Why Do Traditional Opera Houses Work So Well for Opera?

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Abstract: Most computer models of room acoustics assume geometric acoustics (as if sound behaves like light). This has assisted our understanding of how room shape (fan-shape versus rectangular for example) can affect the acoustics of concert halls. The geometric acoustics model of the traditional opera house is likely to show either a serious sound focussing problem or perhaps only one single reflection – the ceiling reflection. The geometric approach holds little promise for understanding the magic of opera house acoustics. One of the acoustical attributes ignored by the geometric model is edge-diffraction of sound. Our research has shown edge-diffraction to be essential in modeling the acoustics of the traditional opera house. We have developed an acoustics model based on edge diffraction.

Traditional Opera Houses and Concert Hall Forms

The traditional concert hall form is the tall shoebox with one or two side balconies. The acoustical characteristics of a good concert hall include, clarity of music, reverberance, strength and envelopment. These acoustical characteristics can be explained by associating objective attributes (such as early energy levels) to room shape thorough geometric acoustics studies.

Figure 1 shows the typical tessellation produced by a simple geometric acoustics model of a concert hall (Musikvereinsaal, Vienna). Such a model can be used to explain the acoustical characteristics of the early sound field and even the development of diffuse reverberant sound (Cremer, 1).

The IMAGES computer program, developed by Nicholas Edwards, extends this 2D concept into 3D with arbitrarily shaped rooms, and has proven particularly useful for studying concert hall design (Edwards, 2).

The geometric acoustics model is reasonably valid in concert hall design because the wall surfaces are large compared to the wavelengths of interest, and because the diffracted sound from balcony edges is only a small component of the sound field and can perhaps be ignored.

The geometric acoustics model is not valid in traditional European opera house design because the exposed wall surfaces are heavily shaded by the multiple balcony tiers, and as such are relatively small compared to the wavelengths of interest. Also, the diffracted sound from the balcony fronts is a larger (or even the predominant) component of the sound field due to the disposition of the balconies within the space and the relatively small vertical distance between them.

A geometric acoustics model may apparently show that the traditional European opera house room shape cannot work, either because of focussing (see Figure 3) or because of a lack of reflected sound. Clearly, these rooms do work acoustically, and leads to the opinion that the geometrical model is not valid for these rooms because of their inability to properly illustrate the effect of diffraction off of the balcony fronts.
Opera house acoustics are very different from concert hall acoustics. The key differentiation is diffraction at the balcony fronts. Diffraction at balcony fronts is to the opera house acoustic as reflections from walls is to the concert hall acoustic. When a wave front impinges on the balcony fronts, each point on each balcony front becomes a secondary sound source. We used the following basic mathematical principles to develop a new model illustrating diffraction off balcony fronts in a traditional European opera house.

As the speed of sound is constant, the locus of points with equal delay time is the same as the locus of points of equal distance from the source-receiver pair. In a two dimensional representation, the locus would be an ellipse; in three dimensions, the locus is the volume of revolution of an ellipse (Figure 4). By studying where this ellipsoidal volume intersects with the balcony fronts, we can locate where, at any given time, the edge-diffracted sound is coming from (Figure 5).

By illuminating a rendered model using light sources located at these intersections, we can produce a visualization of edge-diffracted sources as brighter areas in a rendering. By repeating this process with a constantly-enlarging ellipsoid and compiling the renderings into a moving image, we can visualize the acoustical process.

We have applied this model to La Scala, and a produced a "movie" is to show how the balcony front edges contribute to the sound that is heard (Figure 6).

Our model is just a beginning step in the process of understanding the acoustics of these specialized building types. We hope that the development of this new model will allow us to correlate the acoustical parameters of great opera house acoustics with the architectural features and basic shaping of these rooms much like the geometric models have helped gain tremendous understanding about concert hall acoustics.

REFERENCES