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THE APPLICATION OF AUDITORIA MODELLING TO SOME PROJECTS

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In the past we carried out limited prediction on room acoustics, initial calculations then spreadsheet calculations, supplemented where time and research would allow by a geometric ray-tracing scale model. An example is a new theatre, The Swan, at High Wycombe. The limited commissioning allowed by our consultancy agreement there did not highlight significant deviation from predictions. In any case, the inclusion of an electroacoustics system with its ability to alter the natural acoustic by preset steps, permitted the music parameters to be achieved by other means. However, we found physical model prediction cumbersome, expensive and unable to change apace with the architectural design of the auditorium (for example, the seat rakes and rear wall radii were changed several times).

Large-scale physical models at 1:10 scale and smaller ones at 1:50 remain the most accurate means of examining the most prestigious major halls, and research by Kleiner (1), Lam (2) and others has involved validation of physical and computer modelling against measured data.

This paper reviews our experience of using principally one system, ODEON, for rudimentary modelling on a range of projects. Each project would deserve its own paper if all aspects throughout the design and commissioning period had been run through but input has been constrained by commercial consultancy 'means to an end' targets well short of the academic research thoroughness, which Lam has been able to apply to two of our projects at High Wycombe and Limerick, Eire.

However, our uses have been wide ranging and generated some interesting technical issues:-

- Very large spaces with complex geometry (the Royal Albert Hall, London). Volumes have to be simplified for meaningful results, even for long analysis runs (10,000 ray decays plus).

- Very reverberant interiors (St George's Hall, Liverpool; St Augustine's Chapel; Tonbridge School, Kent). The location of absorption in the space appears to be very significant in the perceived acoustic.

- Theatres with flytowers (The Swan, High Wycombe; North Wales Theatre, Llandudno). Modelling a reverberant flytower coupled with dead auditorium brings in issues of directivity of source and how to model ceiling panel arrays.

- Multi-use auditoria (University of Limerick Foundation Building Concert Hall). Sub-models are needed for altered ceiling and absorption arrays activated by electric motors, to suit conference and music.

- Smaller auditoria (450-seaters at Hallam University of Sheffield and University of Sunderland).

- Part auditoria (platform improvement studies, Free Trade Hall, Manchester). Localised early/first-order reflections only.

Before going on to the specific examples, let me summarise the features which the 'ideal' modelling system program should have:-

- ease of input: perimeter surfaces defining auditorium volume;
- fast estimation of reverberation conditions;
- ease of model updates;
- ease of creating sub-models;
- full choice of source and receiver positions;
- reflectograms with 'sound rose' graphical displays;
- maps of energy parameters to a chosen grid;
- source directivity factors;
- multiple source capability;
- speech intelligibility prediction;
- compatibility with architectural design CAD;
- surfaces library and diffraction, as well as absorption surface, characteristics.

ODEON, a system derived for acousticians by the University of Copenhagen, is a program including a number of the above features.

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The Royal Albert Hall is a unique venue, holding 5733 audience and of 86,650 cubic metres. As part of a Masterplan for refurbishment, we have investigated as an option the replacement of the 'mushrooms' installed in 1969. These had been very successful in taming echoes from long sound paths which had long plagued the 1871 interior, but block off a view of the dome, are increasingly needing maintenance and impede rigging over the arena.

A series of models were generated using ODEON. The geometry of the hall is complex and does not lend itself to the necessary reduction to flat surfaces. A model which accurately represents the hall plan as a series of ellipsoids becoming thinner towards the arena, lead to a fragmentation of surfaces as the model attempts to extrapolate surfaces between ellipses. To obtain usable data, a simpler geometry was used which is most accurate for the perimeter but least accurate at the central arena (Figure 1).

A sub-model with a 'ceiling' along the line of mushrooms gave results encouragingly close to measured values, by ourselves and others, including Barron (3). The 'bare hall' model, ie with mushrooms removed, could be compared to Shearer's taken before the mushrooms were fitted (4).

The models have allowed us to investigate an alternative array, rather than the dished mushrooms which controlled reverberation times and long sound paths but did little for the quality of sound. One approach investigated was to use carapaces directing sound to specific seating areas, coupled with absorption 'sails' in the dome. Marshall's Christchurch auditorium is, of course, an example of strongly directed sound from radial panels (5). A horseshoe array plus a new canopy over the platform could be motorised to retract in a sort of Mexican Wave for non-musical events. Further research is needed before any detailed proposals emerge. Even the initial models, though, have shown the smoothing effect on decay traces for optimal reflector arrays (Figure 2).

