DESIGN METHODS IN AUDITORIUM ACOUSTICS

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The research methods outlined in my earlier paper all influence, either directly or indirectly, the methods we apply to the design of real auditoria. To illustrate the application of acoustics research in our design methods, and how matters outside acoustics are often of even greater significance to a practical design, I will discuss our acoustical designs for the performing arts facilities in Nottingham, Colorado Springs, Colorado, and Tampa, Florida.

The Nottingham and Colorado Springs facilities were designed concurrently in 1979, and the Tampa facility in 1982. Each of these halls has "multi-purpose" aspects, and the Tampa and Colorado Springs facilities are true multi-purpose halls in the sense that they have fully equipped fly towers and proper concert enclosures.

The designs of these halls are acoustically and visually quite different. The reasons for the differences include site constraints, particular intended uses, seat count, and in some instances, the architect's preconceptions for room shape. Indeed, if I have learned anything as an acoustical consultant it is that the practical and political constraints of building design often wield a more powerful influence over the finished building than any acoustical theories and practice. In my thumbnail descriptions of these halls this fact should become quite evident.

In the thirty years the acousticians at Artec have been designing auditoria, we have designed no two halls alike; but each completed hall exhibits adherence to certain acoustical principles. Over these three decades, and continuing today, we have continuously refined design methods as our understanding of acoustical principles has evolved. Sometimes a new hall will include small refinements of the functional acoustical elements developed and proven in earlier designs. Other times, small refinements to acoustical principles such as occur from time to time with the progress of acoustical research, have evolved substantial changes in the acoustical elements and architectural forms of the halls.

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Two of the most important lessons learned empirically between 1950 and 1970, from studies of newly completed rooms and the older European concert halls, may be summarized in these "rules":

1. Adopt a room shape that is rectangular rather than fan-shaped.
2. Adopt narrow, tall room proportions rather than wide, low proportions.

Most of the acoustical research on auditorium acoustics between 1950 and 1970 concerned refinements of reverberation time calculation and discussion of the role of early sound energy in perceived clarity. No study of "early" or "late" energy hints at why room <u>shape</u> should be significant, and why narrow, high rooms would necessarily be better than wide, low ones. At this time then, our empirical observations were viewed by some scientists as mysticisms.

On the other hand, the importance of strong early lateral energy to listener preference offers a compelling explanation for the validity of these "rules". Rectangular rooms, particularly when they are narrow and have soffits on the side walls, can provide strong lateral energy.

In recent years, research in acoustics has offered some confirmation and clarification of our empirical observations, and has permitted us to refine design concepts and derive new acoustical designs for rooms. In our everyday practical applications of acoustics we have found much of value in the research concerning lateral sound energy, particularly that done and reported by Doctors Marshall, Barron, the Gottingen group under Schroeder, and Ando.

We had not understood the importance of lateral energy, <u>per se</u>, at the time we developed the above rules. Now we would perhaps modify them as follows:

1. Adopt a room shape that engenders strong lateral energy.

2. Adopt narrow, tall room proportions to support multiple lateral reflections.

Our designs for halls in Nottingham and Colorado Springs, which opened in 1882, and the hall in Tampa, which is scheduled to open in 1986, were in part based on the importance of lateral sound energy, and key elements in each room are specifically tailored to the generation of lateral sound. Each hall demonstrates a different architectural solution to the problem.

I hope to illustrate our application of acoustics research through the presentation of some aspects of the acoustical designs of these rooms.

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Pikes Peak Center, Colorado Springs
This hall is a concert/opera hall seating an audience of approximately 1900 for concerts. The plan at stalls level is almost rectangular (in fact there is a slight reverse-fan shape) and the room is fairly narrow (the walls are 27m apart). The second order reflections from the side walls and balcony soffits serve to provide some of the early lateral sound in the main floor area. Other, slightly later, first order reflections arrive from the visually prominent tilted upper side walls/ ceiling panels, which are shaped to direct strong first-order reflections to the main floor areas.

