TAYLOR'S UNIVERSITY
Wisdom · Integrity · Excellence

SCHOOL OF ARCHITECTURE, BUILDING & DESIGN

BACHELOR OF SCIENCE (HONS) IN ARCHITECTURE
BUILDING SCIENCE (ARC 3414 / BLD 61303)

PROJECT 1:
AUDITORIUM: A CASE STUDY ON ACOUSTIC DESIGN

KUALA LUMPUR PERFORMING ARTS CENTRE (KLPAC)

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1.0 INTRODUCTION

1.1 Aim & Objective

The aim and objective of this assignment is for us, in a group, to have a better understanding on how sound and architecture correlates with each other; through acoustics; on how sounds travels and dampened; how the shape of the theatre effects on how sound waves dissipates; the application of materiality and how does it effects on sound.

Through what we've learnt, we aim to complete the task through extensive research on sound and acoustics; gather information through equipment, site study, and measurements; and tabulate and calculate the said information through calculations and research.

2.0 SITE INFORMATION

2.1 Site Introduction

Building History

KLPAC began as a wood-crafting workshop back and a sawmill back in the 1800's, and in 1906, KLPAC became a part of Sentul Works, the region's most important railway depot and workshop.

In 1945, just weeks before the end of World War II, the workshops were heavily bombed by British B-29 bombers because it was seen as an important rail complex for the Japanese occupiers, and soon after, the workshops were partially rebuilt but never regained their former glory.

In the late 1960's, the workshop was converted into a makeshift golf clubhouse, before the YTL Group re-designated the area as a private community park for the benefit of the residents of its condominium blocks in the surrounding areas, thus converting the workshop into an arts and cultural icon.

KLPAC History

In 1995, two people that established the idea of KLPAC, Faridah Merican and Joe Hasham, worked for theatre in beneath Dataran Merdeka, the theatre being The Actors Studio at Plaza Putra. In 2003, flash flood occurred in Kuala Lumpur and flooded the entirety of the Actors Studio's underground complex, destroying it. Out of this disaster, the arts community needed a new home, thus, KLPAC was established.

Working together, The Actors Studio, YTL Corporation and Yayasan Budi Penyayang formed the country's first fully-integrated arts centre. KLPAC, a non-profit organisation, opened in May 2005.

KLPAC offers theatre shows and musicals, which are directed and most of the tome written by their own writers. KLPAC has also played a major role in many events, and the KLPAC academy has served more than 1500 participants in its classes, a number which includes students from a community outreach program to members of underprivileged communities.

2.2 Site Selection Reasons

KLPAC is one if the fully–integrated performing art centre in Kuala Lumpur with 7, 614sq metres of built up space, comprising of two auditoriums. One of it called Pentas 1, consists of a 504–seat proscenium (fixed seating), equipped with one of the best materials, sound systems, acoustic absorption, amongst other theatres in Malaysia. Meanwhile, another auditorium (Pentas 2) consist of a 190–seat experimental black box theatre that allows modularity. The indicine, a 100–seat flexing space, and 9 studios, all which allows for various uses.

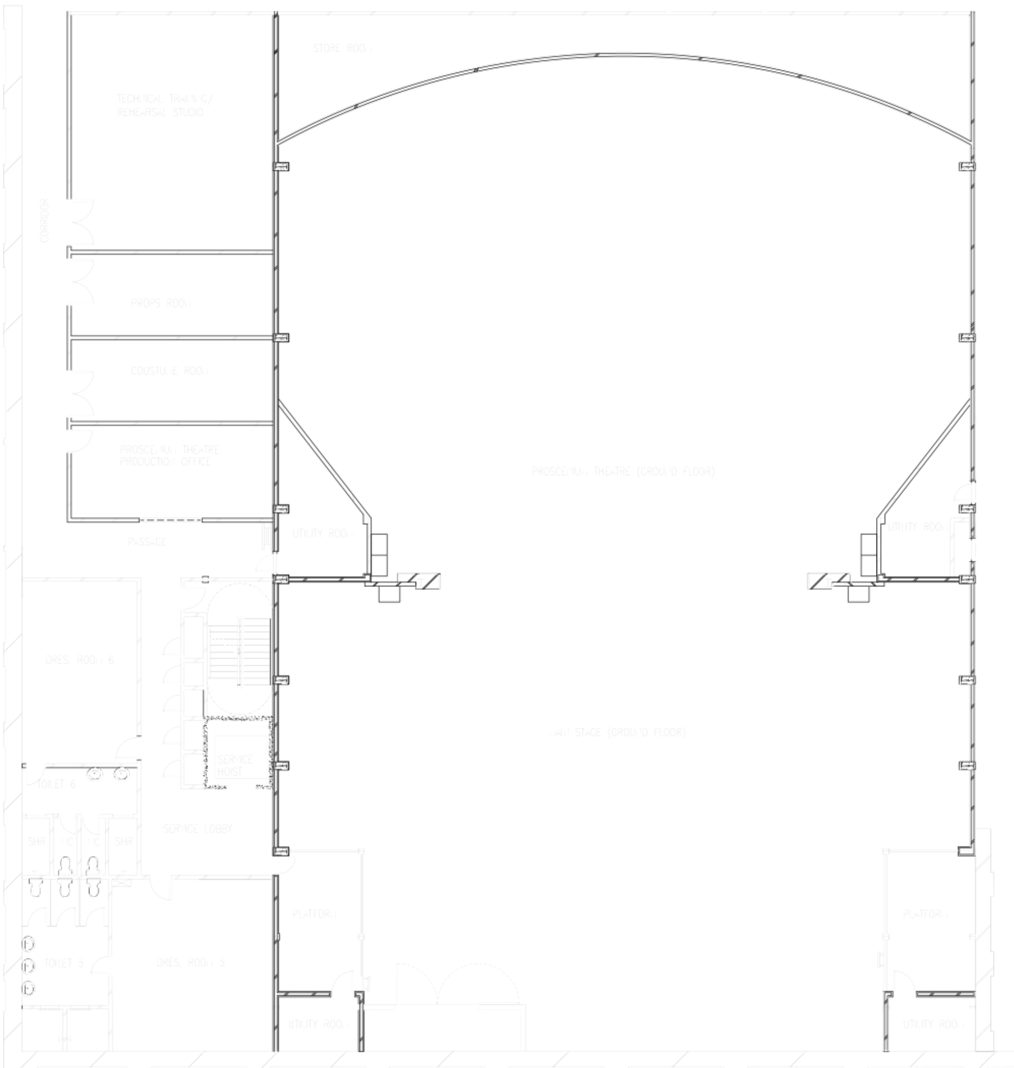
The site also has an impressive long history, and possibly being the heart of the Malaysia's performing arts community. KLPAC almost always has something to offer; will it be a play, a musical, choreographies, or a musical showcase. Amongst the large amount of studios and theatres, KLPAC also houses cafes and restaurants, as well as a small performing arts library, and an academy that offers workshops and seminars for everyone.