St George's Hall, Liverpool has the longest reverberation times we have come across outside a reverberation chamber (Table 1, Line 1):

**TABLE 1 : GREAT HALL, ST GEORGE'S HALL, LIVERPOOL
REVERBERATION TIMES**

			OBCF						
			125	250	500	1K	2K	4K	(Hz)
1.	Measured Values - Hall Empty	a	6.3	7.1	8.0	7.3	5.3	3.1	(Secs)
2.	Calculated Values - Hall Empty, Existing	b	6.3	7.2	8.0	7.3	5.3	3.2	
		c	6.2	7.1	7.6	7.1	4.9	3.1	
3.	Gallery Conversion - Including Curtain, Empty	b	5.7	5.8	5.6	5.0	4.0	2.7	
		c	6.0	6.2	6.0	5.4	4.0	2.8	
4.	As 3 but with carpet	b	5.7	5.8	5.1	4.5	3.6	2.4	
		c	6.0	6.2	5.2	3.7	2.8	2.2	
5.	As above + 500 audience	b	4.4	4.2	3.9	3.6	3.0	2.1	
		c	4.8	4.5	3.4	3.0	2.6	2.0	

Code: a Measured in hall December 1990.

b Calculation (based on Sabine and ray decay analysis)

c ODEON 2 prediction - receiver in centre and to one side point responses.

The 'baseline' model showed a good approximation to the measured values, sub-models then allowing prediction of acoustics in an altered hall (Figure 3).

The 28,000 cubic metre Great Hall was built for ceremonial pomp and organ recitals, but now has to cope with meetings, dinner dances, spectator sports and civic receptions. Design studies have looked at installing, without spoiling the Grade I interior, absorptive finishes to assist an improved quality speech reinforcement system.

The interesting result from outline modelling was the divergence of reverberation times, depending on the location of absorption introduced; rear gallery curtains are much less effective pro rata to their area, than carpet to floor, or other members of the audience (Table 1, Lines 3 and 4).

Tonbridge School Chapel, Kent too shows a variance in acoustic parameters at reception points in the body of the Chapel, compared to the 'overall' acoustic as calculated by Sabine, Norris-Eyring, or ray decay analysis.

The Edwardian chapel is being rebuilt after a major fire, as a reverberant interior for organ recital, worship and assembly. It has dimensions close to those of King's College, Cambridge, which we therefore measured. Any absorption is confined to the 750 pupils and choir, so occupancy changes the overall acoustic form.

The 'overall' acoustic as shown in the decay curve figures, is a mid-frequency (500 Hz) reverberation time of 3.6 seconds when full and 5.4 seconds when empty. However, the 'point response' reverberation time is quite different for a receiver position in the central part of the pews, with the organ as source (2.6 seconds full, 3.4 seconds empty).

An earlier use of ODEON had been to compare reflected sound from the original facetted barrel vault lost in the fire and the architect's preferred alternative ceiling profile (Figure 4).

North Wales Theatre, Llandudno is a design-build contract, due to open in June, which is similar to the Swan Wycombe, but constructed at a fraction of the cost and seating 1600 rather than 1000. The flytower and pit are large enough for any of Welsh National Opera's touring productions, but most of the time the venue hosts conferences and light entertainment. Studies concentrate on sound propagation from the stage and pit, via overhead reflector panels, proscenium walls etc. Reflected sound in the flytower or at the back of the auditorium, or at balcony fronts, was studied with a view to controlling unwanted patterns of sound decay (Figure 5).

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Other applications, on multi-use and smaller auditoria, include the University of Limerick Foundation Building Concert Hall, which Lam has examined in greater detail. The ODEON 'stock' model of Royal Festival Hall has been of interest to us in our investigations on behalf of the South Bank Centre, into how perimeter surfaces can be made more reflective with particular reference to low frequencies. Facsimile cladding areas are being tested in the University of Salford's laboratories, to build up a baseline model more accurately.

Finally, we have used the first order reflection capability to look at orchestral settings. 'Source' and 'receiver' positions can be musicians either end of the platform. The strength of particular orchestra sections as experienced in different parts of the audience can also be assessed.

In conclusion, we have found computer modelling a valuable tool when cautiously used in assessing a range of room acoustic tasks; the frustration is that a single system does not yet cope with all the acousticians needs and that our modelling to date has been relatively crude rather than in depth.

