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THE ACOUSTICAL DESIGN OF CONCERT HALLS

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INTRODUCTION

On April 17th this year, an article appeared in the Sunday Times in London about remedial work to be undertaken at the Barbican Concert Hall. The same article has subsequently appeared in the Melbourne Age (in the context of the Victoria Art Centre) and I have little doubt that it will appear in due course in the Dominion, Wellington's morning paper, following the opening of Wellington Town Hall next month. This suggests that it said something about concert hall design which conformed fairly well with the general public view both of these expensive facilities and the state of the art in concert hall acoustics.

Heavy type picked out quotes from two of my distinguished colleagues: "Acoustics is an art, not a science, much of it is guesswork", "We are all amateurs ...". Is there a reluctance here to accept professional responsibility for the advice we give as acousticians? The issues implied are so central to the credibility of acousticians, and I must say so much at variance with my own attitude, that I have chosen to address them in this talk under the general heading "Concert Hall Acoustics - Science and Art?"

I would like to make some general observations first, then give a brief synopsis of the development of concert hall design as I see it, and finally illustrate some of the points with examples from some of the halls I've been associated with.

SCIENTISTS, ENGINEERS AND DESIGNERS

I suspect that acquiescence in the views expressed in the quoted headlines arises in part from lack of clarity about the professional preoccupations of the diverse people involved in the design of concert halls.

The scientist is preoccupied with the exercise of his/her skills, be they theoretical or experimental. In the context of concert halls this process issues in measurements of known accuracy on sound fields in rooms, and on the populations that hear them. This work establishes principles, fills out our base of underlying knowledge, assures us of the validity of our perceptions and by quantifying the physical properties of the sound fields, provides the means for defining objectives, predicting results and testing completed works. Either real or imagined spaces are a prerequisite for these activities which are not a priori design orientated. Nevertheless scientific work provides the only secure basis for advances in design.

The engineer makes a virtue of compromise - in fact engineers are fond of saying that 'design is compromise'. This view arises from the fact that most engineering problems are linear - they can be reduced to managable pieces without losing the essential characteristics of the problem. Solve one piece after another add them together (with appropriate compromises) and you have a design. Global concerns such as the 'feel of the space', the relationship of audience and performers' and so on are not amenable to this process, yet these are the architectural springs from which to design flows. They include of course an acoustical dimension and there are multiple solutions. Engineering training, at least in New Zealand, does not equip people with these skills. The power of engineering skills which have proved so spectacularly successful in this century, cannot be brought to bear until there is an outline design for them to bear upon -a concept. The architect/designer is primarily concerned, at the conceptual stage with the global issues. Design for him/her is not based on 'compromise' but on a reality which includes both knowledge and imagination. In the welter of competing information generated by a building design project it is essential that the designer's knowledge gets sorted into an appropriate hierarchy of relevance. The design process demands that decisions are made at a rate which appalls the scientist and on an unquantified basis which may sometimes appear arbitrary to the engineer. Indeed sometimes it is arbitrary! But arbitrary decisions in the context of a specialised building such as a concert hall lead to acoustical disasters. Somehow the acoustical input must achieve a high priority in the hierarchy of relevance to the design. But how?.. Certainly not by formulae. The designer depends upon his experience in sorting his priorities. It is essential to extend the designer's experience by demonstrations of the acoustical objectives to be encompassed by the design. In other words, a high level of communication is essential between acoustician and designer and one way this can be achieved is in the context of shared auditory experience.

These sketches are of course caricatures. The design process is iterative rather than one-shot, and the respective roles are not unidimensional. A number of us, from time to time, have filled all of the roles outlined, in our work as acousticians. What is clear however, is that acoustical design problems require design skills.

In this sense acoustical design is as clearly an art as is any design. Acoustics on the other hand is the science from which the designer's knowledge is distilled. Perhaps this goes some way toward clarifying the first quote. The terms "guesswork" and "amateur" are, in my opinion, inappropriate descriptions of a professional design activity, while denial of the scientific nature of the underlying research does a substantial disservice to a very considerable body of unimpeachable work.

SYNOPTIC VIEW

I mentioned that the Sunday Times article seemed to reflect a common view of concert halls and acousticians. How can we account for the numerous shortcomings of halls which have been designed during the past 80 years or so? Is our present state any better than that of the 50s and 60s? Among the difficult questions I get asked is "How does it come about that the Grosser Musikvereinsaal has perfect acoustics - without an acoustician?" I generally respond that it was a fluke.

Nevertheless it is a good place to start a synoptic view because as the slides show, this space is far more than an exercise in acoustics. You can clearly see the importance of the architectural global issues I mentioned, to the communication taking place between musicians and audience here. In some cases - I'm thinking of the Albert Hall - the architectural advantages of the form - the arena - have actually outweighed the acoustical difficulties. Attention to these relationships will always be of the utmost relevance in a communication space.

Coming closer to our own age I discern a marked change of emphasis in acoustical preoccupations since the mid 50s. Prior to that time, research emphasis had been strongly oriented toward the physical properties of sound fields - from Sabine through to Bolt and Doak, Kuttruffand Schroeder. Progressively since then attention has focussed on people - on the way human binaural hearing processes reflections, and on measurements of audience preference.

