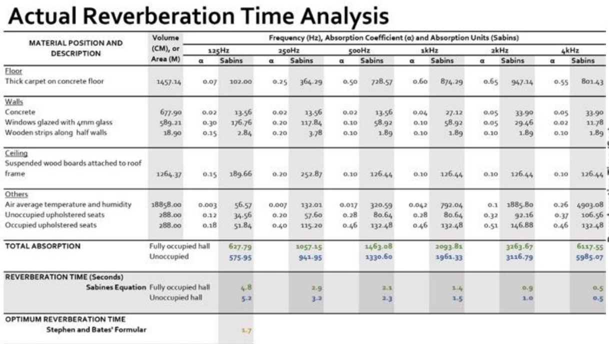


Fig 4 :KICC auditorium plan and aerial view

Source- www.auditoriumsinfo.org



Actual Reverberation Time Analysis

MATERIAL POSITION AND DESCRIPTION	Volume (CM), or Area (M)	Frequency (Hz), Absorption Coefficient (α) and Absorption Units (Sabins)											
		125Hz		250Hz		500Hz		1kHz		2kHz		4kHz	
		α	Sabins	α	Sabins	α	Sabins	α	Sabins	α	Sabins	α	Sabins
Floor													
Thick carpet on concrete floor	1457.14	0.07	102.00	0.25	364.29	0.50	728.57	0.60	874.29	0.65	947.14	0.55	801.43
Walls													
Concrete	677.90	0.02	13.56	0.02	13.56	0.02	13.56	0.04	27.12	0.05	33.90	0.05	33.90
Windows glazed with 4mm glass	589.21	0.30	176.76	0.20	117.84	0.10	58.92	0.10	58.92	0.05	29.46	0.02	11.78
Wooden strips along half walls	18.90	0.15	2.84	0.20	3.78	0.10	1.89	0.10	1.89	0.10	1.89	0.10	1.89
Ceiling													
Suspended wood boards attached to roof frame	1264.37	0.15	189.66	0.20	252.87	0.10	126.44	0.10	126.44	0.10	126.44	0.10	126.44
Others													
Air average temperature and humidity	18858.00	0.003	56.57	0.007	132.01	0.017	320.59	0.042	792.04	0.1	1885.80	0.26	4903.08
Unoccupied upholstered seats	288.00	0.12	34.56	0.20	57.60	0.28	80.64	0.28	80.64	0.32	92.16	0.37	106.56
Occupied upholstered seats	288.00	0.18	51.84	0.40	115.20	0.46	132.48	0.46	132.48	0.51	146.88	0.46	132.48
TOTAL ABSORPTION	Fully occupied hall		627.79		1057.15		1463.08		2093.81		3263.67		6117.55
	Unoccupied		575.95		941.95		1330.60		1961.33		3116.79		5985.07
REVERBERATION TIME (Seconds) Sabines Equation	Fully occupied hall		4.8		2.9		2.1		1.4		0.9		0.5
	Unoccupied hall		5.2		3.2		2.3		1.5		1.0		0.5
OPTIMUM REVERBERATION TIME Stephen and Bates' Formular			1.7										

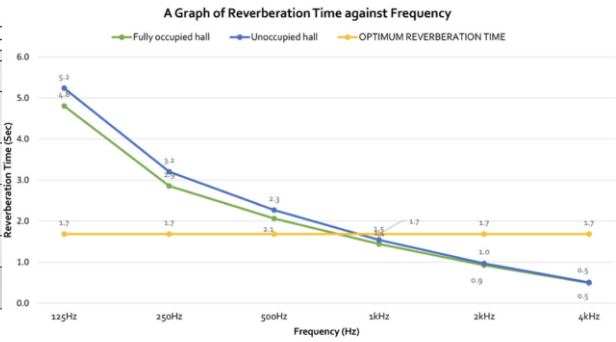


Fig 4: reverberation time analysis

Source -www.auditoriuminfo.org

The Walt Disney concert (acoustical Wonder)

