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ELECTROACOUSTICS IN "SURROUND" HALLS

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INTRODUCTION

The concept of audiences surrounding a performance area dates back to the early Greek amphitheaters. These amphitheaters were primarily outdoors and of course utilized no electronic sound reinforcement, at least none that we know of. Today, "surround" halls have moved indoors and are accommodating audiences ranging from approximately 200 people in small, intimate theaters, to 1,500 or 3,000 in auditoria, to as many as 80,000 in large, multipurpose stadia. This evolution has necessitated the careful design and integration of electroacoustics systems into the architectural and acoustical aspects of a space.

Exhibition halls and stadium and arena facilities frequently utilize centrally located platforms, with audience seated on all sides for religious programs, entertainment, and sporting events. Distributed loudspeakers and loudspeaker-cluster systems have been utilized successfully to provide sound amplification in these spaces.

This paper will discuss the subject of electroacoustics systems for spaces with "surround" seating. Two such projects for which I served as principal electroacoustics designer are the Kingdome in Seattle, Washington, and the University Centre Auditorium at the University of Victoria in British Columbia.

DISCUSSION

Selection, location, and orientation of the loudspeakers are very important. Coordination between the electroacoustics and architectural-acoustics systems design is also essential in all halls. Of course, reverberation control is an important consideration in "surround" halls. In conventional halls, direct sound coverage for reinforced speech is necessary for good intelligibility. In a "surround" hall, even with direct loudspeaker coverage, clarity and intelligibility of music and speech would deteriorate for audience located behind a platform if they were exposed to late-arriving sound reflections from the opposite wall.

In a small theater-in-the-round, some portion of the audience will always be seated behind the performers. The potential exists for reflections of natural sound (echoes) from the opposite wall to persons behind the platform. These reflections can be controlled by proper utilization of sound-absorbing materials and with a sound amplification system which can increase the ratio of direct to reflected sound heard by the audience.

In stadium and arena spaces, where all speech must be electronically reinforced due to the large distances between performers and audience, the echo problem can be acute. Detrimental reflections can come from opposite sites of the stadium due to the series of steep concrete risers and/or the seat backs of the chairs if these are unupholstered and unoccupied.

The problem is minimized when the stadium is occupied, because of the absorptive effect of the audience. If the stadium is partially occupied, this problem can be alleviated by providing absorptive upholstered seating or by restricting the seating and selectively turning off loudspeakers which would have provided sound coverage for the unoccupied areas. This can only be accomplished if the sound-coverage pattern for individual loudspeaker clusters is carefully controlled.

THE SEATTLE KINGDOME

The King County domed stadium, known at the Kingdome, opened on March 25, 1975, following a 3½-year construction period. The construction cost of $60-million places the Kingdome among the least expensive domed, air-conditioned stadia of its size in the world. Located just minutes south of the center of downtown Seattle, it is the only covered multipurpose stadium of its type in the western United States.

The Kingdome is 200 meters in diameter and 76 meters high at the top of the dome. The enclosed volume is more than 1.5 million cubic meters. The stadium seats 60,000 for baseball and 65,000 for football and soccer, with a maximum of 80,000 seats for concerts, conventions, personality shows, political rallies, religious programs, and so forth--all of which have been successfully accommodated since the Kingdome opened. Many of these events utilize seating configurations which surround a centrally located platform.

Reverberation control was one of the primary aims of the acoustical design. However, choices were limited, as in many projects, by the structural and budgetary constraints of the project.

The roof itself is a scalloped concrete dome. The shape and physical appearance were a result of structural and aesthetic design decisions by the joint-venture architects and the project engineers. It was not possible to maintain these structural and architectural aspects and also include a suspended, sound-absorbing ceiling, which was preferred. Therefore, it was decided to use a wood-fiber-composite material to serve as a form for the concrete and act as a sound-absorbing surface for the entire ceiling.

