Proceedings of The Institute of Acoustics

THE ACOUSTICAL DESIGN OF WELLINGTON TOWN HALL: DESIGN ORIGINS, RESEARCH REVIEW AND ACOUSTICAL OBJECTIVES.

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INTRODUCTION

This paper is a review of more than 6 years of effort by a large team of people in the field of Architectural Acoustics. All of this effort has been directed toward achieving conditions of acoustical excellence for the patrons and performers in the new 2800 seat Town Hall which is now approaching completion in Wellington, the capital city of New Zealand.

The review is inevitably selective rather than comprehensive with the emphasis on research aspects of the work and on the Room Acoustics rather than noise control which comprises at least half of the consulting effort. The subject of electro-acoustics will also be omitted along with a discussion of the performers' acoustical environment although these have of course occupied our attention.

ORIGINS OF THE ACOUSTICAL DESIGN

Architectural

We have been involved, as members of the design team, since the inception of the project in 1975. Our starting point was the adoption by the architects of essentially the same form as the Christchurch Town Hall because as they wrote in their design report:

> **"the success of the arena shape has been proven in the Christchurch Town Hall beyond all doubt"**

Christchurch Town Hall is also, from the acoustical viewpoint, the first hall of the "directed reflection sequence" (DRS) type in which the early reflection sequence is controlled by large interior surfaces, independent of the boundaries of the reverberant volume. This concept was also implied in the architect's choice of the form. There is today, in comparison with 1966 when Christchurch started, a large body of research underlying the acoustical design of concert halls of this type.

Research on Lateral Reflections

Following the Philharmonic difficulty in New York, during the late 1960's, there was a growing awareness of the great importance of the direction of early reflections of music in subjective evaluation of concert spaces. Marshall's own contribution in 1966-68 (1,2) in discovering the overriding importance of lateral reflections, was necessitated by his role as consultant for the Christchurch Town Hall when the body of existing acoustical wisdom had been shown to be wanting. Tentatively at first, but with growing confidence as the research came to fruitation in the succeeding years, the weight of concensus has moved toward the view implemented in the Christchurch design. We now know a great deal about the subjective effects of lateral reflections of music.

Following work done by Seraphim (3), Marshall extended the idea to music and postulated that the general masking effects found by Seraphim might be applicable to music reflections. At about the same time, Schubert (4) was studying the masking of delayed music signals. He found that the masking threshold level for lateral sound is about 10 dB lower than it is for frontal reflections.

Keet and Lochner (5) related the apparent broadening of the sound source to "the amplitude and time differences in the echo patterns at the two ears". Later, Keet (6) related this source broadening effect as an important aspect of music quality in halls and reported the results of experiments on the subjective measurement of Apparent Source Width (ASW). Keet found a linear relationship between the subjective ASW and $1-K_{0}^{50}$, the incoherent lateral energy fraction which is an interaural cross-correlation effect. His test results also showed the well known effect of increasing ASW or spatial impression with increasing source sound level.

Perhaps the most comprehensive study on lateral energy and acoustical quality is contained in the work of M.F.E. Barron (7, 8) which dealt with, in part, the masking of orchestral sound in lateral reflections, effects of arrival direction, and the quantitative prediction of "Spatial Impression" (SI) which can be called the subjective correlate of lateral reflections.

A summary of some of Barron's findings include the following: A) A confirmation of Schubert's masking threshold levels and observation of the predominance of tonal colouration for delays in the 10-30 msec. range, B) Subjective constancy of SI measured as a function of a single delay time, and importantly, C) establishment of a clear direct relationship between SI and the lateral to non-lateral early sound. It was found that the derived relationship between SI and Keet's $1-K_{0}^{50}$ is linear showing that the degree of incoherence of a signal is a linear measure of the degree of spatial impression.

Veneklasen and Hyde (9) approached the question more positively, by allowing subjects listening to music in a synthetic sound field to adjust the relative amounts of lateral and frontal energy to what they preferred. They found a preference for early lateral sound levels in the range of -4dB to +1db relative to the full direct level for a range of symphonic motifs. They also observed Keet's finding that the sense of envelopment in the sound increases with loudness for a given lateral energy ratio.

It is also worth noting that there is an anomalous bass enhancement in sound fields with high lateral reflected energy - a factor noted in Marshall's initial paper in 1966.

Subjective Preference Studies by Factor Analysis

In the early 70's Schroeder Gottlob & Siebrasse put the question of audience preference on a scientific footing. Using head-oriented sterophony and factor analysis, they identified the factors on which concert hall audience preference depends and correlated these with the physical characteristics of the sound fields in various halls. The work is deservedly famous. It revealed that reverberation and what has subsequently been called "binaural dissimilarity" have approximately equal weight in determining preference for concert hall sound. Preferred sound fields contain significant interaural differences - and that, of course, is precisely what lateral reflections do. A limitation of this work was that loudness was eliminated as a factor in the trials - the comparisons were made at a uniform level, and in real concert halls that is not the case. Work at Berlin by Wilkins (11) subsequently showed that both loudness and clarity are also both highly desired, but in our view, not at the expense of other preferred qualities. Both research groups determined the importance of reverberation level as well as reverberation time (RT).

