Integrated systems

AWARD OF MERIT

Orpheum Theatre acoustical renovation

AERCOUSTICS Engineering Limited — Toronto

Vancouver's beloved Orpheum Theatre was saved from the wrecker's ball in the 1970s, brought up to date and given a permanent orchestra shell. But the home of the Vancouver Symphony remained more of a vaudeville house than a concert hall, at least in terms of acoustics. A long-term renovation project initiated by the Vancouver Civic Theatres to address this problem and others like it at two other theatres is being financed through parking and seat surcharges. Upgrades are thus being completed with no burden on the taxpayer, and no interruption of programs since construction has been carried out in the summer months when the theatres are dark.

This project marked the first complete application of small-scale acoustical modeling in North America and the first time that a Canadian municipality has hired a Canadian acoustician to direct the design of a major concert hall.

A number of problems became evident when AERCOUSTICS Engineering Limited carried out acoustical measurements in 1994 to quantify existing conditions. The most serious and the most difficult to solve was the image shift heard on the balcony. An acoustical phenomenon, image shift occurs when the sound appears to be coming from a location other than its true source. In the Orpheum, singers or soloists appeared to be perched somewhere above the ceiling, making it very difficult if not impossible for conductors to achieve a reliable balance between the sections of the orchestra.

It was suspected that the effect was caused by concave components at the interface of the wall and the ceiling that focused the reflected sound, thus increasing its amplitude. Computer modeling developed by Aercoustics confirmed that reflections coming from these parts of the ceiling were in fact directed to seating areas where image shift occurred.

These cursory indicators pushed existing room-acoustics computer technology to its limits. Existing algorithms cannot accurately predict the acoustical focusing that was at the root of the problem. Analysis of in-situ measurements also indicated that the sound coming directly from the stage was attenuated by wave effects created at the surface of the seats. The focused reflection from the ceiling was not subject to these effects and thus arrived at the listener significantly louder than the direct sound. Again, existing technology has yet to solve the problem of seat-related wave effects.

Fortunately, both focusing and wave effects are easily handled by physical scale modeling. Until recently, acoustical scale modeling was limited to scales no smaller than 1:10. For the Orpheum this would have meant a $300,000 model (consuming nearly half of the entire construction budget for the acoustical fix) as big as a bedroom, hermetically sealed and dried to less than two-per-cent relative humidity. Recent research has allowed for significant size reductions to 1:50. The model used for the Orpheum was about the size of an office desk and cost only $10,000 to build.

In small scale modeling, the impulse-response functions are measured in the model using a 1000-volt ultrasonic spark source and a ⅛-inch microphone. The signal is digitized using a one-megahertz analogue-to-digital converter and then conditioned to compensate for environmental conditions inside the model and the non-uniform frequency characteristics of the spark and microphone. Small scale modeling is based on the fact that the behavior of sound scales up or down perfectly. Wave effects, focusing and the chaotic nature of reverberant sound are all present in the model; computer-based algorithms are used only to correct for the well-known ultrasonic characteristics of air and microphones.

Conversely, computer-based acoustical modeling uses algorithms to describe acoustical phenomena that are not as yet completely understood. In this regard, scale modeling is a useful research tool and has been employed by Aercoustics on several other projects.

The Orpheum model was used first to confirm the existence of image shift and then to fine-tune the solutions. Convex reflectors were hung underneath the offending areas of the model ceiling. Aercoustics commissioned researchers at the National Research Council, who found that the reflection coming from the ceiling must be 0 to -2 decibels with respect to the direct sound, that is, no louder than the sound coming from the stage.

The first convex reflector proposed by the architect did reduce the focused reflection but it was still 7 dB higher than the direct sound. A series of tests were carried out using cardboard drawing tubes, drain pipes and a heat-sensitive plastic that was malleable when hot and quickly hardened to shape when cool. It was determined that an arc radius of 15 feet was required to reduce the reflection to the required 0 dB, a finding that would have been difficult if not impossible to reach without the leading-edge scale-modeling methods Aercoustics employed. The reflectors, fabricated of one-inch plaster, were installed during the summer of 1995.

The impulse-response function contains within it all the necessary information to describe the acoustics of the space. Under ideal conditions the impulse response of a concert hall should look like a Christmas tree turned on its side. The focused reflection that led to the image shift dominates at 50 milliseconds. After the renovation, a measurement at the same location shows the complete eradication of the 50-ms focus and an ideal 'Christmas tree' shape.

Inset: a view of the stage inside the 1:50 plexiglass model.

In the 1970s plastic reflectors were installed above the stage, but their acoustical efficacy was soon questioned and they presented formidable lighting problems. Using state-of-the-art stage-acoustics measurements developed by Aercoustics, it was determined that only half of the reflectors were required. Measurements were confirmed with blind listening tests presented to expert listeners, including members of the Vancouver Symphony. The front row of these reflectors was removed during the renovation.

Acoustics in the seats underneath the balcony were significantly improved by making a subtle adjustment to an existing but disused electro-acoustic system installed in the 1970s on the false assumption that the timing of the very first reflections heard by a listener were of paramount concern (a commonly accepted thesis in North America at the time, it has since been disproved). Moving the system's microphones from in front of the stage to a new location under the balcony resulted in a louder sound underneath the balcony that is more reverberant and spacious where, prior to these modifications, the system used to howl with feedback. The audience seated under the balcony now experiences some of the best acoustics in the house.

The Orpheum's renovated acoustics have been very well received by music-makers and concert-goers alike. Renovation technology has become a growth industry in the 1990s: most major cities have a post-war performing arts centre ripe for renovation. This application of modern engineering solutions, and particularly of small scale modeling, demonstrates a confidence in acoustical design unheard of 25 years ago. The success and practicality of these solutions is encouraging to the firm and to performing-arts groups.