Proceedings of The Institute of Acoustics

SIGHTLINES AND SOUNDLINES - THE DESIGN OF AN AUDIENCE SEATING AREA

ANITA LAWRENCE
UNIVERSITY OF NEW SOUTH WALES, AUSTRALIA

INTRODUCTION

The acoustics of auditoria has intrigued many people since classical times and there have been many principles of acoustic design expounded - sometimes based on less than rigorous scientific evidence. Over the last two or three decades a plethora of criteria has confronted acousticians attempting to design auditoria, but this has brought the danger that some very simple requirements are overlooked.

BRIEF HISTORICAL REVIEW

Lord Rayleigh's pioneering work on the theory of sound provided an excellent basis for modern acoustics. Following this, W.C.Sabine's painstaking applied research at the beginning of this century did much to discredit the "wire-stringing" school. Others such as Eyring, Fletcher, Knudsen, Bekesy, Meyer and Cremer, to mention but a few, gradually built up a credible theoretical basis for auditorium design - taking into account the characteristics of human perception as well as the physics of sound propagation. At the same time instruments for making precise objective measurements of sound fields became available. However, few large auditoria were built in the first half of the twentieth century.

The advent and development of movies in the 1920's and 1930's had a profound effect on auditorium design. Acoustically neutral auditoria were required in which the recorded sound effects of the Wild West would seem equally realistic as those of a living room. This was achieved by making the theatres acoustically dead. The emphasis on pictorial representation meant that cinemas were built with steeply raked stalls and stepped balconies. In addition, the more-than-life-size dimensions of the pictures projected on the screen and the use of amplified sound enabled very large audiences to be accomodated - with good vision and sound even at the remote upper gallery seats.

It is not surprising that when the next wave of auditorium building took place in the Western world in the 1950's, the erstwhile "cinema" architects and their acoustical consultants placed much emphasis on reverberation time as a criterion for good design. Some of the resulting auditoria were radically different to the earlier traditional models, and, not surprisingly, so was their sound. The London Festival Hall is a well-known example of this period, and, as Beranek (1) pointed out "most of the experiments of the first half of the twentieth century had to be run in the Royal Festival Hall. And much was unknown."

NEW ACOUSTIC CRITERIA

The most publicised attempt to quantify subjective acoustic criteria was that undertaken by Beranek when asked to act as consultant for the new

Philharmonic Hall at New York's Lincoln Center. The results of his survey of over fifty concert halls, opera houses and theatres, mainly in Europe and the Americas were published (1), together with the criteria he had derived from his own and others' critical listening experiences. Unfortunately, many of Beranek's ideas were rejected along with the destruction of Philharmonic Hall's interior.

The controversies surrounding the Royal Festival and Philharmonic Halls greatly encouraged research into all aspects of auditorium design. In particular, investigations were made into the detailed perception of sound fields by both experienced and naive listeners. As a result of these studies, many new criteria have been proposed, some of which will now be discussed.

EARLY DECAY TIME

Jordan (2) proposed Early Decay Time (EDT) as a criterion. This is determined from the slope of the first part of the decay curve (from 0 to - 10 dB) and is thought to be more representative of the subjective impression of reverberation. As a design tool, however, EDT suffers from the same problems as T_{60} itself.

SPATIAL RESPONSIVENESS

Marshall (3) investigated the reflection sequences in two idealised halls and showed that in a wide hall, all lateral reflections are masked by the overhead reflection, but this is not the case for a narrow, high hall. He concluded that an auditorium should have "Spatial Responsiveness" which he attributed to the presence of many lateral reflections. However, Seraphim(4) had previously shown that relatively few of the numerous reflections which are present in an auditorium need to be included if a room's impression is to be simulated electroacoustically, because a few strong components will mask the remainder.

VOLUME

Lawrence(5) discussed a similar concept to Spatial Responsiveness, which she termed "Volume", which is related to the perception of reflected sounds coming from many different directions. Referring to Lochner and Burger's work (6) it was pointed out that whether or not a reflection will be perceived depends on the relative levels of the direct sound and other reflected sounds. In addition, side-wall reflections will suffer considerable attenuation through diffraction and absorption at grazing incidence, within the body of an audience, and they will tend to be masked by reflections coming from the ceiling, which are less attenuated. Thus a listener will have difficulty in perceiving lateral reflections unless they arrive before those coming from overhead.

BINAURAL SIMILARITY

Recently, Schroeder (7) has suggested Binaural Similarity as a criterion. It is related to the correlation function of the first 80 ms of the impulse response at the two ears and should ideally have a value of zero. It too is related to the directional distribution of reflected sounds - since plane ceiling reflections will produce rather coherent signals at the two ears, whilst lateral reflections should not. However, Schroeder suggests that the problem of coherent ceiling reflections may be overcome if specially modelled diffusing surfaces are used (quadratic residue differences).

