Acoustical Engineering: The Influence Of The Structures Of Concert Halls On Their Acoustic Properties

The claim, “Acoustical engineering, based on an understanding of the behaviour of sound waves, is used to reduce noise pollution. It focuses on absorbing sound waves or planning structures so that reflection and amplification does not occur,” has several aspects that could be investigated. One aspect is that an understanding of the behaviour of sound waves has been used to reduce noise pollution. Noise pollution, defined by Encyclopaedia Britannica, is “unwanted or excessive sound that can have deleterious effects on human health and environmental quality.” Another aspect is that sound waves can be absorbed. Sound is absorbed if the sound is not reflected from the medium or material it contacts. A third aspect is that acoustical engineer's design structures where reflection and amplification do not occur.

The research question to be investigated is:

- How do the structures of concert halls influence their acoustic properties?

If evidence shows that sound is reflected or amplified inside concert halls, then the first aspect of the claim will be contradicted as noise pollution will be created. However, if sound is absorbed, preventing reflection and amplification, the second aspect of the claim will be supported.

Overview of the properties of sound waves

The speed of sound through air is affected by atmospheric conditions and the medium it is moving through. The speed that sound travels at through air can be calculated using the equation:

$v=331+0.6T$,

where v is the velocity of the sound wave and T is the temperature of the air. Sound waves travel outwards colliding with anything in their direction of propagation and are either reflected, absorbed, transmitted or diffracted by the new medium. Reflection occurs when sound bounces off a material. Absorption is the opposite of reflection as it occurs when sound does not bounce off a material. Sound is reflected by hard surfaces and is absorbed by soft mediums and gradually fades as its energy is dissipated (Lynch P, 2015 and Classic FM, 2017). Transmission occurs when sound waves pass through a boundary into a new medium or material and diffraction happens when the waves bend as they pass through a boundary (Walding R, 1999).

The natural or fundamental frequency of a body is the frequency at which it will resonate when made to vibrate by an imposed frequency or force. A body resonates when it vibrates at a particular frequency, causing it to oscillate with greater energy. Resonance can be heard when certain frequencies or pitches sound louder than others despite being the same volume (Walding R, 1999).

Longitudinal waves, characterised by their alternating compressions and rarefactions, travel parallel to the motion of the medium's particles (Walding R, 1999). Compressions are the parts of the wave where the particles are more spread apart, and rarefactions are the parts of the wave where the particles are more compacted together. Sound waves are longitudinal waves as the particles of the medium they travel through vibrate parallel to the direction the sound wave moves, hence they require a medium to propagate (the Physics Classroom, 2019 and Walding R, 1999).

Separate sound waves can combine to either cancel or interfere with each other. If two waves meet so that the compressions of one exactly match the rarefactions of the other, then they will cancel each other out and no sound will be produced. If two waves meet so that the compressions and rarefactions of both waves align, then the waves will combine, creating a larger wave through a process called interference (Lambourne M, 1995).

Manipulation of the behaviour of sound waves through acoustical engineering

Acoustics is the study of sound, especially the behaviour of sound waves in enclosed spaces such as concert halls, thus acoustical engineering is the science of designing and building structures with a focus on sound and vibration (Ardley N, 1990 and Environmental Science, 2019). Acoustical engineers work in areas where sound improvement or noise reduction are prioritised. Sound pollution can affect wildlife to a certain degree and contributes to an area's desirability. It is the job of an acoustical engineer to assess the noise impact of places such as construction sites (Environmental Science, 2019).

Direct sound travels straight to the listener without any reflections and is heard with more clarity than reflected sound. Reflected sound is heard by the listener after being reflected off different mediums. First reflections are sound waves that bounce off a surface once before reaching the listener. Reverberation time is the time taken for a sound to disappear in a space. Reverberation is heard when sound waves reflect off multiple surfaces or mediums (Drummond M, 2017 and Classic FM, 2017). This reverberation time is proportional to the size of the room and inversely proportional to the total absorption. Wallace Clement Sabine developed a formula, seen below, for reverberation time (Lynch P, 2015).

?RT?_60=0.16V/aS,

where V is the volume of the room, s is the total surface are and a is the absorption coefficient. When V, s and a are in standard metric units, RT¬¬60 is given in seconds (Lynch P, 2015).

As reflected sound travels further than direct sound, it is heard with a slight delay (Drummond M, 2017). The quality of sound is influenced by the room's acoustics (Microsoft Research, 2016 and Ardley N, 1990). Although direct sound is heard with more clarity, it cannot be heard as well, relative to reflected sound waves (Drummond M, 2017).

The Law of the First Wavefront, also known as the precedence effect, describe the way that the brain suppresses early reflections from the same sound source. The brain gives less weight to sound that hits the ear within a fraction of a second after the direct sound but if it reaches the ear significantly later, it can be heard as an echo. If too many reflections are heard in a room,

the listener's brain will become confused as it will not be able to figure out where the sound is coming from (Lynch P, 2015 and Drummond M, 2017).

Individual vocabulary profiling, which uses words to describe what is experienced to create a personal reference list, is used to compare sounds of different places. These lists are compared and lists of main attributes are discussed and created by a group of people. The five arguable main attributes of concert halls that are considered can be seen in Table 1 below (Microsoft Research, 2016).