A severe budgetary constraint was also placed on the type of seating. Absorptive upholstered seating was recommended, but only metal benches for the upper tiers, and hard fiberglass seats for the lower tiers, could be provided.

Although the total exposed surface area of the vertical walls at the rear of the upper tiers was comparatively small, these surfaces were covered with glass fiber mounted behind a protective, perforated metal facing.

The resulting reverberation time at 1,000 Hz, measured in the unoccupied stadium, is 5 seconds, which is not unusual for spaces of this size. This decreases to 2.5 seconds at 4,000 Hz. Below 1,000 Hz the reverberation time rises sharply due to the decreasing sound-absorption efficiency of the wood-fiber-composite material at low frequencies, and due to the concrete roof enclosing the stadium. The reverberation time drops considerably when the space is occupied.

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Because of the enormous enclosed volume of the space and the resulting high, reverberant sound levels, it was also of primary importance to design a sound amplification system which could provide high levels of direct sound to the seated audience, keeping unnecessary amounts of sound out of the reverberant field.

The main sound amplification system which serves the permanent seating areas is comprised of 13 loudspeaker clusters located on the circumference of a circle with a diameter of approximately 98 meters. These clusters are within 37 meters of the listeners and each is designed to provide direct sound levels of 95 to 100 dB.

A separate single loudspeaker cluster serving 360 degrees is located above one end of the stadium floor, to be utilized with a portable platform and "surround" seating configuration. For basketball or platform seating of between 10,000 and 80,000, the loudspeaker cluster operates in conjunction with the permanent circumferential loudspeaker clusters which serve the seating areas around the stadium. A system of 11 different audio delays is utilized to synchronize the arrival of sound from loudspeakers at different distances which serve seats in zones of overlapping coverage.

Some seats in the upper portions of the lower seating tiers and the middle seating tiers do not have line of sight to the circumferential loudspeaker clusters, due to balcony overhangs. These seating areas are provided with distributed full-range overhead loudspeakers. These low-level loudspeakers are provided with the proper time delay to synchronize their sound with the later-arriving sound from the more-distant loudspeaker clusters for listeners in zones of overlapping coverage. Distributed loudspeakers are also located in the concourse and concession areas.

UNIVERSITY CENTRE

The University Centre Auditorium at the University of Victoria in British Columbia was completed in 1978 at a cost of approximately $3-million. It was part of a larger administrative office complex.

The auditorium, which seats a total of 1,300 people on the ground floor and in the balcony, is the first "surround" hall built in Canada. The stage is encircled by seating, with approximately 300 seats to the rear of the stage forming a choir loft.

This "surround" hall was designed primarily for serious music. For seats behind the stage/platform, good speech intelligibility and echo control were achieved by utilizing low-level distributed loudspeakers.

The sound amplification system at the University Centre Auditorium consists of a full-range central loudspeaker cluster which provides sound coverage for the entire main-floor and balcony audience seating in front of the platform. Loudspeaker coverage for seating behind the platform is provided by 90 small, full-range loudspeakers mounted near the top of the backs of the choir/audience seats. These loudspeakers are located approximately 1.25 meters on center. The first row of choir/audience seating is served by 22 small loudspeakers mounted in the concrete parapet.

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The first few rows of audience seating in front of the platform on the main floor have supplemental sound coverage to improve directional realism. This consists of 12 small loudspeakers in enclosures recessed into the top of the orchestra-pit rail.

Objective measurements and listening tests revealed excellent uniformity and frequency response from the distributed loudspeakers as well as the main loudspeaker cluster. The signal to the distributed loudspeakers behind the platform is delayed to synchronize the arrival of sound from these loudspeakers and the central loudspeaker cluster for seats in zones of overlapping coverage.

