Building Services III
Lecture 11

Open Air Theatres

First, let us look at the design principles for an open air theatre. Long term acoustic studies conducted in outdoor spaces have shown that the basic principles of design include; minimisation of external noise (noise protection). A harmonic development of the functional elements of the theatrical space within the limits of the human vocal and acoustic scale i.e theatre form and the capacity. Sufficient emergence of directly propagated sound and its reinforcement through early positive sound reflections from the amphitheatre gradient and the natural loudspeaker response of the space. Control of late sound reflections, limitations of the reverberation times, elimination of echoes.

Here in the design of Open air theatres, the control over the design is very less, that's why we have to ensure all these things. Ensure that there is minimum noise, that there is a direct sound reaches the audience with early positive reflections because we rely on the natural gradient or the shape of the amphi theatre for good acoustic property and we also have to control the late reflections which tend to convert as echoes.

Next, we move on to the designing or the design principles of cinema or a cinema hall. In a cinema hall, the recommended reverberation time is 0.8 - 1.2 seconds, maximum. Here, the background noise levels should be kept to a minimum. Three primary potential noise sources are mechanical equipment (HVAC), noise from adjacent theatres and lobby, and outdoor noise. HVAC noise, which is often overlooked, can negatively impact the usability of the space. The noise from the lobby area can be disruptive. Be sure openings such as doorways are properly sealed. Consider a vestibule door system. What is this vestibule door system? Those who have been to a Cinema hall might know this. You have a two door system, a double door system where you enter from the lobby through a door, then you enter the anti space vestibule, then you enter the actual cinema hall. This anti vestibule space takes care of the noise from the lobby. You also have to take care of the dimension of the rooms, excessive room length should be avoided in cinema halls.

Next we move on to the design principles for a broadcasting studio. The fundamental principle behind broadcast acoustics is that the treatment should improve communication and bring intelligibility up to the very highest level. AS you might already know, a broadcasting studio is where people read news or they record for a specific item. Here the clarity in communication is of utmost importance. Here you have to apply acoustic treatment to the wall surfaces. This will eliminate flutter echo, significantly reduce first order reflections and vastly improve communication. Treating the wall surfaces will reduce the reverberant field which in turn will improve intelligibility over the air. In Broadcasting Studio most of the energy is centred between 300 Hz and 2000 Hz; in order to control the reverberant field in this frequency region, the acoustic panel choice must be effective from 300 Hz and up.

Next comes the concert hall. For classical or orchestral music, a higher reverberation time would be appropriate (approximately 2 sec), for a rock concert, a lower reverberation time be appropriate (approximately 1 sec). Find a happy medium, perhaps 1.5 seconds. It is vital to control the reflections from the back wall; it's usually necessary to splay or tilt the back wall to avoid slap back. Control the reverberation time on the stage. Ideally, the reverberation time in the stage area should be the same as in the house. Since the stage area might have a higher ceiling than the rest of the auditorium, more absorptive materials might be required in this area. Beware of potential noise impact to your space from exterior spaces and/or excessive HVAC noise.

Next we move on to classroom acoustics. Here, the recommended reverberation time is 0.4 - 1.0 seconds, depending on the size of the space. Numerous studies demonstrate how chronic noise exposure i.e noise found in the community as well as noise to which we are voluntarily exposed, negatively impacts education. Noise from adjacent classrooms can be easily transmitted into other classrooms, particularly in an open-classroom setting. It is vital to control the noise transfer between spaces. To ensure isolation, the wall must extend to, and seal to the deck, deck meaning the ceiling or the roof. Even if everything else is controlled perfectly, the space might not be usable if the background noise, (eg; HVAC system) is too loud.

Next comes the lecture hall. Here, the recommended reverberation time is 1 second. Once again, we have to be beware of potential noise impact to your space from exterior sources or excessive HVAC noise which can greatly degrade the speech intelligibility. The front wall and ceilings can be reflective enabling sound to reach everyone. Absorptive material on the back and side walls will help reduce the reverberation time and unwanted reflections. If possible, try to avoid parallel surfaces which can cause flutter echoes. Consider splaying or canting the sidewalls.