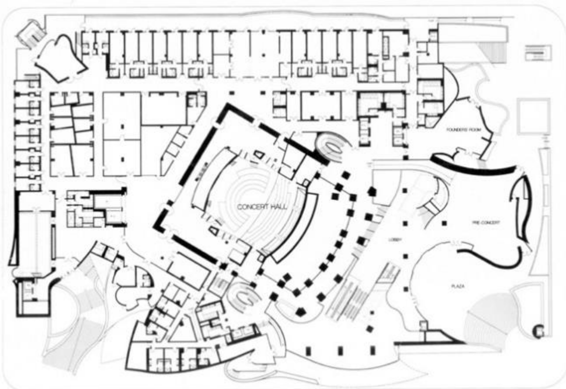


Fig 5: walt Disney concert plan

Source- Disney.walt.com

The auditorium designed by Frank Gehry between 1999-2003 in Los Angeles was composed of a "shoe box outline" with vertical "vineyard" seating at the edges of the orchestra. To test and study the acoustics of the auditorium, the frequency of the sounds was increased to lessen the wavelengths by ten. To oust the oxygen and water vapor that retain high-frequency sound, the model was loaded with nitrogen. An acoustical expert, Yasuhisa Toyota, sharpened the halls.

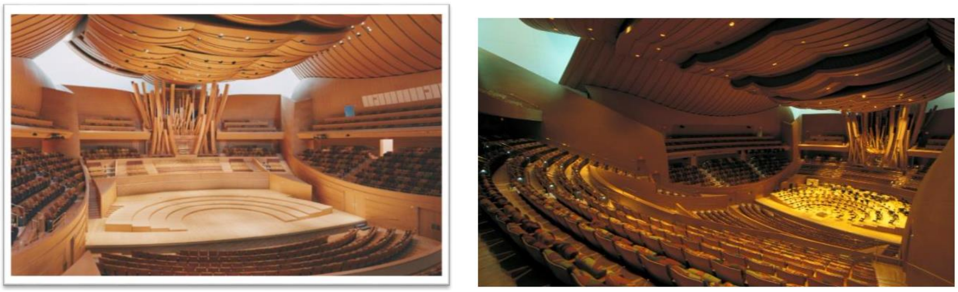


Fig 6: walt Disney's aerial view

Source -www.waltdisney.com

3. Comparative analysis

PARAMETERS	Braeburn auditorium	KICC auditorium
Volume	2981 m3	18864 m3
Capacity	416 people	800 people
Shape	Decagon	Closed lily bud
Platform	12x8m size	16x8m
Materials used	Wooden paraquet	Wood
Ceiling height	5m	18 m
Reverberation time	5.8 sec	5.2 sec
Ceiling design	19 curved wooden panels	Metallic panels placed at an angle 600 subtended against roof frame
Balcony design	56 people capacity with height of 2.4 m	180 people capacity and divided into three levels
Seating layout	The floor of the main arena is finished in wood parquet with a red carpet on the pathways The cushioned leather seats with metallic handles and frame reach a height of 650mm and stretch to 450mm in width.	The placement of the seating rows on the same level without a floor rake means that sightlines for the second row on each level are seriously compromised.

4.Conclusion

For knowledgeable experts, architectural acoustics has been referred to as a thing of the past. The capacity to test designs before construction is now accessible, the fundamental elements of excellent acoustics from the past to the present are much better known, and the standing of the acoustician in relation to the architect has significantly improved. There is now more confidence in the acoustic design of auditoriums, and there is a rational demand for good acoustics in auditoriums. Recently, the price of success has been a more preservationist strategy with a notable increase in reliance on references. The acoustics of the Walt Disney Concert Hall were refined by Yasuhisa Toyota, and a 1:10 scale replica of the auditorium was constructed to test and examine its acoustics.

This study reveals that both the previous and contemporary auditorium acoustics have good acoustics solutions, however the present auditoriums have the issue of low-quality sound brought on by loudspeaker issues. In place of concrete floors and walls, the idea is to employ flat panel technology and limestone materials.

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