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 can predict both early and late sound in shoebox-shaped concert halls.

The geometric acoustics model of the traditional opera house is likely to show serious sound focussing problems for early sound and perhaps only one single reflection for the late sound. 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. For the typical source-receiver pair shown here in a virtual La Scala opera house, the sound diffracted via the balcony fronts arrives at the listener over a 40ms period.

Animated color pictures of the diffracted sound and the text of this paper are available from www.acousticdimensions.com/research.htm.

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 tesselation produced by a simple geometric acoustics model of a concert hall (Musikvereinssal, Vienna). Such a model can be used to explain the acoustical characteristics of the early sound field. The development of diffuse reverberant sound can also be predicted in shoebox concert halls using geometric acoustic models (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), see Figure 3.

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 of the early sound (see Figure 4) or because of a lack of reflected sound (see figure 5). 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, as in Figure 6.

The wavefront is of course spherical, and where the spherical wavefront intersects the balcony fronts, the diffracted sound will be generated (see Figure 7).

However, this “universal” view of the acoustic process does not represent *when* the diffracted sound arrives at a *particular* listener. If we consider sound propagation between a source-receiver pair in a two dimensional representation, the locus would be an ellipse (see Figure 8). The envelope of an equal-delay-time solid will thus be an ellipsoid rather than a sphere (see Figures 9).

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 (Figures 10 and 11).

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 (Figure 12). 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 an animation showing how the balcony front edges contribute to the sound that is heard over the first 40ms.

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 an understanding of concert hall acoustics.

REFERENCES

1. Edwards, N, Considering concert acoustics and the shape of rooms, Architectural Record, Aug 1984, pp133-137.
2. Cremer, L, and Müller, H, Principles and Applications of Room Acoustics, Volume 2, Applied Science Publishers Ltd, 1982 ch IV.2 pp22-26
3. Bagenal, H and Wood, A, Planning for Good Acoustics, Methuen & Co Ltd, 1931

Figures

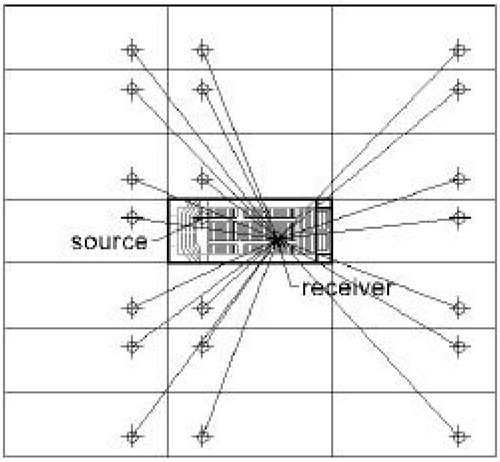

FIGURE 1 Typical Geometric Model of a concert hall showing the tesselation of source locations. Charcteristics of the early and late sound in concert halls can be derived from this type of model.

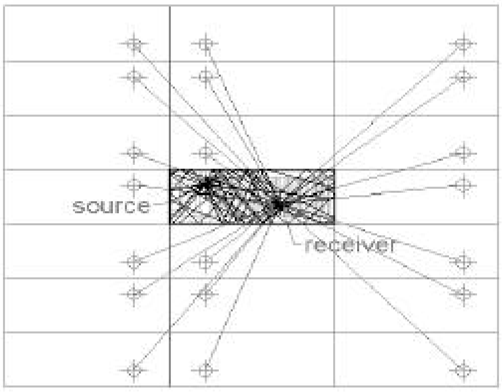

FIGURE 2 Typical geometric sound paths in a concert hall, showing the same source-receiver paths as in Figure 1 but with the sound paths folded within the room boundaries.

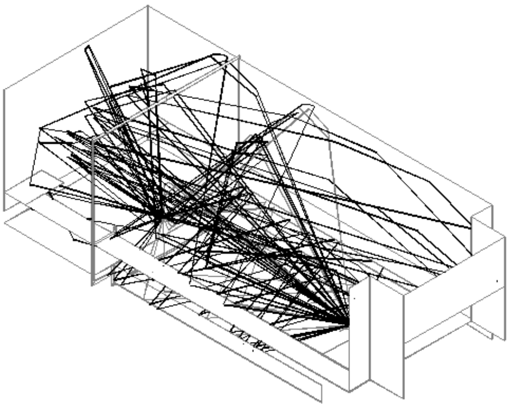

FIGURE 3 Early and late sound energy in a geometric acoustics model of the Musikvereinssaal, predicted using the IMAGES program. Reflections up to sixth order are shown here. Many sound paths (shown in black line) indicate sound arriving more than 80ms after the direct sound.