References

(1) M KLEINER, R ORLOWSKI and J KIRSZENSTEIN 'A Comparison Between Results from a Physical Scale Model and a Computer Image Source Model for Architectural Acoustics'; Applied Acous. Vol. 38, pp. 245-266.

(2) Y W LAM 'On the Modelling of Auditorium Acoustics, Part II : The Validation of a Hybrid Computer Model '; draft paper submitted to JASA, 1994.

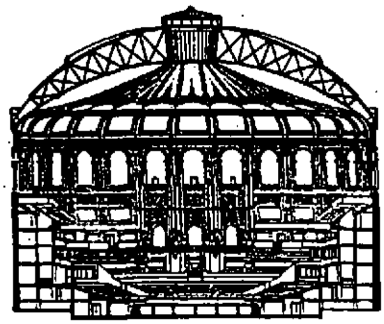
(3) M BARRON 'Auditorium Acoustics and Architectural Design', E&FN Spon, 1993; p. 123.

(4) K SHEARER 'The Acoustics of the Royal Albert Hall', British Kinematography Sound and Television', February 1970.

(5) A H MARSHALL 'Acoustical Design and Evaluation of Christchurch Town Hall, New Zealand', J Acoust. Soc. Am., 65(4), April 1979; 951-957.

FIG. 1 ROYAL ALBERT HALL: RUDIMENTARY 'BASELINE' MODEL

i *Cross Section (Saucer array removed)*
ii *Model with Gallery*
iii *Sample reflection off dome*



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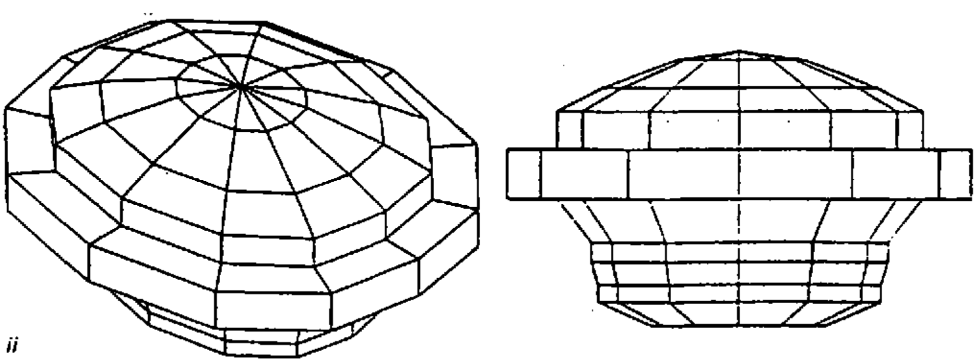

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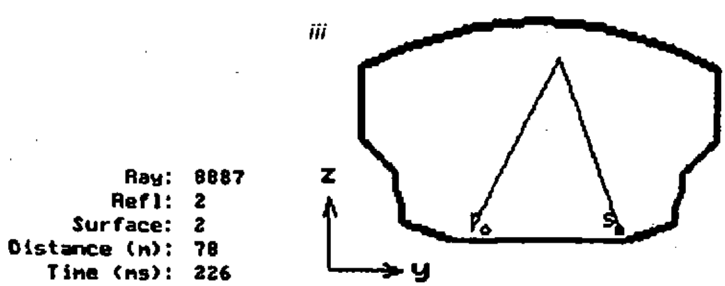
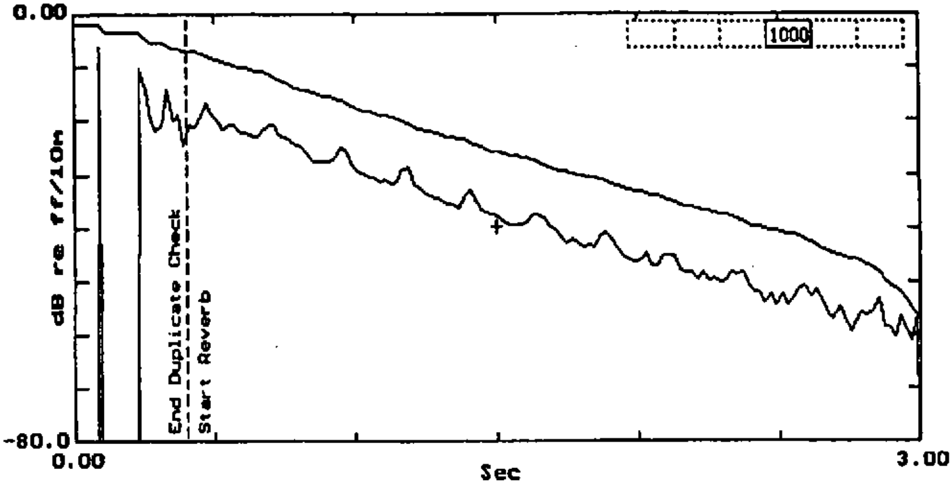