In the preceeding 60 years or so only one result seemed to be applicable to concert hall design - the classical reverberation time formula and its derivatives. With good reason there has been a growing disenchantment with it inspite of numerous modifications, both theoretical and in the case of Kosten and Beranek, pragmatic. In my view many of the shortcomings in concert hall design are attributable to the dominance of the reverberation time formula this century. In the first place it predicts a quantity that has little to do with human hearing. 60 dB of decay is arbitrary and even measured RT is a poor predictor of subjective reverberance. This point was driven home by Schroeder's experiments in the 60s which gave us

EDT as a more appropriate measure.

In the second place calculated RT is only reliable where the absorbing power of the audience has been measured in the field for halls of similar shape - the pragmatism of Kosten and Beranek mentioned a moment ago. Our calculation of the RT for Christchurch Town Hall was 20-30% wrong at mid and high frequencies because there was no precedent for that room configuration. Wellington Town Hall using the pragmatic approach - with measured absorption coefficients from Christchurch - is closer.

The third point is more subtly damaging. Since the classical RT formula takes no account of room shape, there is no way in which an acoustician could present arguments which were significant to a designing architect - arguments which compared for example, with the imperatives for excellent sightlines, more seats, greater comfort and so on. Acoustics thus had a low position in the designer's hierarchy of relevance, not because it was unimportant but because reverberant control could occur in <u>any</u> room shape. "Acoustical consultation" was seen (and still is in some quarters) as a matter of tricking up the reverberation time by fiddling about within an arbitrary room shape.

A direct result was the emergence of halls which are universally disliked - the broad low ceilinged fans, and a second was the now virtually universal belief that large multipurpose spaces were not possible without a serious compromise of one or more of their functions; such spaces were inevitably fan-shaped from a slightline requirement.

Frankly I am astounded that there are still major concert halls being built today in which the principal design criterion is reverberation time and its derivatives. It is a view which gives scant regard to the research of the past 25 years on reflections and audience preference.

From the 60s to the present, our understanding of the significance of early reflections has developed greatly. This research was driven by the failure of the NY Philharmonic Hall, and for me personally, by the revelation that concert hall design was, in the mid 60s, devoid of reliable acoustical design guides. This led me to the perception that early lateral reflections played a crucial role in the subjective appreciation of concert halls. It shifts the emphasis from reverberation time to control of the early reflections sequence.

The advantages of the new approach, to the designer, are profound. Since the early reflections depend directly on the disposition of surfaces in the space the relevance of the acoustical input to the design is immediately established. It is easy to simulate the effect of early reflections and so convince the architect to try for a spatial form to produce the preferred sound. Architects in my experience are quick to realise the potential of the new design rationale.

The larger the hall, of course, the less scope there is, as a matter of simple geometry, to seat people in correct relationship to reflectors. For 1000 - 1200 seats the room shape is far less critical than for 2500 - 3000 seats. The physical correlates of the subjective effects sought have been formulated and measured, and the factors which constitute to audience preference identified.

PROGRESSIVE PRIORITY

In the early 70s Schroeder, Gottlob and Siebrasse put the question of audience preference on a scientific footing. Using head orientated stereophony and factor analysis, they identified the factors on which concert hall preference depends and correlated these with the physical characteristics of the sound fields in various halls. The work is deservedly famous. It revealed inter alia that the lateral reflections hypothesis was correct and of comparable weight with reverberance. A limitation of this work was the elimination of loudness as a factor in the trials - the comparisons were made at uniform levels unlike the real hall situation, and the inference was drawn that 'clarity' is unpreferred. Work at Berlin subsequently showed both that loudness is an essential dimension and that clarity is preferred, but not at the expense of the other factors.

I have found the concept 'progressive priority' useful in pulling all this together. The slide shows the 4 factors on which our design objectives are based. In contributions made at the 103rd meeting of the Acoustical Society of America in April 1983, Professor Lothat Cremmer, Dr. Yoichi Ando and I were unanimous about three of the four factors: loudness, envelopment and clarity. For the fourth, Cremer offered timbre I offered reverberance and Ando offered the initial time delay for the first reflection, in terms of the autocorrelation function of the music concerned. This means distances to reflectors which vary with the music - not easily achieved in the real world.

Practically, realisation of clarity in addition to the other factors in large halls is only possible by directing the early reflection sequence as has been done at Christchurch and Wellington Town Halls, and more recently in the design for the Orange County Centre for the Performing Arts.

My address concludes with a brief account of the process involved in each of these halls, comprising as it must, the art of design, the engineering of the means for achieving the design and the underlying research.

CHRISTCHURCH TOWN HALL

2650 seats, Architects Warren and Mahoney, Acousticians A. Harold Marshall, Engineering Design Consultants.