Figure 2.0 *Figure 2.1* *Figure 2.2*

Figure 2.0: Image of Pentas 1
Figure 2.1: Image of Pentas 2
Figure 2.2: One of the 9 studios for rehearsal purposes

2.3 Technical Drawings of Auditorium 1, KLPAC



KLPAC Pentas 1
1st Floor Plan

Scale 1:100 (mm)

Figure 2.3: First Floor Plan of Pentas 1

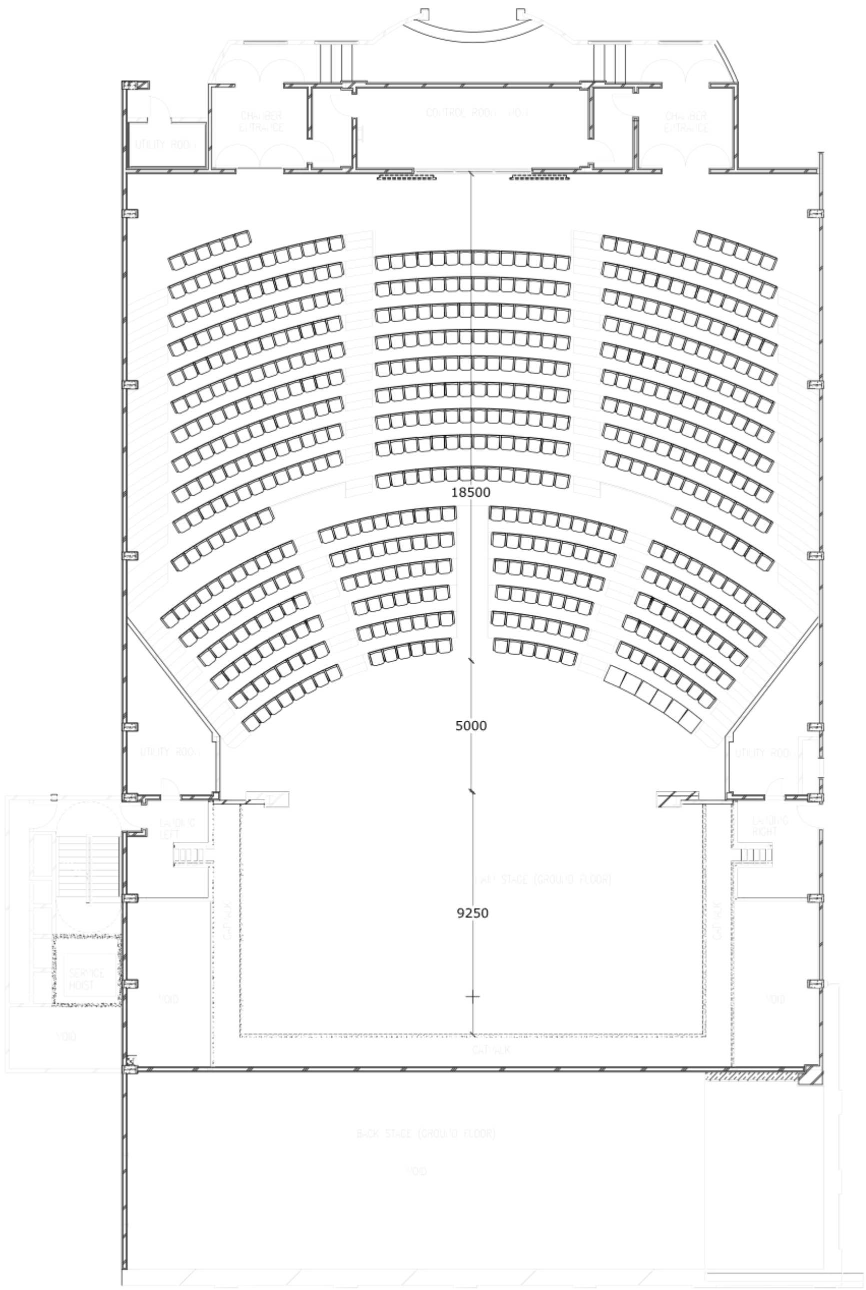
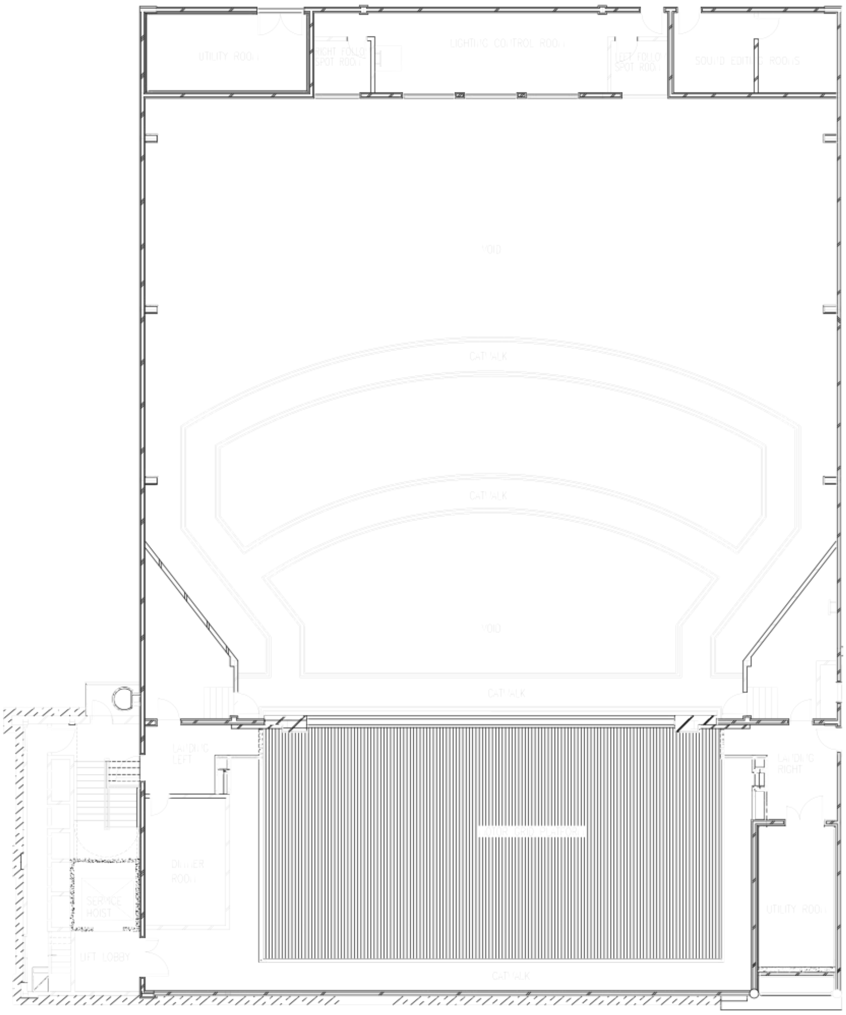