FIG. 2 ROYAL ALBERT HALL: SAMPLE DECAY TRACES

i 'Bare hall'
ii With reflectors



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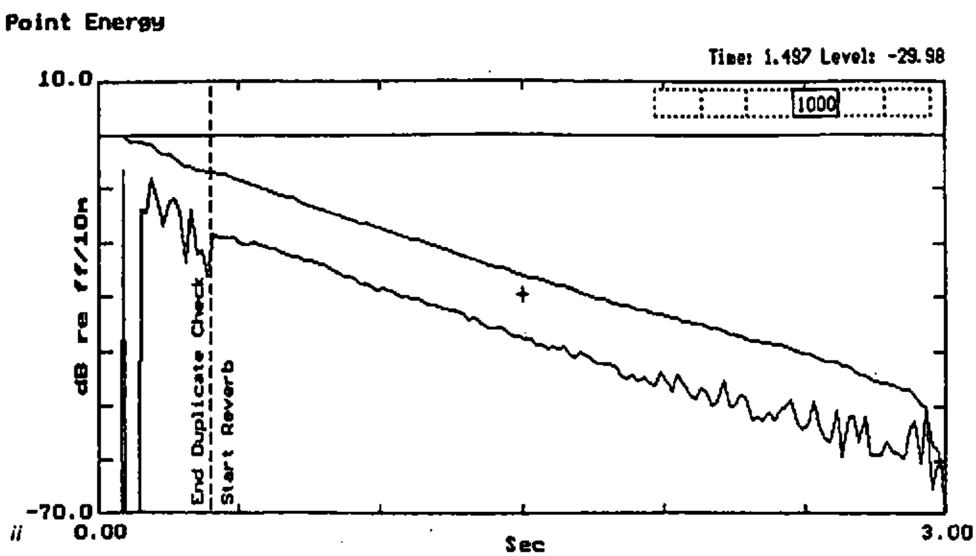
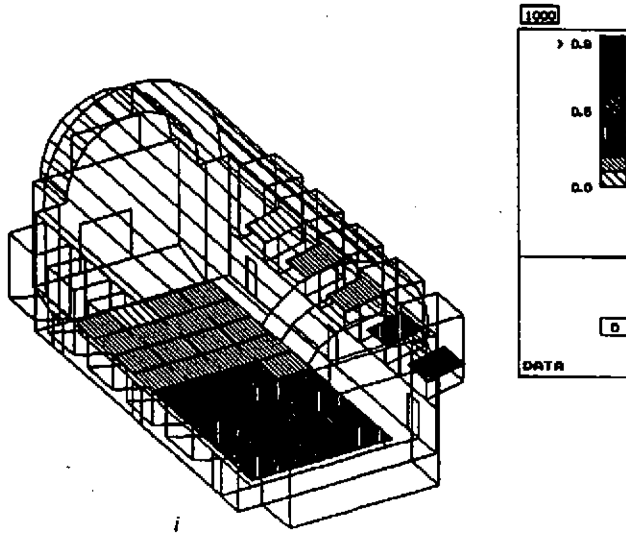


ii

FIG. 3 ST GEORGES HALL, LIVERPOOL:
GRID RESPONSES SHOWING DEUTLICHKEIT

i Baseline Model
ii Curtains, Audience



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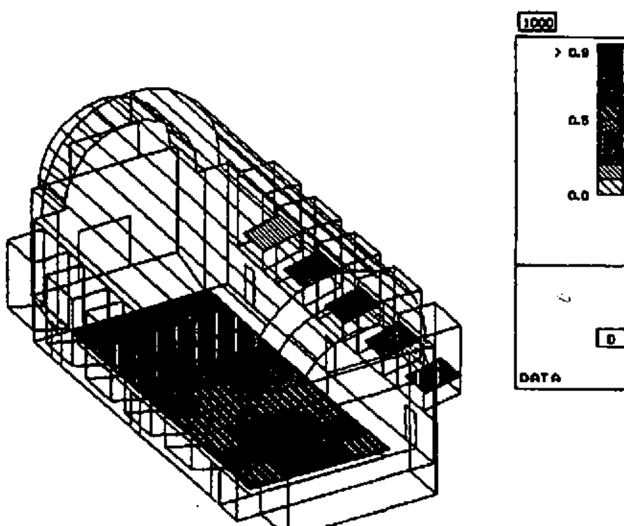