Progressive Priorities

We can pull all this research together into a "progressive priority" of factors for audience preference - a useful concept which arose in discussions with Dieter Gottlob. The underlying priorities must be satisfied to within some "interval of indifference" before the overlying elements are significant in preference.

The foundation for the progression is Loudness which of course bears a close relationship with the subsequent major factors. Loudness is assured by the combination of sufficient early sound energy and reverberant field energy. Since in a DRS hall, the early energy levels are higher than would occur in a "statistical" enclosure (where the volume boundaries provide the major early reflections), the need for concomitantly high reverberant sound levels become critical.

The RT is seen as not having an optimal value, but rather finds its indifference interval in the 1.8 sec. to 2.2 sec. range. Obtaining an RT in the desired range must occur by placing emphasis on reverberation efficiency in the design, since an increased volume reduces the reverberant level especially important to the DRS hall.

Spatial impression from early lateral reflections enhances the experience of involvement and base response while contributing to loudness. Clarity is an obvious quality which relates directly to the early energy contributing to loudness. The factors, indeed have a complexity of relationship which comes down to two basic physical entities: A) a dense early reflection sequence, a good portion of which is out of the median plane of the listener, and B) a space with high reverberation efficiency.

Realization of Clarity in additon to the other factors in large volumes, as far as we are aware, is only possible in halls of the DRS type such as Christchurch and Wellington, and gives musical sound in them an unique and thrilling quality.

SPECIFIC DESIGN OBJECTIVES & THEIR REALISATION

Finally, we will summarise the design objectives we had in 1976. While these have been refined in various ways, in essentials they have remained our objectives.

A. General Objective: To maintain the combination of Spatial Impression, Reverberance and Clarity exhibited by the Christchurch Town Hall. (This objective is achieved by a moderately large, acoustically efficient volume (22,700 m^3), and the provision of a rich pattern of early lateral reflections from large surfaces independent of the room boundaries.)

B. Provide integrated lateral reflected energy at a level between 0 and -7dB relative to integrated frontal energy; the delay of all lateral reflections must exceed 10 msec.; multiple lateral reflections are preferred to single specular reflections. (This is accomplished, primarily, by an array of suspended reflectors along each side of the hall above the galleries. These are linear quadratic residue diffusers providing multiple reflections for a majority of seats in the hall.)

C. Provide a smooth reverberation time characteristic in excess of 2 seconds from 500 to 2000 Hz and increasing significantly at low frequencies.

D. Provide reverberant coupling from behind the main longitudinal reflector and the gallery seating to the seats below.

E. Provide excellent conditions on stage for ensemble and balance.

F. Reduce audience interaction with direct sound and reflections at grazing incidence.

G. Freedom from echo and noise.

The companion paper at these proceedings discusses the design development and model results for the hall.

REFERENCES

1. A H Marshall, J Sound Vib, 5, p 100-112 (1967). A note on the importance of room cross section in concert halls.
2. A H Marshall, J Sound vib 7, 116-118 (1968). Levels of reflection masking in concert halls.
3. H P Seraphim, 1961 Acustica 11, 86-97. Uber die Wahrnebarkeit mehrer Rückwürfe von Sprachschall.
4. P Schubert, 1966 Tech. MRFZ, Berlin 10, 124-127. Unbersuchaingen über die Wahrnehmbarkeit von Einzelrückwürfen bei Music
5. J P A Lochner & W. de V Keet, J. Acoust - Soc. Am, 32, 393 (1960). Stereophonic and Quasi Stereophonic Reproduction.
6. W de V Keet, Proc. 6th ICA, Tokyo, E-2-4 (1968). The influence of early reflections on the spatial impression.
7. M F E Barron, PhD thesis, University of Southampton, (1974). The effects of early reflections on subjective acoustic quality in concert halls.
8. M F E Barron, J Sound Vib 15,475 (1971). The subjective effects on first reflections in concert halls.
9. P S Veneklasen & J R Hyde, J Acoust. Soc. Am. 46,97 (1969). Auditorium Synthesis - Early Results of Listener Preference.
10. M R Schroeder, D Gottlob & K F Siebrasse, J Acoust Soc Am 56 1195-1201 (1974). Comparative study of European concert halls: correlation of subjective preference with geometric and acoustic parameters.
11. H Wilkens, Acustica 38, 10-23 (1977). Mehrdimensionale Beschriebung subjectiver Beurteilungen der Akustik von Konzertsälen.