Next we move on to a residential project, a multi-storey residential project. Here, in a residential project, there are two types of sound that must be controlled. One is the airborne sound and the other is the impact sound. A typical airborne sound is music or talking. A typical impact sound is the football sound of an upstairs neighbour. Factors that contribute to noise transmitting into a neighbouring unit include a resident's living habits, background noise and the isolation quality of the partitions. All air-gaps and penetrations must be carefully controlled and sealed. The perimeter of the wall and any penetration must be sealed air-tight with a non-hardening acoustical sealant. Avoid the installation of back-to-back penetrations (outlets, light switches and phone jacks). Ideally, elevator shaft footings, floor pads, masonry shaft walls, elevator equipment mountings, etc, should be totally isolated from the building structure. The majority of noise concerns can be alleviated through proper space planning. Sensitive areas should not be located near potentially noisy areas. Plumbing noise can be both airborne and structure borne. To reduce, plumbing noise, pipes should be resiliently mounted, that is, adequately insulated from their supports. Any roof-mounted equipment should be analyzed for potential noise/vibration impact. Be concerned about exterior noise impacting the interior rooms such as nearby airport or freeway. The majority of this noise is transmitted through the windows. Upgrading the window assemblies might be necessary.

Next we will move on to Office acoustic design. In offices, the typical reverberation time is between 0.4 to 1 second. Once again, very similar to a classroom setting. The absorptive materials will most likely be necessary for the ceiling. Parallel reflective surface can cause an annoying condition called flutter echo or standing wave. Ideally, at least 2 non-parallel walls should be treated with acoustically absorptive material. Once again, here also, you beware of potential noise impact to your space from exterior sources and/or excessive HVAC noise. Some of the sound paths that can contribute to potential noise transfer are; wall assembly, door assembly, penetrations (outlets), Air-Gap between the wall and window mullion, Flanking over the wall/through the ceiling and through the ductwork. Here the sound paths are also called as flanking paths. With this, we have completed the acoustical design principles for the various spaces.

Now, let's look at noise control. Noise control, the first aspect is sound absorption. Sound absorption is the capability of a surface, or a building material to absorb sound instead of reflecting it. Surfaces that absorb sound better will not allow for reflections to bounce around as much, and will deaden the sound wave more quickly. Fiberglass insulation is very absorptive and can be used where control is a concern. Thick carpet with padding is also very absorptive and acoustical ceiling files are designed to absorb rather than reflect sound. Even in cases where these options are not viable, absorptive materials can be added to finished rooms in other ways; furniture with thick cushioning is extremely absorptive, as are thick and heavy curtains and drapes. Acoustical baffles with absorptive materials can be purchased for use in areas where sound is a major concern, and most are designed to be unobtrusive and visually nondescript so as to allow for installation without drastically altering the aesthetics of a room.

The next aspect in noise control is 'Airborne Sound transmission'. Airborne sound transmission in interiors deal with how well sound is controlled from room to room, and from the outdoors to indoors or vice versa, through walls and ceilings. Sound transmission loss is the decrease in sound energy when it passes through a building element. Different materials provide different levels of transmission loss and thus, different less of diffusion of sound. Dense, heavy materials increase the mass of floors and walls, allowing less sound to pass through. A break in framing or a resilient drywall connection breaks the path of vibration for the sound wave, causing it to halt. This is the most effective method for controlling strong, low frequencies, which are the hardest to block. Blocking airborne sound from leaking through gaps and cracks by sealing them is also very effective.

Next is the 'Impact Sound Transmission'. After an impact noise is transmitted through a floor or ceiling assembly, the airborne sound that has made it through is the impact-sound transmission. The sound of someone stomping around on the floor above you is can impact sound transmitted through the ceiling to the room you are in. Wood joist floor-ceiling systems transmit a lot of impact sound. Adding fiberglass insulation will improve their capability of blocking impact sound, as will decoupling by using a wire-suspended drywall ceiling. Lightweight concrete flooring is generally good at reducing airborne sound transmission, but it does not help block the impact sound as well. Resilient underlayments beneath floating floors can isolate the unfinished flooring from the concrete slab.