* This hall has now been opened for more than 10 years - it is wearing well. There is a strong expression of architectural intention in the arena relationship between audience and performing area. This intention is strengthened by the form of the principal acoustical reflectors implicit in the architect's conception and willingly included in the developed design. Technical details of the design process and results have been fully published.
* The project illustrates the way in which an innovative design outstrips research. My hypothesis about the significance of reflection masking was supported by only <u>one</u> data point (10 ms delay) in a paper by Somerville, Gilford Spring and Negus. Five years later when the hall was opened the importance of lateral reflections had gained considerable currency and the PhDs of Barron, Gottlob and Siebrasse were well underway. It is a matter of record that the research has by and large supported the design idea.
* A new research effort was sparked off by the ensemble difficulties encountered on such an open stage and this has led to the design and installation of an orchestral reflector and a further PhD study in Denmark. The requirements for ease of ensemble are now understood. It is worth noting that the need for the reflector design led to the hypotheses which were tested experimentally. By the time the experiments were over, the reflector was installed.
* The unexpected clarity (due to a high early energy fraction) in a long reverberation time (2.7 sec empty), both points up the weak dependence of clarity on RT and suggests the possibility of truly multipurpose halls, so long as the early reflections can be controlled and directed. The sound in this hall is loud, clear, enveloping and reverberant.

WELLINGTON TOWN HALL

2600 seats; Architects Warren & Mahoney; Acousticians A Harold Marshall and Jerald R. Hyde.
* This hall has the same basic concept as Christchurch Town Hall. The design was started in 1975 and the official opening is due next month.
* Close collaboration has taken place with the architects from the start.
* The design includes the results of the research on lateral reflections carried out by Barron during the intervening years.
* Specifically improvements in the delay of the principal reflections and correction of occasional false localisation noticed in seats too close to the main reflectors in Christchurch has been sought in the design of the reflectors and their diffusing surfaces. Full accounts of the design basis have been published. Improvements in reverberant coupling have been sought. Ensemble requirements have been provided for by stage reflectors.
* Diffusion is provided by the first use of the Quadratic Residence sequence surfaces as suggested by Schroeder.
* 1/10 scale model studies both objective and subjective, were carried

out and additional sundry surfaces were subsequently added. The QRD surfaces were found to produce audible backscattering of the high frequencies for high angles of incidence and were modified accordingly.
*The model study was necessitated by the limits of knowledge and predictive techniques.

ORANGE COUNTY CENTRE FOR THE PERFORMING ARTS

3000 seats; Architects Caudill, Rowlett, Scott and the Blurock partnership; Acousticians: JVAC (Paoletti Lewitz Associates, Jerald R Hyde and Marshall Day Associates).
*This is a multi-purpose space which seeks to apply the Christchurch experience in a proscenium hall. The brief calls for opera, symphony and (reinforced) drama and musical theatre.
*Acousticians actively involved in the "design squatter sessions" at the site and actually led the design team in the conceptualisation of the space.
*Symmetrical visual requirement of uncompromised stage sightlines leads to fan shaped hall.
*Asymetrical subdivision of the audience to provide each seating level with correct reflection sequences within the overall symmetry of the fan.
*Adjustable proscenium and elaborate orchestral enclosure essential for orchestral function.
* 1/10 scale model study necessitated by the innovative design for this multi-purpose function.

CONCLUSION

In this paper I have addressed the question of acoustical design, how much an art, how much science. I conclude, as I said earlier that to the extent that the process is design it is an art, but it is an art utterly dependent on the Science of Acoustics to provide systematic answers to the questions that good design inevitably raises.

Browning wrote 'Ah! a man's reach should exceed his grasp or what's a heaven for?'
We might well ask ' .... or what's science for?

PROGRESSIVE PRIORITY SUBJECTIVE FACTORS	ARCHITECTURAL CONSEQUENCES	OBJECTIVE PARAMETERS	DEFINITION	DESIRED RANGE
LOUDNESS ↓	*Room volume not too large *Proximity to source *Rake seating planes *Integrated early reflections		Total energy referred to direct level at 10m dB	> +2dB
SPATIAL IMPRESSION ↓	*Narrow halls rather than wide *Provide early lateral reflections *Surround each seating layer with reflectors *Subdivide audience *Reverse splay walls *Reflections not at grazing incidence *de-emphasise ceiling reflections	Early lateral Energy Fraction Interaural cross-correlation coefficient	$L = \sum_{5\ \mathrm{msec}}^{80\ \mathrm{msec}} r \cdot \cos\theta / \sum_{0}^{80\ \mathrm{msec}} r$ $K_{\Delta t} = \int_0^t p_1(t) \cdot p_2(t)\,dt \Big/ \sqrt{\int_0^t p_1^2(t)\,dt \cdot \int_0^t p_2^2(t)\,dt}$	> .15 Low value
CLARITY ↓	*Plentiful early reflections *No echo *Moderate reverberance	Klarheitsmass	$C = 10 \log \left\{ \int_0^{80\ \mathrm{msec}} p^2(t)\,dt \Big/ \int_{80\ \mathrm{msec}}^{\infty} p^2(t)\,dt \right\}$ dB	> 0 dB
REVERBERANCE	*Adequate volume *Controlled absorption	Classical RT EDT	$T_{60} = \frac{.16\ V}{A}$ Time for 60 dB of decay	1.6. - 2.2 sec

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00. GENERAL

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