The directional realism behind the platform was found to be excellent. A number of factors contributed to the satisfactory sense of directional realism in the seating behind the stage. These included: (1) the fact that the distributed loudspeakers are along the line of sight between the listener and performers on the stage, (2) the psychological benefit of seeing and hearing a performer at the same time onstage, and (3) the proper mix of sound from the distributed low-level loudspeakers and the central loudspeaker cluster above the stage.

The problem of echoes reflecting off the rear wall, from the central loudspeaker cluster to the seating area behind the platform, does not arise at University Centre because of the careful location and orientation of the loudspeakers and the architectural treatment of the rear wall. The rear wall, which is similar to all other wall surfaces in the hall, is concrete, splayed, and faceted to diffuse sound. During speech functions, adjustable sound absorption, in the form of a series of heavy velour banners, tracks vertically from concealed enclosures to cover the walls, reduce reflections, and absorb sound.

Although the sound amplification system is not utilized for symphony concerts, it *is* utilized for most speech reinforcement; including announcements prior to a concert, as well as reinforcement of certain musical performances such as jazz programs. Reinforcement of music during these types of programs has subjectively been quite clear and natural. Because of the sound amplification system's location and the related architectural treatment, the loudspeaker systems are fixed and barely noticeable. Therefore, they do not have to be mechanically lowered or raised for use.

CONCLUSION

The major conclusion which can be drawn from our recent experience with electroacoustics systems design in "surround" halls is that electroacoustics systems can be designed and properly coordinated architecturally to provide the demanding functional and performance requirements of these spaces. Of primary importance is the control of echoes, the maximizing of direct-to-reinforced sound ratios, and the very careful directional control of reinforced sound, utilizing low-level distributed loudspeakers and/or highly directional loudspeaker clusters.

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Motto: Though this be madness, yet there is method in 't. (Hamlet, Polonius, 2.2.204)

Introduction, design philosophy

Herman Hertzberger, the architect for the new music centre of Utrecht, felt inspired by the Philharmonie of Berlin (architect H.Scharoun, acoustic consultant L.Cremer, opened 1962).
Hertzberger designed what is sometimes called a "surround" or "vertical" concert hall, for approx. 1500 people: see figures.
The architect's aim was to create a maximum of visibility for all in the hall, from as short a distance to the platform as possible. A concert in his view is as much a performance to be seen as to be heard. The influence of orchestral concerts on T.V. seems apparent.
The acoustics consultants *, when confronted with the preliminary sketches, had to think deeply before accepting the idea.
The design went even further than the Philharmonie as to the number of people sitting behind and beside the platform; would not the orchestra sound very much unbalanced to the many people sitting there? How could the other requirements be met, e.g. for the sequence of early reflections? Could a room of this shape reverberate at all? After ample consideration we felt that it would be wrong to single out the acoustical aspects from all others.
A concert visitor receives many impressions, both visual and auditive, and they should be in harmony with each other. Only when one impression is quite unsatisfactory - say seeing an instrumentalist and not hearing him - the situation is unacceptable.
In other words, the acoustics are important, but not the dominating factor. The acoustician should try to obtain a good result with full regard for the non-acoustical objectives. Certainly he should not impede the development of architectural design of concert halls by sticking to the safe shape of the 19th century shoe box hall!

* The author worked together with Mr.L.G.Booy (T.N.O.-Delft).

The acoustical shaping of the hall

We told the architect that we believed we could obtain good acoustics (if perhaps not in all seats) on the basis of the preliminary design, provided the architect would accept our suggestions for a number of changes. Those we based on the (then available) knowledge of the desired reflection pattern in a hall (e.g. after M.Barron, A.H.Marshall, W.Reichardt and co-workers).
We insisted on a considerable number of reflecting surfaces providing the all-important early lateral reflections.