Figure 2.4: Second Floor of Pentas 1



KLPAC Pentas 1
3rd Floor Plan

Scale 1:100 (mm)

Figure 2.5: Third Floor of Pentas 1

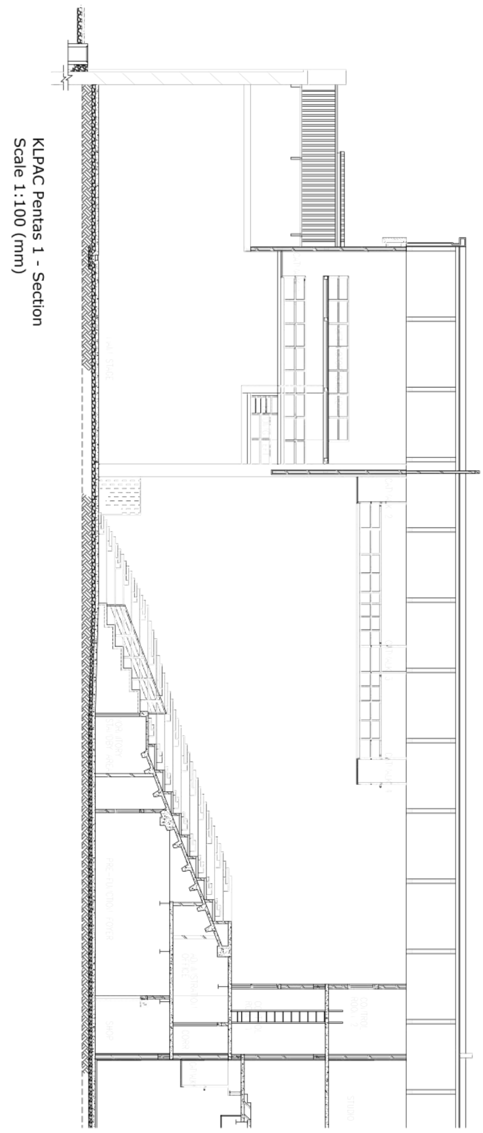


Figure 2.5: Third Floor of Pentas 1

3.0 ACOUSTIC PERFORMANCE

3.1 Literature Review

3.1.1 Architectural Acoustic

Architectural acoustic is a study of achieving good sound in a room. Room acoustic affects on how sound behaves in an enclosed space by controlling the sound within it as to provide the best conditions for the production and the reception of desired sound and to negate unwanted sound, through further analysis of the design of acoustic space; the auditoriums in KLPAC.

3.1.2 Reverberation

Reverberation is the collection of reflected sounds from the surfaces in an auditorium. This phenomenon is defined as the continuous presence of an audible sound that came from a sound source, whether active or inactive. It is occurred by multiple reflections between the surfaces in a room.

Observation on KLPAC auditorium was purely based on analysing the time taken for sound pressure level to decay affecting the acoustical quality of the enclosure, which is also known as Reverberation time.

Reverberation time of an auditorium can be calculated dependently on the design of the auditorium – volume of the enclosure, total surface area and material absorptions.

The formula of reverberation time is as follow:

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

RT – Reverberation time (sec)
V – Volume of the room (cu.m)
A – Total absorption of room surfaces (sq.m sabins)
x – Absorption coefficient of air

3.2 Research Methodology

3.2.1.1 Digital Sound Level Meter

Figure 3.0: Image of Digital Sound Level Meter

By using a digital sound level meter, we were able to detect any sound leakages due to external noises, or amenities that might produce sound indirectly, such as air conditioning units, ventilations, or generators.

3.2.1.2 Camera

Figure 3.1: Image of a camera

Cameras were used to take pictures of the theatres, seat arrangements, materiality, stage equipment. The pictures then were used as a method of documentation and proof.

3.2.1.3 **Measuring Tape**

Figure 3.2: Image of measuring tape

Measuring tapes were used to measure certain dimensions the stage, the distance between seating, the distance between one object to another.

3.2.2 Methodology

In Pentas 1, we measured the acoustics of the auditorium using a digital sound level meter to identify sound leaks due to external noises, and amenities such as vents and air conditioning. Pictures of them were taken with cameras for us for identification, research purposes, and proof. Measuring tapes were also used to measure dimensions and distance between objects.