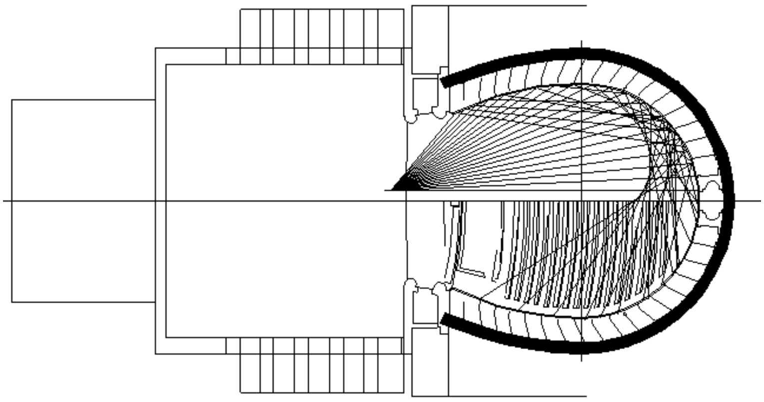

FIGURE 4 Typical geometric sound paths for early sound in an opera house indicate severe focussing.

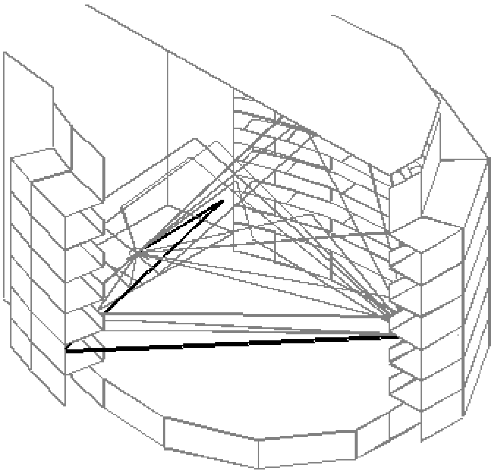

FIGURE 5 Early and late sound energy in a geometric acoustics model of La Scala. Reflections up to sixth order are shown. Only one sound path arriving more than 80ms after the direct sound is found in the model.

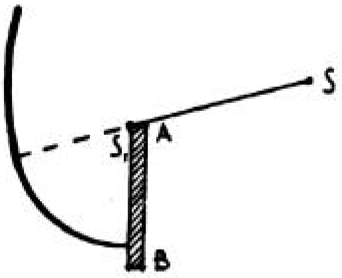

FIGURE 6 The diffracted sound wave propagating from an edge [from Bagenal, 3, p9)

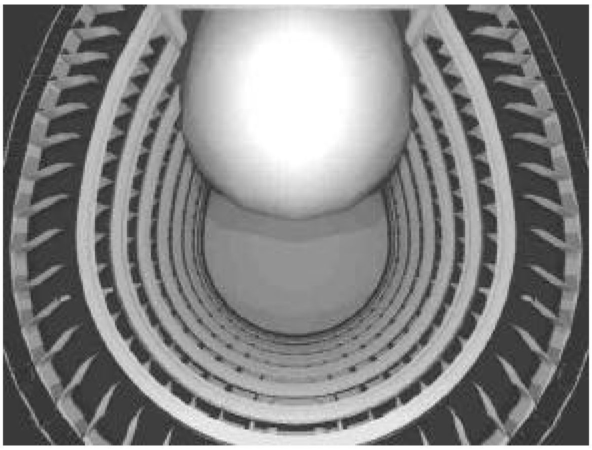

FIGURE 7 The direct sound propagating from the source, represented by a solid spehere. Diffracted sound will be generated where the surface of the sphere intersects the balcony fronts.

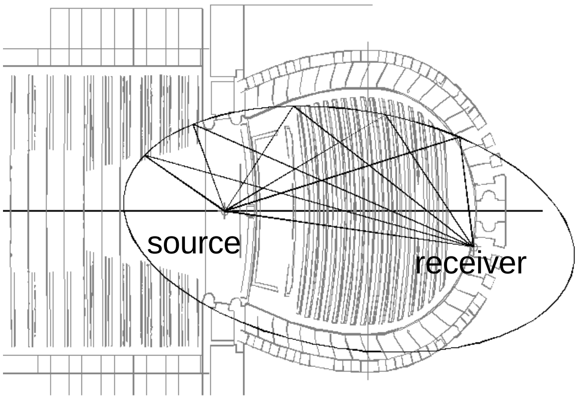

FIGURE 8 Ellipse representing the locus of an equal-delay-time contour. The foci of the ellipse are located at the source and the receiver. In 3D, this becomes an ellipsoid.