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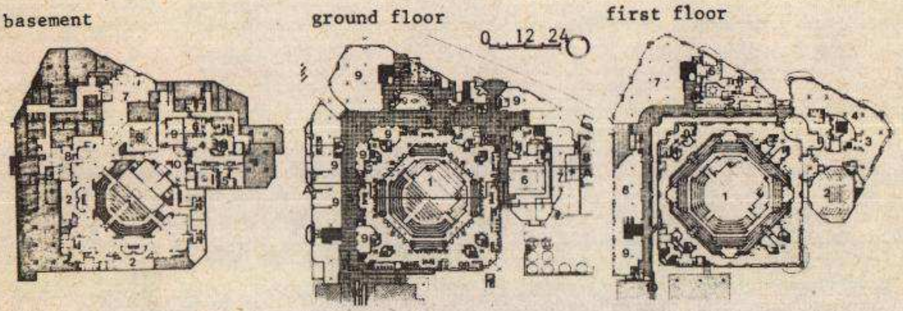

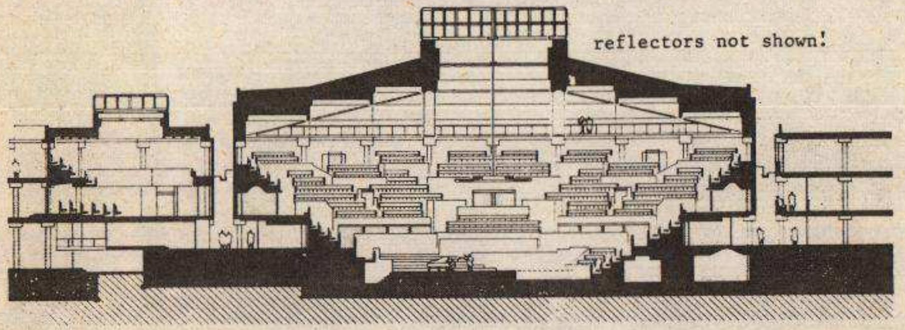

To this end the steep seating areas were interrupted by vertical planes at different heights, on all eight sides of the largely symmetrical hall. These surfaces are the equivalent of Cremer's "vineyard steps".
We had also to advise changes in the steepness, in view of the sightlines.
We further requested a number of platform reflectors, to be designed at a later stage.
The ceiling in our opinion should be diffusely reflecting in such a way, that the listener receives oblique reflections rather than overhead ones. The shape was chosen accordingly.
The average height of the ceiling determines the hall's volume and so the possible reverberation time T_{60} which, it seemed to us, is still very important if no longer the predominant quantity in concert hall acoustics.
It is true that the early decay time (EDT) determines what has been called by Newman and Schultzthe running reverberance as opposed to the terminal ditto.
A good T_{60} does not always mean a good EDT, but in a hall where T_{60} because of lack of volume or excess of absorption cannot have a long enough value, EDT will normally not be good either. It is therefore necessary to make a good T_{60} possible.
We aimed at a value a bit lower than in De Doelen, the 1966 Rotterdam concert hall, namely 1.8-2.0 s instead of 2.15 s (occupied). Keeping in mind Cremer's decision to give the Philharmonie a 10% "over volume" in view of its shape

(audience more exposed than in less steep halls), we fixed the volume at what turned out to be 17020 m^3 (almost exactly 600000 cu ft).

Materials, noise problems

The architect preferred bare concrete and (thick) plywood as his main materials. The ceiling consists of 20 and 30 mm thick plywood panels, the floor of the platform and of the two large lifts of the stalls are of wood on wooden joists. The chairs were designed by the architect and their upholstery improved by the acousticians.
Some tough sound insulation problems had to be solved. The huge roof light, a "greenhouse" of 9.5 x 9.5 m^2, and 5 m high, had to be sealed against aircraft noise and the rain's impact sound.
The doors were up till recently still lacking in sound insulation.
The air conditioning system meets the noise criterion: NR 20.