Flanking Paths

Next we move on to the 'flanking paths' or the parts through which sound is travels in the building. The most common flanking parts are supplied by plumbing pipes, air ducts and electrical conduit, rigidly connected between floor and ceiling. Continuous walls between floors, columns or any other continuous structural elements will act as flanking paths for impact sound. In fact, any rigid connection between the two diaphragms will effectively transmit impact sound.

This is a graphic or a sketch that denotes the various flanking parts in a building. The ceiling diffuses, the ducts, the fixed plant or the wall is continuous, then the floor is continuous, then through the electrical sockets are outlets. All these are flanking parts. When you see the common flanking practices, the book practices or the best practices to be adopted to avoid or control the noise transmission. For instance, in the building we have HVAC. Each room has a separate branch out from the main duct with a diffuser. This is a good practice to be followed. To avoid this noise transmission between rooms rather than running ducts across the rooms, you have to run a duct through the common area and then connect to the main duct using a secondary duct. The negative impacts in the flanking paths happen at Electrical boxes where we put boxes back to back. The electrical metal boxes. Then we have HVAC, where we don't do proper perimeter seals, at doors and other penetrations. All are very potential flagging paths which allow for sound transmission.

The next type of flanking path, is this. The best better option of doing the electrical boxes, staggering them on either side of the wall and the best is to stagger them and give them some acoustic salient or the salient material. Next comes the cutouts or cabinetry. Whenever you do a cutout, you have to close the backside of it, using another panel so that the opening is sealed properly.

Next comes an example where you can eliminate the flanking path with a non-resilient material. Say for example if we have two ducts or shafts, you can have a lead sheet a resilient material to avoid noise transmission. Next comes the sound seal. Here is a partition between two rooms, a gypsum board partition which is an insulation but without a sound seal. What happens is, the gap between the floor and the gypsum partition creates a good sound path for sound to travel. One option is to provide an acoustic sealant beneath the insulation area. The sound path is cut, the sound cannot travel directly. What happens is, the sound goes and travels through the insulation and then reaches the room. So, it is reduced a little bit. The best way to block it completely is to put an acoustic sealant here, now the rooms are completely sealed, sound doesn't travel.

Here, there is an example showing the construction in detail, where you have a sound path similar to the case above. Where you go and butt the wall panel or the partition to the resilient floor. If you do it this way, still sound will travel to the other room. However, when you cut or break the resilient floor and make the partition touch the actual concrete floor or ceiling. This creates a proper sound seal. Similarly, the same detail for the roof acoustic panels is shown here.

Next we move on to 'Sound reinforcement systems'. As you can see in the graphics, a sound reinforcement system consists of a microphone, a monitor, then the an amplifier and then the loudspeakers.

Generally a sound reinforcement system is used to enhance and distribute live or pre-recorded sound across a wide area. The key aim of sound reinforcement is to allow the sound to reach a larger or more distant audience while retaining or enhancing the quality of the existing audio, rather than just amplifying it. Sound reinforcement systems can vary from complex setups comprising of many microphones, multiple arrays and complex mixing and signalling processing systems to something as simple as a small public address system consisting of a single microphone connected to an amplifier and loudspeaker. The main requirements of any sound reinforcement systems where speeches are being amplified. The program material must be heart comfortably by all the audience or the public present and that the speech is easily intelligible. Naturalness is a desired quality and in instances where speech reinforcement is required, if everyone present can hear clearly without being aware that amplification is in use then the installation can be claimed as successful. Even after using sound reinforcement systems, if you can produce or give a natural effect or a natural sound, then that is a highly successful system. You have two types of systems; simple system and a complex system. The simple system consists of a limited number of microphones, most of them in fixed positions. These should all have a pre-set input. Simple systems have a limited number of loudspeakers, placed to avoid 'feedback' from the microphones. Such a system normally needs no adjustment during a service except possibly altering the overriding volume control. On the contrary, complex systems may include microphones, each needing continuous monitoring. These systems may also include a number of low powered 'whisper' loudspeakers to avoid feedback if microphones are used in a mobile way.