Table 1: Five main attributes of concert halls

- Attribute Description
- Loudness/Bass How much sound/bass can be heard
- Reverberance/Width How much reverberation can be heard or how wide the sound is
- Clarity/Definition How clear the different instruments and parts of the music can be heard
- Proximity/Bass/Warmth How close/distant the sound is
- Brightness/proximity How brilliant the sound is

Preference, along with these five main descriptors, influences how the audience in the concert hall perceive the acoustics. Most people prefer acoustics that carry quite a lot of bass, which is largely explained by the attribute of proximity. The description of proximity cannot be explained in objective terms yet as it is not yet known what acoustically defines proximity (Microsoft Research, 2016).

Features of concert halls that achieve their acoustic

The acoustical properties of rooms are greatly influenced by its echo and diffraction of sound (Lehman College). The Sydney Opera House was known for its "bad" acoustic as sound produced by orchestras disappeared into the void above the stage, making it hard for players to hear each other. Niels Erik Lund, a sound engineer who oversaw the works to improve the acoustics of the Sydney Opera House stated that, "Improving the acoustics [of the Sydney Opera House] is a matter of getting the right mix of direct sound and reflected sound, especially the first reflections." There is no way to design a perfect concert hall as "good acoustics depend on what is being played" and the "preference of the listener." (Drummond M, 2017 and Microsoft Research, 2016 and Lehman College).

Due to the behaviour of sound waves, many concert halls have many hard surfaces with heavy curtains, with the only other soft surface found in the seating (Classic FM, 2017 and Ardley N, 1990). The audience also absorb sound (Lehman College and Classic FM, 2017 and Microsoft Research, 2016). Rough surfaces disperse sound in all directions so are usually used to eliminate echoes that would distract performances (Classic FM, 2017). Acoustical engineers make use of the many reflections in concert halls. Professor Trevor Cos, who teaches Acoustic Engineering at the University of Salford, said that "sound bounces and reverberates around the room and so reaches the listeners from lots of different directions and spread out in time… This reverberation enriches the sound the orchestra makes, and with the right design makes you feel enveloped by the sound and involved in the music-making… We need to get rid of unwanted noise… to ensure that the sound is clear and yet provides reverberance and envelopment."

(Classic FM, 2017). Hard walled buildings have a long reverberation time while soft furnished rooms have almost none, due to the reflective and absorptive properties of each surface (Classic FM, 2017).

The shape of concert halls also greatly affect reverberation (Ardley N, 1990 and Lynch P, 2015). Circular or elliptic-shaped halls concentrate reflected sound in particular areas, resulting in a non-uniform sound in the audience area. Parallel walls also tend to form resonant waves with non-uniform sound intensity. If resonance forms between parallel stage walls, the performers may not be able to hear each other well. Resonance does not affect the audience part of the hall to the same extent as the stage part as sound is reflected from the walls obliquely, preventing the formation of resonant waves. Resonance is not as important in big halls as it is in small halls due to diffraction (Lehman College).

Unwanted outside sound can make its way into concert halls by being transmitted through the air or building. The Bridgewater Hall in Manchester is mounted on springs to help reduce sound transmitted from traffic and trams to the structure. Most modern concert halls are surrounded by a gap of air to prevent outside wound intruding into the hall (Classic FM, 2017).

Quality of the evidence

Information about the influence of the shape of concert halls on its acoustics were only provided by one source, Leham College, so it is unsure if this information reliable. The source does not the year it was published so the information could be out of date. If at least one other source supported the information provided by Leham College, then the correctness of the information would be confirmed.

Most of the information regarding the properties of sound waves was supported by Walding R who wrote New Century Physics For Queensland, a physics textbook included in the Queensland Curriculum, in 1999. With Walding’s book supporting many different sources, it can be confirmed that it and the supported sources are credible.

Evaluation of the claim

Evidence was gathered to investigate the research question, “How do the structures of concert halls influence their acoustic properties?” The evidence suggests that the features of concert halls influence their acoustic properties. The findings of the investigation did not support the aspect of the claim stating that “acoustical engineering… focuses on… planning structures so that reflection and amplification do not occur,” as manipulation of reflection was found to be a crucial part of acoustically engineering concert halls. However, the aspects that “acoustical engineering, based on an understanding of the behaviour of sound waves, it used to reduce noise pollution,” and, that “it focuses on absorbing sound waves,” were supported as unwanted noise was found to be reduced and unwanted reflections were stopped by being absorbed using thick curtains.

Improvements to the investigation

Some improvements could be made to address more aspects of the research question. The first improvement would be to research how and where sound waves are reflected or absorbed at

different points of concert halls. It would be beneficial to support the evidence gathered if patterns could be established in the paths, directions and angles that sound travels in concert halls with similar shapes, materials or layouts. Further information would be required if no apparent pattern can be observed as the evidence would not be supported by physical evidence.

Extensions to the investigation

The research question used to prompt the investigation focussed on one aspect of the claim, the idea that acoustical engineers design structures where reflection and amplification do not occur. The aspect that an understanding of the behaviour of sound waves has been used to reduce noise pollution was not directly considered. Further research that could be considered is whether acoustical engineering reduces noise pollution in concert halls, which make use of multiple reflections to achieve their acoustic. This would help to establish whether manipulated reflections are considered noise pollution.

Conclusion

It can be seen that the materials, shape and positioning of objects and walls in a concert hall as well as the presence or absence of people influence the acoustic properties of concert halls. However, no evidence was found that demonstrated exactly how the structures of concert halls influenced sound waves. Aspects of the claim “Acoustical engineering, based on an understanding of the behaviour of sound waves, is used to reduce noise pollution. It focuses on absorbing sound waves or planning structures so that reflection and amplification does not occur,” are supported, however, parts of it are contradicted.