3.2.3 Data Collection Procedure

Before gaining access to KLPAC's Pentas 1, we were required to send an application email to the person in charge of the staging to allow us to be able to do research. After the confirmation, we were given an allotted time slot to avoid interference during performance/set–up. In KLPAC, we were required to attend a brief tour around the building for us to get a better understanding on how the acoustics of KLPAC works, and learn on the equipment and materials it took to make it all work. We were given a brief time frame to take pictures and to measure the sound level using the digital sound level meter to record in the acoustics, and the measuring tape to measure in the dimensions. We were given plans, elevations, and sections of Pentas 1 through email for us to get a better understanding of the stage through drawings.

3.3 CASE STUDY OF KPLAC AUDITORIUM – PENTAS 1

3.3.1 KLPAC Auditorium – Pentas 1

In this case study, the focus of architectural acoustic is Pentas 1, a rectangular shaped, or a 'shoe-box'–shaped auditorium with mixed acoustics. There were certain compromises that had to be made in designing the Pentas 1, as it was made for various purposes – such as for speech and music. The volume of Pentas 1 is roughly 8020$m^{3,}$ which plays a significant role in acoustical qualities. Further analysis will explain the material usages in Pentas 1, which affects the acoustical phenomenon – sound diffusion, sound diffraction and reverberation.

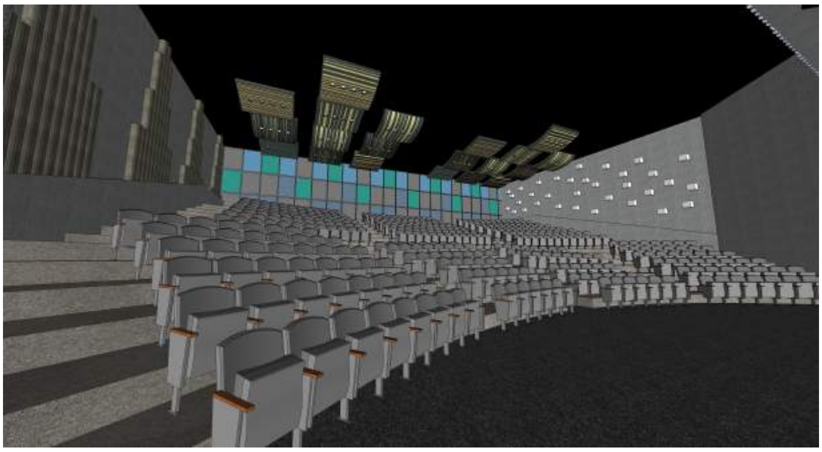


Figure 3.3: 3D Images of perspectives view of Pentas 1

3.3.2 Material and Properties

3.3.2.1 Furniture Material

Audience Seat

Figure 3.4: Image of the audience seat in Pentas 1

Chairs causes a great impact on the acoustics of the hall. Sound-absorbing properties of armchairs and chairs, as well as the audience are very important factors that have a huge influence on the acoustic conditions of concert, theatre and congress halls. In rooms with properly designed acoustics, reverberation time is always the key; therefore, it is necessary to determine exactly what this is. It is highly important to precisely define the sound absorption coefficients for armchairs and chairs.

The arrangement of armchairs, their shape and density of the materials used should ensure the orchestra is always able to hear itself in the same way, regardless of whether the hall is full or not during recording. Perfection is when the level of acoustic absorption with empty seats is close to that with a seated audience, meaning that a full or empty hall always has the same acoustic climate.

The sitting at KLPAC comprises of flip-up seats covered with different solid colors fabric to absorb the echo of the sound. This sound absorbing acoustical fabric is used to eliminate sound reflections to improve speech intelligibility, reduce standing waves and prevent comb filtering. This material can be varied in thickness and in shape to achieve different absorption ratings depending on the specific sound requirements.

Stage Chairs

Figure 3.5: Image of stage chairs in Pentas 1

Beneficially, a reflective front stage area provide strong early reflections that are integrated with the direct sound and enhance it. On the contrary, strong late reflections and reverberation, such as from rear walls, would not integrate and may produce echoes. To accommodate this, the stage area and front of the hall are made reflective and absorption is placed in the seating area and rear of the hall.

The furniture that they used at the stage are basically plastic metal chairs. Plastic and metal are both reflective materials. During the perfomance, the sound that produces at the stage will not absorbed by the chairs, but it will be reflected by it. Another main reason is because, plastic metal chairs can be moved. So, the chairs can be rearranged into different positions based on the situation.

Black Curtains

Figure 3.6: Image of black curtains at Pentas 1

Black curtains (black drapery, black masking or blacks), are a staple of theatres. When used for blackout curtains, legs, borders, tabs, black box theatres, or arena reduction curtains, the intent is to absorb light and hide objects. Black curtains provide designers an environment within which there are no distracting elements, other than the show itself. Black masking fabrics all have a matte finish so they won't reflect light.

Sound absorption curtains won't be able to significantly reduce noise transmission between two adjacent spaces; they are rather designed to improve sound quality and reduce reverberation levels within the room that they are installed.

The acoustic curtain material at KLPAC are thick. Since we know mass is the critical factor in absorbing sound, so the thicker the absorption material, the more effective it will be against a longer wavelength (lower frequency) of sound.

The curtains at KLPAC are pleated to improve the low and mid frequency sound absorption performance of their acoustical curtain. This will cause the fabric to be "gathered," such that it loops in and out (i.e. does not lay flat). To expose more sound-absorbing surface, the pleating is as deep as possible thus increasing effective thickness and improving low frequency sound attenuation.

The drapery at KLPAC is spaced several inches from the wall, so it will become more effective at absorbing longer sound wavelengths (lower pitches). Up to a point, the deeper the spacing, the more improvement to low frequency absorption. The means and mechanism of mounting will not affect acoustical performance but does determine how easy it will be to open and close the drapery.

3.3.2.2 Wall Material

Figure 3.7: Image of concrete well

For the wall material, the walls of the auditorium are made up of concrete, with the reason that they used concrete is because concrete absorbs sound. A good soundproofing wall relates to the overall ability of it to reduce the sound transmission through it. The sound absorption for plain cast concrete is about 0.02, indicating that about 98% of the sound energy is reflected by the surface. The more the concrete weighs or the denser the concrete, the greater the sound transmission loss so the thick concrete walls of the auditorium are really capable of soundproofing.