Next we move on to the 'Equipments' in a sound reinforced system. The first and foremost system is a microphone. Microphones which respond to sound mainly coming from one specific direction are used in sound reinforcement systems. These pick up a maximum of sound from the speaker and also lead to a reduced risk of acoustic feedback. To minimize the wear and tear it is better for microphones to be mounted on brackets or stands in fixed positions. Radio microphones which need no wiring, can provide greater flexibility but they are more expensive than wired microphones.

Next comes the loudspeakers. The multiple speakers or whisper speakers are generally more useful in very large spaces where excessive resonance or echo hinders clarity. The number of speakers required will depend upon the size and layout of the building. If possible, loudspeakers should be situated so that they produce a sound beam that travels almost over the heads of the audience and parallel to the floor. In Amplifiers a present control should be provided to limit the overall amplification to prevent instability ('feedback') in the worst conditions. An amplifier with little response to the low and high audio frequencies is generally required, but if music is to be played through the system then a broader response is preferable. The amplifier can usually be placed anywhere convenient.

Case Study

A case study here, is based on the performance Nairobi, Kenya. The issue or the task given here is, measuring reverberation time and speech intelligibility using balloons and an MP3 Player as external sound sources. Following the first concerts inside the theatre, it became clear that the acoustics were insufficient for proper communication between the acrobats and for live music performances. Acoustical researchers and consultants Constant Hak and Remy Wenmaekers of the University's Laboratorium voor Akoestiek (faculty of architecture, building and planning, building physics and systems unit) and level acoustics are willing to work together to improve the acoustics and the theatre. As mentioned, the acoustic consultants used a balloon, an mp3 player, along with a few softwares and this Omnidirectional microphone to test the acoustics of the space, thereby allowing them to work on a better solution.

The Sound absorption element - in the theatre, 6 mm multiplex panels on a 25mm cavity filled with low-density foam were used as low frequency, sound absorption material. The resonance frequency of the wooden panels seemed to lie in the 250 Hz octave band (theoretically 200 Hz). This explains the shape of the reverberation time curved which has a dip at the 250 Hz out of band. Hence it was proposed to use low density foam for the cushions and mattresses. The cushions could be used as baffles and the mattresses could be put up against the walls and ceiling. The sound absorption of the cushions have been tested in an improvised laboratory setup in an empty reverberant room inside the theatre. The baffles proved to be sound absorbing up to 100%.

Next comes the 'Acoustic Design'. The goal for the acoustic design is to achieve at least a reverberation time reduction from 3.5 to 1.5 seconds for an empty theatre, which is acceptable for rehearsing. Because there are no seats in the theatre to compensate for audience sound absorption, the reverberation time will be down to 1.0 seconds in a situation with the audience, which is ideal during performances. To better absorb the low frequencies, the current wooden panels have to be modified by enlarging the cavity of half of the panels from 25 to 100 mm and closing the panel's edges. To effectively absorb mid and high frequencies, a total of 700 meter square of cloth has to be added to the theatre walls and ceiling. 300 m square of heavy curtain 150% draped have to be hung in front of 200 meter square of the theatre back wall below and above the sanctuary. The other 400 meter square of cloth has to be draped in a double layered curtain on 200 meter square of the ceiling like a tent structure and 50mm of foam has to be put in between the double layered curtain. These are the following proposals, the contestants made. Here you can see a section of an auditorium, where all they have used is fabric and created a tent like structure in an auditorium.

The Results are as follows; As a result, the predicted reverberation time is 1.4 seconds without an audience and 0.9 seconds with an audience. The predicted speech intelligibility STI is 0.53 (Fair) without audience and 0.65 (Good) with audience. Recommendations were also made to improve the sound insulation to reduce the background noise level from 48 dB(A) to an acceptable level of 35 dB(A). To achieve this, sound insulating doors are to be installed into the entrances from the theatre towards the foyer and all ventilation openings are made to lock by introducing a labyrinth of foam.