ii

BUILDING DESIGN PARTNERSHIP ODEON

FIG. 4 ST AUGUSTINES CHAPEL, TONBRIDGE

i *Original facetted ceiling, organ source*
ii *Original facetted ceiling, choir source*
iii *Proposed inclined ceiling, organ source*
iv *Proposed inclined ceiling, choir source*

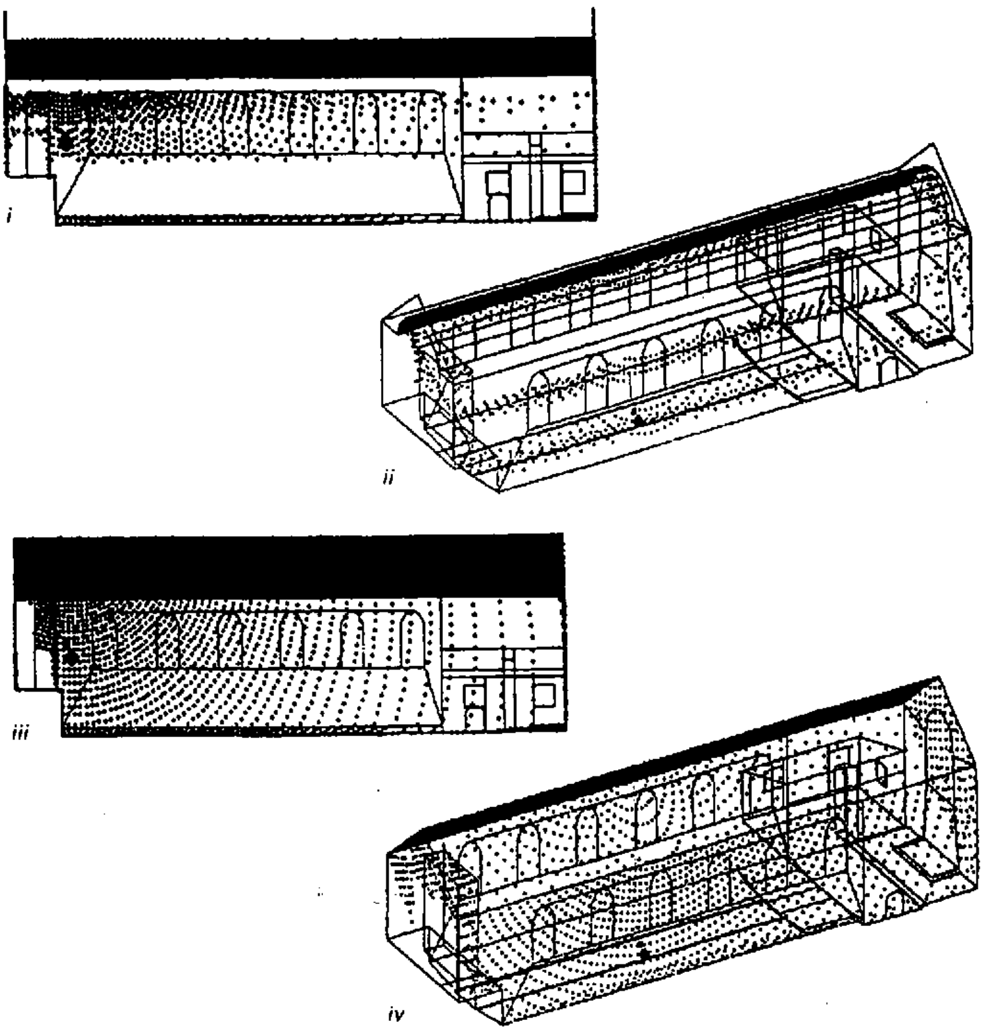

FIG. 5 LLANDUDNO THEATRE FOR THE ARTS: COVERAGE OF TWO OF THE REFLECTORS, SOURCE IN ORCHESTRA PIT