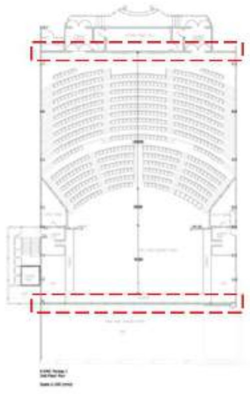
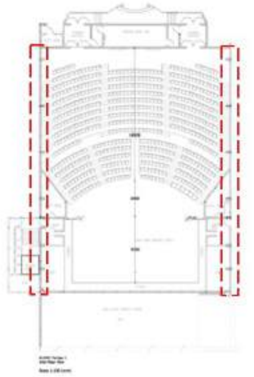
 

Figure 3.8 (left): Indication of the black acoustic panels
Figure 3.9 (right): Image of black acoustic panel

For the wall material, the walls at the front and the back of the auditorium are made up of acoustic wall panels from bottom to top. Specifically, they are black fabric wrapped panels. These wall panels are soundproofing material that prevents sound from travelling. It blocks sound from leaving or entering the auditorium.

On the other hand, it also enhances the space's sound quality, which is very suitable for auditoriums as sound quality is one of the important factors for shows. Acoustic sound panels utilize a rigid, high-density 6-7 PCF glass fiber with an acoustically fabric material for maximum absorption. Sound absorption is the process by which sound waves are taken in or soaked up by soft surfaces. They are intended to absorb unwanted noise like echo within a space. So, it reduces the sound disturbance that would occur during the shows. The echoes will not disturb the audiences and intense built up of muddied sound. Furthermore, these panels install easily on the walls, saving up to 50% time and money on installation and since this auditorium is a low cost building, using acoustic wall panels can help to create an adequate acoustic auditorium environment at a reasonable cost.

Other advantages of acoustical wall fabric are that it is a dimensional fabric that offers excellent acoustical properties, unmatched fade resistance and a fire retardant class with a class-A rating. It is also resistant to moisture, mildew, and rot, bacteria and is non-allergenic so it would last for a really long time. The wall panels are black in color to increase the quality of lighting effects.



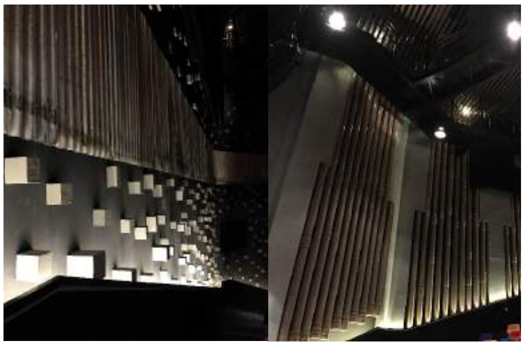


Figure 3.10 (left): Indication of concrete blocks and PVC tubes
Figure 3.11 (right): Images of concrete blocks and PVC tubes

While the walls on the side of the auditorium are made up of concrete, recyclable raw materials are used as finishes. This is the most interesting part of the auditorium since the auditorium holds a very strong concept on sustainability. On the right wall, not only the materials are recyclable, they are actually bits and pieces from the history of the site, which was founded from World War II. Their intention was to preserve the history of the building by reusing whatever that was left. It is also one of the efforts of building a low cost auditorium. The leftover historic materials that they used were roof zinc and concrete blocks while on the left wall were PVC tubes that go up to the ceiling. These materials actually help in reflecting the sound and adding on to the aesthetic values of the auditorium as well.

At the area of the stage, there are partition walls that are non-fixed and are arranged according to different set ups of the stage. The partition walls are fabric wrapped as well to maximize sound absorption.

3.3.2.3 Ceiling Material

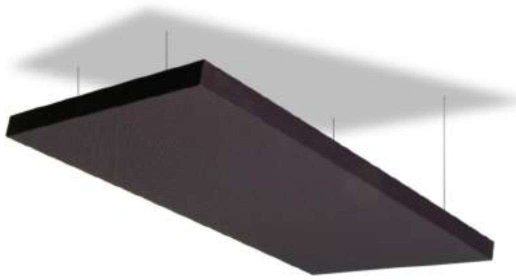


Figure 3.12 (left): The black fabric ceiling cloud with PVC tubes
Figure 3.13 (right): A clear diagram of the black fabric ceiling cloud

For the ceiling of the auditorium, it uses black fabric wrapped acoustical ceiling clouds. These ceiling clouds absorb noise and block sound transmission. They offer outstanding control across all frequencies as well as outstanding design flexibility. They also solve challenging acoustical problems to aid in improving sound quality and occupant's enjoyment. They are unique in combining noise and reverberation reduction with architectural effects to add visual beauty and interest to its space. Besides than that, they are easy to install and are low cost as well which serves the concept. The PVC tubes on the walls actually extend up to the ceiling, which helps to reflect the sound, and as well as for aesthetic reasons.

3.3.2.4 Floor Material

Stage Floor

Figure 3.14: Image of the stage floor of Pentas 1

Pentas 1 uses epoxy concrete coating floor, with the intention of creating a monolithic and exceptionally easy to clean. Being among the most used of all surfaces, Pentas 1 stage floors require the best in durability, impact and abrasion resistance, easy low cost maintenance and slip-resistance, in order to produce the best sound quality for the audience, as well as provide the best sound quality for the musicians when performing. Besides, Pentas 1 flooring systems also have the beauty and high performance selection that meets exacting requirements.

Auditorium Floor

Figure 3.15: Image of the auditorium floor of Pentas 1

The material used in the flooring of auditorium is woolen carpet as it is a very good absorptive material made of 80% wool and 20% nylon. The floor had a black finishes to absorb the light so it will not disturbing the performer when they perform the shows. There are several reasons of the usage of woolen carpet in this auditorium. Firstly, it provides quality as woolen carpet is carefully tested for its performance, consistency, performance, and overall adherence to strict product specifications. In terms of comfort, woolen carpet is a naturally lustered fiber that is appealing to the eye and allows for a soft and comfortable appearance on the floor, as well as provides a warm and comfortable environment for the audience. Other than that, woolen carpet's natural luster and gentle light reflection characteristics give Pentas 1 an elegant and peaceful background. Last but not least, Pentas 1 promises audiences' safety. So, the usage of woolen carpet is essential as it is naturally flame resistant and does not come in contact with fire. It has the ability to self extinguish itself.