The shaping of the upper side walls was developed after we undertook careful studies in a 1:24 scale model. As we were primarily studying first order reflections, we used a simple modeling technique, with a light source and mirror surfaces. We calculated delay times simply by measuring the direct and reflected path lengths with pieces of string!

The architects for this hall had originally proposed a wide, low, fan-shaped room, and our radically different proposals for this room shape were not accepted immediately. With support from the conductor of the orchestra, our proposals were eventually adopted. The hall has received exceedingly good reviews, by several of the world's top musicians for its excellent acoustics. Whereas almost all new halls seem to receive good reviews for their acoustics when they first open, the good reviews for the Colorado Springs hall are persisting and appear to be well founded.

Royal Concert Hall, Nottingham
Artec's appointment to this project occurred after the building owner had already determined the seat count (2500 seats).

The seat count was set to ensure that the hall would attract and support the lucrative rock music and popular entertainment events. The acoustical requirements of symphony music were to receive no less consideration in the detailed acoustical design, however, but the high seat count had to be accepted from the start.

Severe site restrictions wielded perhaps the strongest control on the plan shape of the Nottingham room: a hall of Colorado Springs' long, narrow proportions simply would not fit on the site. Further, the architect's and theatre consultant's understandable desire for visual intimacy in so large a hall also exerted a significant influence on the general configuration of the audience seating layout. In addition to the constraints on plan size and shape, the height of the roof trusses was also limited by planning permission constraints and exterior light angles.

The acoustical boundaries of the room were, then, somewhat predetermined by non-acoustical constraints. The portion of the design most readily available for acoustical modifications was in the zone between the seats and the roof trusses, and in this area, working with the architects, we developed a complex, shaped ceiling. The ceiling design incorporates production lighting ports, HVAC terminals, house lighting fixtures and adjustable sound-absorbing banners.

The shaping of the ceiling planes, it turned out, was more heavily influenced by the room plan than we had at first expected. Whereas in Colorado Springs we had been able to accommodate ceiling planes that are in plan section quite definitely reverse-fan shaped, the architectural necessity of relating these planes to the plan form of the seating layout restricted the extent to which this was possible in the Nottingham room.

The design of the ceiling was developed, as in the Colorado Springs room, with the aid of light modeling techniques. Perhaps the strongest criticism of this method is that although it has proven adequate for the study of first order reflections, second and higher order reflections are almost impossible to see and to trace.

The surfaces of the room are designed to provide lateral sound arriving from various angles. The angles were selected to satisfy acoustical and practical requirements. Thus there are areas of the hall where listeners receive lateral sound arriving at 45 degrees to the sightline, and other areas where the lateral sound arrives at 90 degrees. We had some concern that sound arriving at 90 degrees would cause unusual image shifts or other deleterious effects, but we observe in the finished building that this is not the case.

The tight site restrictions that dictated many of the room dimensions also made deep balcony overhangs essential from the outset. Some of the wall surfaces in Nottingham are positioned to direct lateral sound into the seating areas beneath the deep balcony areas. We have observed that, compared to many other rooms with deep balcony overhangs, the sound quality in these areas is surprisingly similar to that in the other areas of the room. These areas are served with lateral reflections that arrive almost perpendicular to the listener's sightline to the concert platform.

For listeners seated in the front rows of the balcony areas, the ceiling provides first order reflections arriving approximately ± 45 degrees above and to the side of the listener's sightline.

In the center of the front rows of the top balcony the ceiling provides a strong overhead reflection and the tilted ceiling planes provide strong lateral reflections. A few rows back similar lateral reflections arrive, but without the energy from directly overhead. It is interesting to compare the sound fields in these two locations. Contrary to what the change in the expected lateral to non-lateral energy ratios might indicate, there is almost no discernable difference between the sound heard in the two locations. We have not yet undertaken measurements to find out if there is a measurable difference between the lateral to non-lateral ratios at these locations.

In two other areas of the hall we have consciously provided non-lateral energy to listeners. One area is the concert platform itself, where sound reflected from the overhead canopy assists communication between the musicians. We hear good reports from the musicians who perform there, and the presence of the canopy no doubt contributes to the good hearing conditions.