FURTHER CRITERIA

Other suggested criteria include the Modulation Transfer Function (8), related to the effect of reverberation on the envelope of the original signal, Hörsamkeit, or Hearingness (9), dependent on the spread, multi-source nature of an orchestra and various Musician's Criteria (1, 2). Design guidelines to achieve such criteria are not readily available.

SIGHTLINES AND SOUNDLINES

In nearly all the research which has been carried out into the perception of reflection sequences, etc., the first sound that is received, i.e. the direct sound has been taken for granted. Yet the direct sound, travelling from source to listener has suffered less distortion and less attenuation than any other component received. Provided that the (now) well-known low-frequency interference affect is avoided, the direct sound should include almost the complete sound spectrum from each source, in the correct temporal sequence, so that musical transients can be perceived. (It is these transients which aid listeners to differentiate between the sounds emitted by the various instruments.)

There will be some distortion of the direct sound, due to instruments' directional characteristics, and high-frequency absorption by air, as well as a reduction in overall level, determined by the distance between source and listener. It is known that the position of the source is fixed by the amplitude and time difference at the two ears of the first signals received; reflections arriving within a certain period are masked subjectively by the direct sound, but their energies are integrated with the direct sound and increase the overall loudness (10). Reflections coming after this period, probably of the order of 30 ms, are presumably the ones that contribute to the room's overall acoustic impression. The perceptibility of these "surround" reflections then depends on their relative levels, delays and directions.

Whether or not direct sound will be received depends on whether there is a clear line-of-sight between the listeners and the sound sources. Human eyes and ears are conveniently located at about the same level in the head! Naturally, some low-frequency direct sound will also be received by diffraction in out-of-sight locations. Thus the provision of direct sound for all listeners is relatively simply achieved, if the design of the seating area is determined using three-dimensional geometry. It is necessary to take into account the distribution of the orchestra as well, and this implies a stepped platform if the instruments further back are not to be shielded by the ones in the front.

Cremer's excellent paper on audience distribution traced the development of theatre design from Epidaurus to the Berlin Philharmonic Hall (11). He showed that not only acoustics but social philosophies have shaped our auditoria. In many traditional concert halls and opera houses, and indeed in some built quite recently, there are many seats with restricted or no view of the performing area (and thus with no direct sound). Such auditoria have good and bad seats, normally with a pricing policy to suit. However, if Cremer's "terraced" seating system is used as a guideline, all members of the audience should receive good direct sound as well as a good view of the performers.

CONCLUSION

Undoubtedly there has been much progress in auditorium design in recent years, although an agreed set of criteria (accompanied by design guidelines), that can be used to guarantee an auditorium will be accorded general critical approval is not yet available. The exact number and sequence and distribution of reflections required is still to be determined, and extensive listening tests are needed to obtain consensus on what comprises "excellent", "good" and "mediocre" acoustics.

However, it is a simple matter to determine whether or not listeners have a clear view of the performers, both at the design stage and in the completed auditorium. Since it is the direct sound that determines perception of source location and also the perception of reflected sounds, it needs far more attention than appears to have been the case in some auditoria.

Cinema, stereo and television have accustomed people to high standards of sight and sound - if they are to continue to visit auditoria to enjoy the additional experience of being present at a live performance, they will expect to enjoy ideal sight and sound conditions from all parts of the auditorium.

REFERENCES

1. L.L.Beranek,1962."Music,Acoustics & Architecture",John Wiley,New York.
2. V.L.Jordan,1975.App.Acoust.8,217-235. Auditoria acoustics: developments in recent years.
3. A.H.Marshall,1967.J.Sound Vib.5,100-112. A note on the importance of room cross section in concert halls.
4. H.P.Seraphim,1963.Acustica 13,75-85. Raumakustische Nachbildungen mit Elektroakustischen Hilfsmitteln.
5. Anita Lawrence,1970."Architectural Acoustics", Elsevier,London.
6. J.P.A.Lochner & J.F.Burger,1964.J.Sound Vib.1,426-454. The influence of reflections on auditorium acoustics.
7. M.R.Schroeder,1979.J.Acoust.Soc.Amer.65,958-963. Binaural dissimilarity and optimum ceilings for concert halls; More lateral sound diffusion.
8. T.Houtgast & H.J.M.Steeneken,1973.Acustica 28,66-73. The Modulation Transfer Function in room acoustics as a predictor of speech intelligibility.
9. G.Plenge et al.1975.J.Acoust.Soc.Amer.57,1292-1299. New methods in architectural investigations to evaluate the acoustic qualities of concert halls.
10. J.P. Lochner & J.F.Burger,1961.Acustica 11,195-200. The intelligibilty of speech under reverberant conditions.
11. L.Cremer,1975. App.Acoust.8,173-191. The different distributions of the audience.