Woolen carpet is the antithesis of hard, echoing surfaces. Sound waves are effectively absorbed and deflected by the carpet and by the padding under the carpet, and the level of sound absorption can be enhanced with a thicker pad.

3.4 Acoustic Analysis

3.4.1 Sound Source

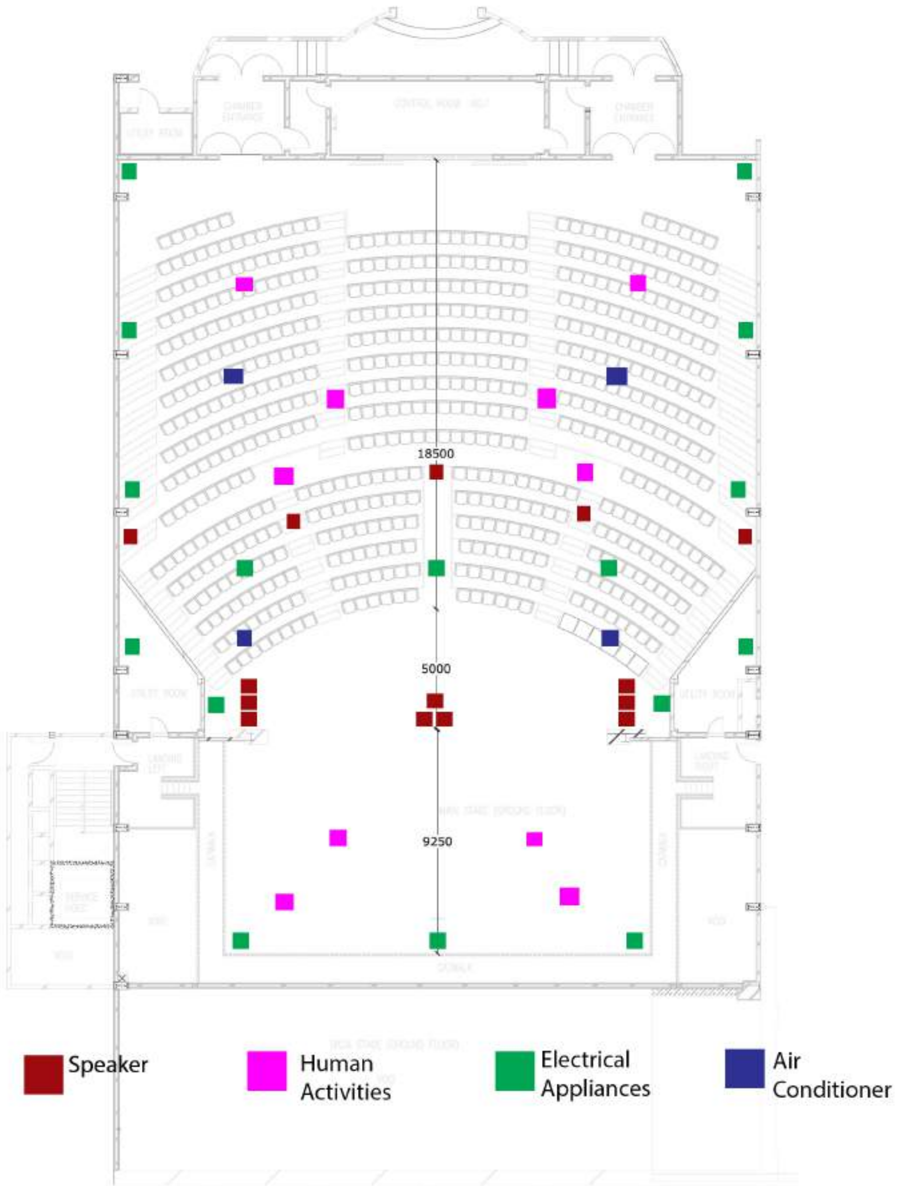


Figure 3.16: Identification of sound sources found in Pentas 1

INDICATION	SOUND SOURCE	SPECIFICATION	
	Speaker/Microphone	Product name	Meyer Sound UPJ-1P Meyer Sound UPM-1P Meyer Sound UMS-1P Meyer Sound UPA-1P
		Power Handling	50-100W
		Frequencies Response	65Hz-20kHz
		Input Configuration	70v – 100v
		Sound Pressure Level	35-45dB
		Placement	Wall / Ceiling
	Electric Appliances	Product name	Fresnel
		Power Handling	3.3kW
		Frequencies Response	200Hz
		Sound Pressure Level	30 – 40 dB
		Placement	Ceiling

Figure 3.17: Table of sound source and its specification

3.4.2 Sound Intrusion

Pentas 1 is designed in a way that sound insulates and mechanical noise control are fixed at certain area to negate background noise, such as heavy rain. Thus, rain noise isolation is also fixed in to achieve speech intelligibility within an enclosed environment without sound amplification, relying only on natural sound for propagation.

3.4.3 Sound Propagation

When sound is released from a source point, it propagates outwards in a spherical wave front and the sound waves can be reflected, refracted, diffracted or attenuated by the medium it hits. As an architect, it is important to take into account the design and materiality used to achieve the perfect acoustics.

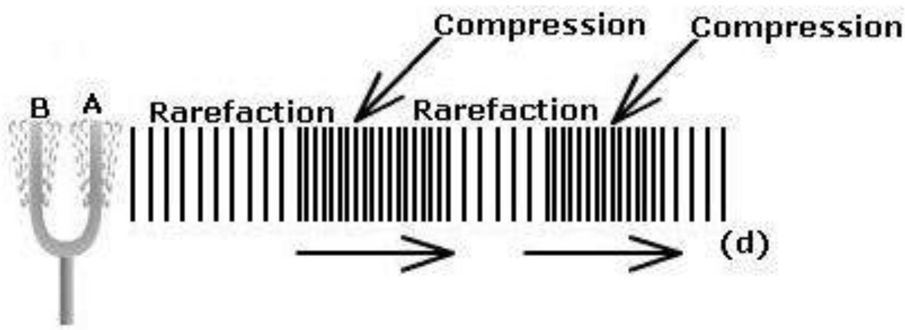


Figure 3.18: Propagation of sound in the air

Air is the most common medium through which air travels. When a vibrating object moves forward, it pushes and compresses the air in front of it and forming a region of high pressure called compression, which moves away from the vibrating object whereas when the object moves backwards, it creates a region of low pressure called rarefaction. As the object moves to and fro rapidly, it produces a series of compressions and rarefactions in the air, which makes the sound to propagate in the medium.

