The Influence of Simple Room Geometries on Acoustical Parameters

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Introduction

In most rooms the Early Decay Time (EDT) is shorter than the Reverberation Time (RT). This often means that the room does not sound reverberant enough. For acousticians, RT has been the predominant quantifier of sound since it was first developed by Sabine, at the beginning of this century. One reason for this is that it can be easily calculated. If you know the enclosed volume a room and the amount of acoustical absorption, you know the RT. Nothing could be easier!

Unfortunately, things aren't quite that simple. It turns out that the subjective significance of RT is not as important as was originally thought. The EDT is a measure of the early part of the decay, those few fractions of a second that separate musical notes. In the 1960s it was found to correlate much better with the subjective assessment of reverberation.[1] Unfortunately, the only way to predict EDT is with a computer or scale model.

Hypothesis

One possible explanation for the difference between EDT and RT has been suggested by Hodgson[2]. It came about during scale model experiments on the Queen Elizabeth Theatre (QET) in Vancouver. The EDT/RT ratio is very low in the QET. The QET is a bit different from other theatres in that it has a relatively low ceiling. Traditionally, opera houses or concert halls are high and narrow. The QET is flat and wide. When this was pointed out, Hodgson suggested that it might be the reason for its low EDT/RT ratio.

The hypothesis can be explained as follows:

1. A theatre or concert hall, in its simplest form, can be thought of as six sided box with acoustical absorption on only one of the six sides, i.e. the floor.
2. One might expect the early reflected sound (and hence the EDT) to be influenced by the sides of the box that are closest to each other. In a narrow shoe box shaped room, this would be the two non-absorbent side walls.
3. In a flat and wide room like the QET, the closest pair of sides is the ceiling and the floor. The latter, of course, is the only acoustically absorbent surface in the "box".

Experimental Procedure

To test this hypothesis, a number of experiments have been performed using computer models of six sided shoe box and fan shaped rooms. In all cases the floors and ceilings were flat, the acoustical absorption was limited to the floor and the rooms were 40 m in length. The height of the rooms was varied from 1/8th of the width to twice the width. Two room widths were tested, 20 m and 40 m. The angles of the fan shaped rooms were 8.5° and 16.7° for the 20 m and 40 m rooms respectively. Calculations were performed at five receiver locations in each of the four computer models. A single source location was used, situated at the front of the room, stage left of the centre line. The computer program employed for the experiments was CATT Acoustic Version 7. The method of images algorithm was set to 5th order with a truncation time of 300 ms and diffuse reflections commencing after the 1st order. The ray tracing algorithm was set to 12,000 rays and a truncation time of 6000 ms.

Early Decay Times

The computer model studies confirm the hypothesis. Please see Figure 1. For both the shoe box shaped and fan shaped rooms, the height to width ratio has a strong influence on the EDT/RT ratio. For height to width ratios greater than 1.0, the EDT/RT ratio is perfectly efficient, i.e. there is no compromise in Early Decay Time for a given Reverberation Time. If the height to width ratio is less than 1.0 there is a degradation of the Early Decay Time and hence the perceived reverberance in the room.

An interesting aspect of Figure 1 is that there appears to be no difference between shoebox and fan shaped rooms. This is intriguing because in most other acoustical aspects, the shoebox shaped format is superior to a fan shape. Indeed, measurements in existing auditoria have demonstrated low EDT/RT ratios in fan shaped rooms. The explanation for this apparent discrepancy is found in the geometry of the fan shaped format. Unlike our computer model, actual fan shaped auditoria have sloped floors and ceilings. The reality of the format is that the majority of seats are at the back of the room and, hence, closer to the ceiling. The effective height to width ratio for a fan shaped room is therefore quite low. For example, the Hummingbird Centre in Toronto has a height to width ratio of 0.24 (when measured in individual seats). Compare this to the 0.38 on the orchestra level of the QET (measured in individual seats) and 0.88 in the tall and narrow Musikvereinssaal in Vienna (gross average).

The Effect Of Balconies and Side Wall Boxes

These findings prompted three further computer model experiments. In the experiments, two levels of balconies and side wall boxes were introduced into the standard six sided shoebox room, i.e. 40 x 20 x 20 m (l-w-h). The balconies were 3 m deep and were wrapped around the two side walls and the wall opposite the stage.

In the first experiment, the vertical distances between the two balconies was varied from 3 to 7 m. Merely introducing these shallow balconies into the shoebox shaped model reduced the EDT/RT ratio by almost 30%. Contrary to received wisdom, the height between balconies had little influence on the measured acoustics. Parameters that were investigated included RT, EDT, Strength, 80ms Clarity, Early Lateral Fraction and the EDT/RT ratio.