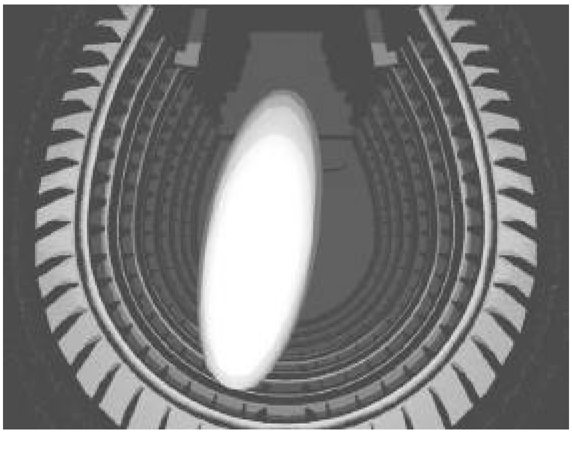

FIGURE 9 The ellipsoids expand from the source-receiver line, with increasing detla T (see animation on www.acousticdimensions.com/research.htm)

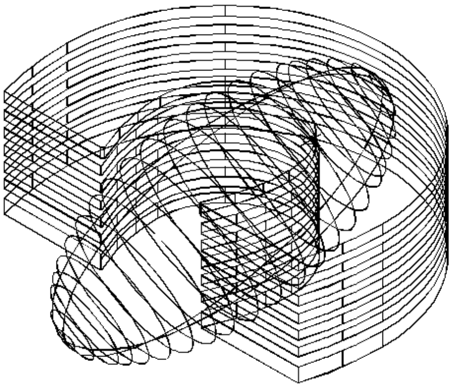

FIGURE 10 Intersection of ellipsoid at balcony fronts identifies the source locations of diffracted sound

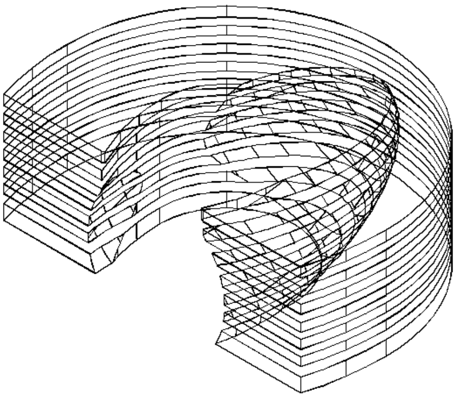

FIGURE 11 The solids subtracted to determine the locations of the Intersection of ellipsoid at balcony fronts.

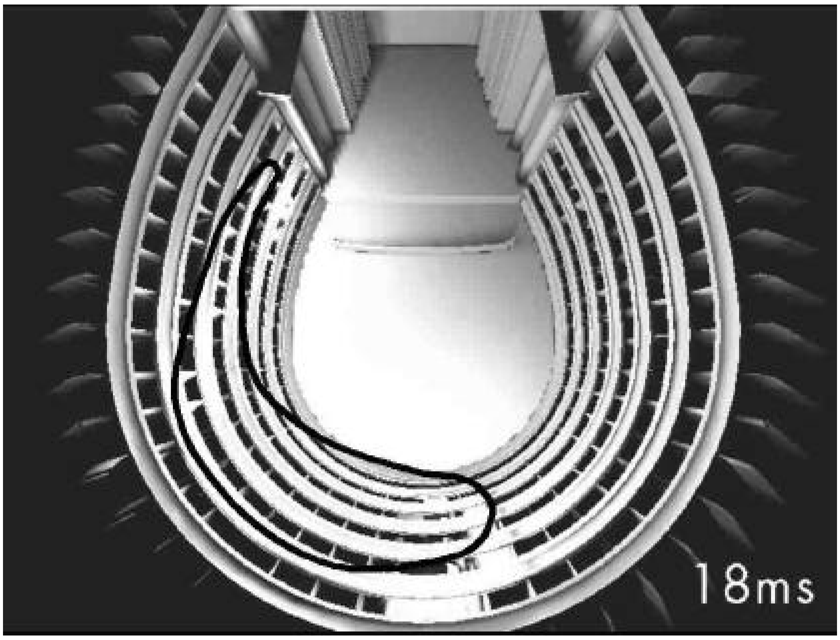

FIGURE 12 The acoustic model is illuminated by light sources located at the intersection points (sketched here with a heavy line). This frame shows location of diffracted sound sources with 18ms delay. The full animation in color is available from www.acousticdimensions.com/research.htm.