There are a few acoustical phenomena that can be found in KLPAC, which are:-

- Sound diffusion
- Sound absorption
- Sound reflection

3.4.4 Sound Diffusion

When sound bounces off a hard flat surface, it will be scattered and the energy remains very much intact resulting in discrete echoes. These echoes will produce destructive effects such as comb filtering; flutter echoes and standing waves, which disrupt the quality of speech intelligibility and music clarity.

Figure 3.19: Sound diffusers can be seen on the both sides of the walls of Pentas 1, KLPAC by using DIY items such as PVC pipes and white boxes.

From Figure 3.18, KLPAC installed a very unique piece that not only for aesthetics, but it is also used as sound diffuser panels. The uneven surfaces of the walls will not absorb the sound. Instead, it will preserve the energy by dispersing them across the room thus making it livelier.

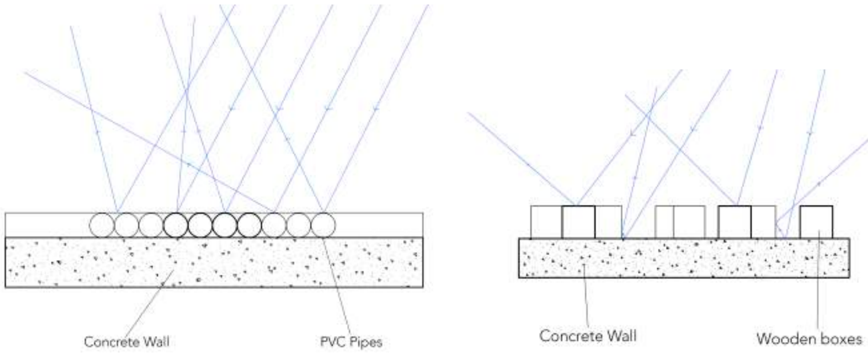
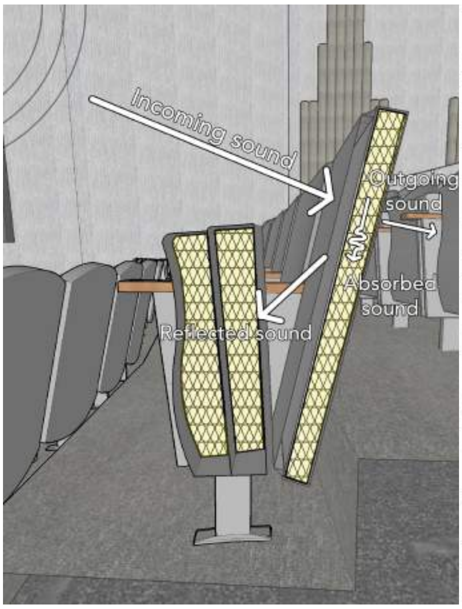


*Figure 3.20**:** Due to the uneven and hard surfaces, sound energy is dispersed, instead of being absorbed.*

3.4.5 Sound Absorption

Sound absorption refers to the process by which a structure, material or object takes in sound energy when sound waves are encountered, as contradicting to reflecting the energy. Part of the absorbed energy is transformed into heat energy and part is transmitted through the absorbing body. Soft, porous materials such as acoustic fabric panels, foam chairs are used to absorbed sound energy.



Common building materials		Absorption coefficient (125 Hz)	(500 Hz)	(2000 Hz)
Brickwork	plain	0.02	0.03	0.04
Clinker blocks	plain	0.02	0.06	0.05
Concrete	plain	0.02	0.05	0.05
Cork	tiles 19mm, solid backing	0.02	0.05	0.10
Carpet	thick pile	0.10	0.50	0.60
Curtains	medium weight, folded	0.10	0.40	0.50
	medium weight, straight	0.05	0.10	0.20
Fibreboard	13mm, solid backing	0.05	0.15	0.30
	13mm, 25mm airspace	0.30	0.35	0.30
Glass	4mm, in window	0.30	0.10	0.07
	Tiles, solid backing	0.01	0.01	0.02
Glass fibre	25mm slab	0.10	0.50	0.70
Hardboard	On battens, 25mm airspace	0.20	0.15	0.10
Plaster	Lime or plaster, solid backing	0.02	0.02	0.04
	On laths/studs, airspace	0.30	0.10	0.04
Plaster tiles	Unperforated, airspace	0.45	0.80	0.65
Polystyrene tiles	Unperforated, airspace	0.05	0.40	0.20
water	Swimming pool	0.01	0.01	0.01
Wood blocks	Solid floor	0.02	0.05	0.10
Wood boards	On joists/battens	0.15	0.10	0.10
Wood wool	25mm slab, solid backing	0.10	0.40	0.60
	25mm slab, airspace	0.10	0.60	0.60
Special items		Absorption coefficient		
Air	Per m³			0.007
Audience	Per person	0.21	0.46	0.51
Seats	Empty fabric, per seat	0.12	0.28	0.28
	Empty metal, canvas, per seat	0.07	0.15	0.18

Figure 3.20 Figure3.21

Figure 3.21: Shows the absorption characteristics of a foam used
Figure 3.21: Table of material absorption coefficient