The canopy is adjustable in height and tilt, so that for small-scale performances such as string quartets or guitar recitals, the canopy can be set at a low elevation, matching more closely the acoustics of a small room. For large-scale performances, with full orchestra, chorus and organ, the canopy can be set to the highest elevation, thereby allowing the sound more direct access to the upper surfaces of the concert room.

In our experience it is far more difficult to adequately serve listeners located near the concert platform than those distant from it. Thus the canopy extends over the first few rows of the audience to provide strong reflected energy to listeners in this area of the main floor. The canopy is designed to keep the sound at the front of the room rather than, as in the Royal Festival Hall, to throw it to the back of the hall.

The unusual shape of the Nottingham canopy comes out of a marriage between our recommendations for a shaping that makes the reflected sound as lateral as possible, and the architect's sculpting of the form to complement the rest of the room.

<u>Festival Hall, Tampa Bay Performing Arts Center</u>
By the begining of the design for the Tampa room, our hall in Kitchener, Ontario, which is in many ways similar to the Colorado Springs hall, had opened and we had listened to more than a dozen concerts in it. Studying this and other halls with strong lateral energy, including as the older European concert halls, helped convince us that lateral sound was playing a very significant role in the acoustical success of a hall.

In our planning for the Tampa room, then, we have set out to achieve even stronger lateral sound. Indeed, the room is designed around that concept, providing as much lateral energy as possible given the large seat count.

Our curiosity concerning the relationships of room shape and lateral energy, particularly that associated with second and higher order reflections, could only be satisfied with a modeling tool more effective than a mirror-surfaced model. To meet this need we had developed a computer program called IMAGES (described in my earlier paper) to trace the paths of reflected sound in arbitrarily shaped (three dimensional) rooms.

With the IMAGES model completed and yielding results, we learned that rectangular shaping of a room should, theoretically, be better for music than fan-shaping of a room. Hardly an earth-shattering result, but it gave us a degree of confidence in the validity of the model. Perhaps the more interesting result from the IMAGES study was that reverse-fan rooms seem to produce even stronger lateral energy than is found in comparable rectangular rooms. This is a much more difficult result to test against observations in existing rooms: the "pure" reverse fan shape is virtually impractical as a room, and no useful examples of this room shape were known to us.

In the design of the Tampa Festival Hall we have used the concept of reverse-fan shaping extensively. In order to achieve a room that will accommodate an audience of over 2500, the reverse fan is implemented as a series of large wall panels varying in plan angle from parallel (0 degrees) near the concert platform through -45 degrees to -60 degrees at the rear.

The refinement of our understanding of the acoustical principles of lateral energy (its importance in listener preference and a practical means of achieving it through room design) have resulted in significant differences between the layout and appearance of this room as compared to rooms we designed earlier.

The concert enclosure to accommodate the orchestra in this multi-purpose hall includes three motorized stage lifts that rise to stage level to form the platform, a "concert wall" (a thick, solid wood fire curtain) that shuts off the entire stage house, a partially coupled reverberation chamber (that encircles the auditorium at high level), and a vertically adjustable acoustical canopy. The overhead canopy is designed to similar acoustical principles as the one in Nottingham, but is larger and has a heavier surface. Because the Tampa room is to accommodate fully staged opera, musical theatre and other lighting intensive events, its canopy contains more performance lighting positions than does the Nottingham canopy.

CONCLUDING REMARKS

One of the ever-present problems facing a concert hall or opera house designer is that between conception of design and the opening of the building there is usually at least five years (although Nottingham was "fast tracked" and opened only three years after the design was finished). If we add to this period the seven years required before critical judgments can really be reliable indicators of acoustical quality, it is at least twelve years between conceptual design and fully valid feedback. In the interim, we must trust judgment born of practical experience, scan the literature for more leads as to what consititutes good acoustics, and also carry out our own research programs.

We try to ensure that each hall we design is the best hall we have ever designed. Thus, through our designs, it is just possible to track the evolution of our theories. However, two halls designed at the same time, such as Colorado Springs and Nottingham, illustrate the extent to which influences other than acoustics can shape the designs of auditoria.

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