In the second part of the balcony experiments, the importance of the facia height was examined. In the experiment the first balcony was 5 m above the orchestra level and second was another 5 m above that. The height of facia was varied from 0 m (i.e. no facia) to 4.5 m. It turns out that facia height may have a marginal effect on the EDT/RT ratio. The EDT/RT ratio is in the range of 65% for facia heights less than 1.0 metre. A larger facia, for example 2 metres or higher, results in a ratio of 70% to 74%, an improvement of almost ten percent. Difference limen for Reverberance are thought to be in the range of 0.1 seconds.[3]

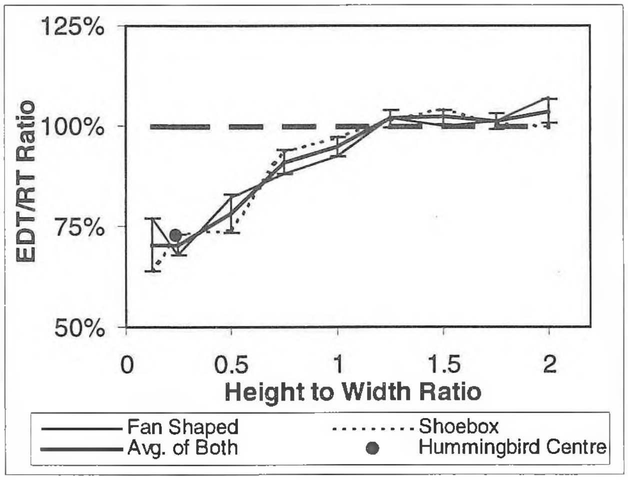

Figure 1 EDT/RT versus Height/Width Ratio.

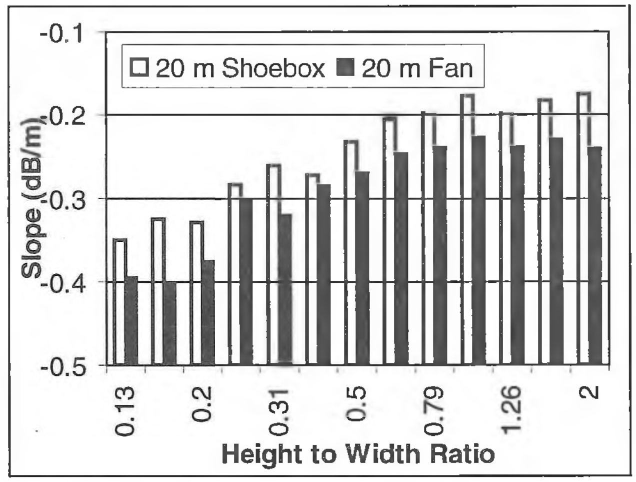

Figure 2 Slope of Strength versus Height/Width Ratio.

In the last of the three experiments in this series, the depth of the balcony overhang investigated. As before experiments were performed in both the 20 m and 40 m wide shoebox shaped rooms. In both cases the rooms were 20 m high and 40 m long. The depth of the overhang ranged from 1 to 8 m in the 20 m wide room and 2 to 16 m in the 40 m wide room. As expected, the EDT/RT ratio is reduced significantly as the overhang is increased.

Clarity

The balconies and boxes increase Clarity quite a bit. In the 20 m wide shoebox shaped room, Clarity is about 0 dB without the boxes. Introducing boxes on the side walls increases the Clarity by approximately 3 dB. The difference limen for Clarity is 0.67 dB[4]. A change in Clarity of 3 dB - more than four times the minimum noticeable difference - would surely be heard by audience members.

The explanation for the increased clarity proves interesting. Acoustical Clarity is a simple ratio of early to late reflected sound. One might expect that the reason for increased Clarity is because the side wall boxes provide stronger early sound to the listeners. The computer model study suggests otherwise. When balconies are introduced into the 40 m wide shoebox the strength of the early reflected sound remains essentially the same, regardless of the height of the balconies. In a 20 m wide room, the early energy goes up slightly, about 1.0 dB. However, in both rooms, the late reflected energy is reduced by approximately 3 dB when the balconies are added. Once again, the vertical distance between balconies does not appear to influence late reflected sound. In other words, contrary to expectations, Clarity is increased not by stronger early reflected sound but by weaker late reflected sound.

Strength

Measurements in the 1980s established that acoustic Strength decreases towards the back of a hall and that the rate of decrease is in the range of 0.1 to 0.2 dB/m[5,6]. Some room shapes, for example, a fan shape, tended to have higher rates of decrease.

These computer based experiments confirm that finding. Figure 2 shows the slope of Strength versus the Height to Width ratio predicted in the six sided boxes without balconies. The solid bars represent the fan shaped room and they can be seen to be consistently lower than the shoe-box shaped room. Note however that the Height to Width ratio of the room has a greater effect on Strength than its shape in Plan.

Wall and Floor Angles

Starting with a 40x20x20 m box (without balconies), the angle of the side walls and floor were varied systematically; in Plan and Section respectively. Increasing the side wall angle from a shoebox shape to a very broad 36° fan had the anticipated effect on parameters like Strength and Early Decay Time, both of which were lower than statistical calculations. The Early Lateral Fraction, of course, was found to decrease as the angle of the side walls increased. Interestingly, the EDT/RT ratio is effected more by the angle of the floor than by the angle of the side walls. This suggests again that the shape of a room in Section is as important as its shape in Plan.

Acknowledgements

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