Acoustic model

Although most decisions had already been taken we requested permission (and money) to build a chipboard model (1:20) of the hall and test it.
The technique at the time was not unusual: a spark burst as the sound source, egg crates for the audience.
We took several (omni directional) pulse responses, a.o. without the roof, in order to decide on place of origin of early reflections.
The vineyard steps apparently did their duty and gave rise to reflection patterns which to us seemed satisfactory.
After filling the model with nitrogen we measured T_{60}: 2.3 s, and so proved that the hall could indeed reverberate.
Shape, position and inclination of the 6 + 1 reflectors were determined by acoustical and optical means in the model. The 6 reflectors hang at 10 m above the stage; they are 2.6 x 2.6 m^2 and consist of 16 boards of 0.65 x 0.65 m^2, each with its own position and inclination. The middle reflector is 5.4 x 5.4 m^2, has a large hole in the middle, and hangs at 9 m above the stage. The reflectors are made of 8 mm plywood.
The reflectors have a double purpose: providing early (preferably not overhead!) reflections in the stalls and reflections for the orchestra members.
It took a lot of convincing architect, lighting engineer and air conditioning people before we got our reflectors as we wanted them!

The outcome

Three test concerts gave ample opportunity to make measurements with a full audience and orchestra. The following results were obtained.

a. Pulse responses, made with the help of a new technique (after Berkhout), showed an abundance of early reflections.
b. T_{60} for the empty and fully occupied hall are shown in figure 1 (next page). The values are quite satisfactory and as forecast. The amount of bass absorption can perhaps be explained by the large number of doors and many other panel surfaces.

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c. From the recorded signals the computer could determine the EDT's: see figure 2. According to some authors (e.g.Jordan) the EDT should be at most 10% smaller than T_{60}.
d. The I.I. (inversion-index, after Jordan) was computed at: 1.14 (500), 1.11 (1000), 1.09 (2000). This quantity should be larger than 1 for satisfactory platform conditions.
e. The sound pressure levels throughout the hall (7 places) and on the platform show rather small differences: 1.2 dB (500); 1.1 dB (1000); 1.4 dB (2000).

The acoustical appreciation of the hall to our deep satisfaction of course, was very laudatory, both among music critics, musicians and conductors. Most visitors do not try to avoid the seats behind and beside the orchestra, although some do.

It is true of course, that a singer when heard from behind does not satisfy the listener. The grand piano when without lid sounds better to the people behind (not to the conductor!).

There is certainly sufficient bass in the hall. Musicians can hear each other very well; the platform is "easy". However, we would still like a diffuse back wall on the stage; it is in the design stage.

Moral

This type of concert hall, at first sight, seems doomed to fail acoustically. In spite of its succesful history the Berlin Philharmonie, prototype of the new shape of concert halls, is still considered by quite a few "diehards" as inferior to the traditional concert hall. They find their champion in Cyril Harris (an "acoustics virtuoso" Time Magazine called him), who in 1975 and 1976 redesigned Avery Fisher Hall acoustically (previously Philharmonic Hall, Lincoln Center New York). In a long, hero worshipping article in the New Yorker ("Annals of Architecture, a better sound" - Nov.8 - 1976, anon.) Harris is quoted as saying: "All the greatest halls in the world are rectangular", and: "I am using no new techniques or materials".

We beg to differ, we consider Harris' opinion very conservative, unscientific and dangerous for our profession.

If acousticians want to be taken seriously they should try to understand what is going on in architecture. They should not remain on the safe side but be prepared to stick out their necks.

The Utrecht concert hall has in our view shown that thanks to the development of theory the practical acoustical consultant is now in a position to help design a modern hall which fulfills all demands, also acoustically.

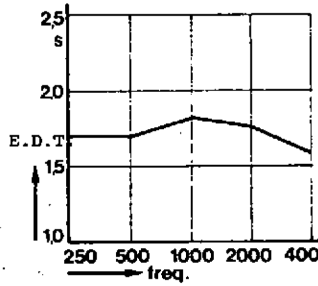

fig.2

fig.1