3.4.6 Sound Reflection

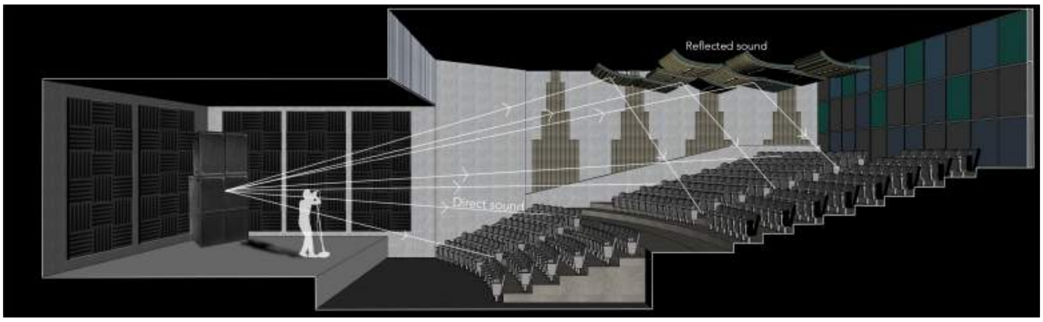


Figure 3.22: Shows the reflection of sound versus direct sound

The reflection of sound follows the law "angle of incidence equals angle of reflection", sometimes called the law of reflection. The same behavior is observed with light and other waves, and by the bounce of a billiard ball off the bank of a table. Hard surfaces such as concrete walls, floorings and cloud acoustic panels are used to reflect direct sound thus dispersing the sound equally in the auditorium.

3.4.7 Sound Reverberation

Reverberation is defined as the prolongation of the reflected sound. When a sound ceases in space, the sound wave will continue to be reflected to hard surfaces until it loses enough energy and dies out. **Reverberation Time (RT)** is the number of seconds it takes for the reverberant sound energy to die down to 60dB of its original value from the instant of the sound signal stops. Sound reverberation depends only on the volume of the space and acoustically absorptive quality of the room's finishes.

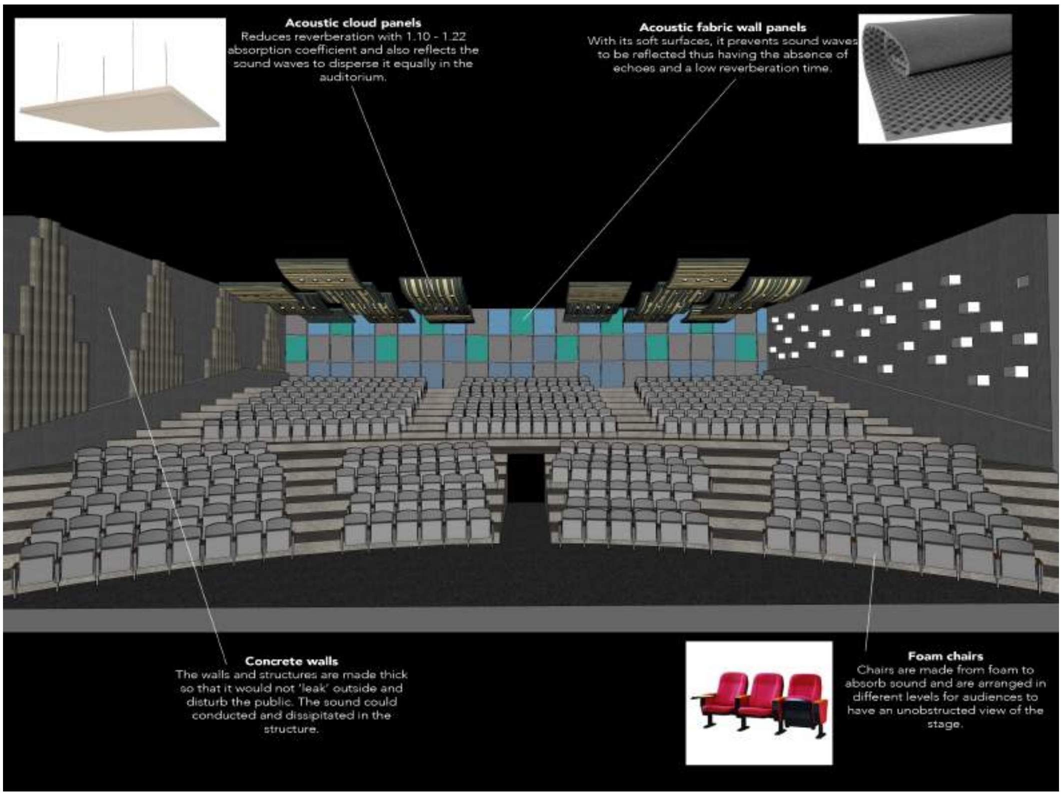


Figure 3.23: Certain materials play a very important role in the acoustics architecture.

Calculation of reverberation time:

Surface	Material	Area (m²)	Absorption (500Hz)	Abs. Unit (m²)
Wall	Acoustic fabric panels	161	0.44	70.84
Wall	Concrete with zinc	135	0.02	2.7
Wall	Concrete with PVC	135	0.02	2.7
Ceiling	Concrete with fabric clouds	802	0.02	16.04
Floor	Concrete with epoxy coating	802	0.02	16.04
Occupants	-	506	0.46	232.76
		Total Absorption (A)		**341.08**

Figure 3.24: KLPAC's Pentas 1 total absorption of sound

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

$$RT = \frac{0.16 \times 8020}{341.08}$$

$$\boldsymbol{RT = 3.76s}$$

Figure 3.25: Reverberation time (RT) calculation in seconds at 500Hz

From the calculation above, Kuala Lumpur Performing Art Center's (KLPAC) **Pentas 1** has an above average reverberation time by 3.76 seconds because of the usage of various materials, which is quite high compared to other auditoriums and could produce echoes. Materials such as roof zincs and PVC pipes were used as a decorative purpose on the walls of the auditorium which affects the reverberation because they have hard surfaces that reflects the sound waves instead of absorbing them. Softer materials like acoustic fabric panels; fabric cloud ceilings and woolen carpets are a good example of better acoustics absorptive fabrics to reduce the sound reverberation of the auditorium.

4.0 CONCLUSION

As a conclusion for the research, we've learnt that KLPAC has an above average reverberation time, which is quite high compared to other echo-producing auditoriums, and offers a fully–integrated performing art centre, equipped with one of the best materials, sound systems, acoustic absorption, amongst other theatres in Malaysia, along with an impressive long history, and the significance of being the heart of the Malaysia's performing arts community, KLPAC almost always has something to offer.

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