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THE ACOUSTICS OF THE CORN EXCHANGE, CAMBRIDGE

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1. INTRODUCTION

The Corn Exchange, Cambridge, built in about 1875 was typical of many similar buildings of its era, having decorated brickwork walls, some areas of timber panelling, and large areas of glazing, including a pitched glazed roof.

Prior to its recent conversion, the building had been in use for a wide variety of events, but in addition to requiring refurbishment and modernisation, suffered from a number of acoustic deficiencies.

The reverberation time was lengthy (about 4 seconds at mid frequency in the unoccupied state), and because of the long flat seating area, acoustic quality was poor in many seats.

The sound insulation of the building envelope was inadequate because of the large areas of glazing, some of which was broken. As a result, traffic noise was intrusive during noise sensitive events, and during pop-concerts, noise emanating from the hall was a problem.

The brief for the renovated Corn Exchange building was to create a versatile venue on a relatively restricted budget within the confines and restraints of the existing building, to achieve an audience capacity of about 1500. The list of possible functions was wide ranging, from musical performances of all types, conferences, banquets, exhibitions, to roller skating and badminton.

The paper describes the main aspects of the acoustic design, and the results that have been obtained.

2. THE ACOUSTIC DESIGN

2.1 Acoustic Aims:

After discussion with the client, it was decided that the acoustic design would be aimed at providing the best practicable acoustics for musical performance, particularly orchestral and choral works.

The provision of any means of varying the reverberation time to suit other uses was ruled out on economic grounds. However, a speech reinforcement system was provided for conference use.

2.2 Layout:

The existing building envelope had to be retained, and in order to achieve an audience capacity of 1450 people, a balcony was introduced. A flat floor with removable seating was essential in the stalls area to accommodate the multipurpose uses. In order to achieve the required seating capacity, a balcony with fixed seating at a shallow rake had to be accepted. Raked bleacher seating was installed in the rear stalls area. A stage lift was incorporated.

A plan and section of the building is shown in Figure 1. The volume of the hall is about 9750m^3.

2.3 Reverberation Time:

The reverberation time, since it is determined mainly by the volume of the hall and the seating area, could not be altered to any significant extent. No other absorbent surfaces were deliberately introduced.

It was envisaged that the large areas of timber panelling and glazing would provide adequate low frequency absorption.

2.4 Spatial Response:

The hall has a narrow rectangular plan shape and it was expected that there would be strong lateral reflections from the side walls, and that except perhaps at the rear of the balcony, these lateral reflections would not be overpowered by reflections from the ceiling. This was expected to provide good spatial response.

2.5 Loudness:

The lack of absorbing surfaces other than the audience, together with strong early reflections was expected to give adequate loudness at the majority of seat positions. It was, however, expected that loudness for the seats in the rear balcony would be a problem because of the fact that the direct sound passes over the heads of the balcony audience at a shallow angle.

2.6 Ensemble:

The narrowness of the hall and the reflective side walls were expected to promote ensemble among the performers. In order to enhance this effect, and to scatter sound from the performers over a predictable wide range of angles, a Quadratic Residue Diffuser was placed on the rear stage wall. The diffuser is also intended to act at low frequencies in order that instruments such as horns and timpani playing close to the rear stage wall do not become overpowering due to reflections from the wall.

The diffuser was designed by Dr M Barron on the basis proposed by Schroeder [1]. Two two-period arrays were used, each period containing 7 wells of width 275mm and depth of multiples of the fundamental depth of 125mm. The maximum well depth was 500mm. The fins were vertical to achieve scattering in the horizontal plane. It is believed that this is the first Quadratic Residue Diffuser to be used in a concert hall in the UK.

2.7 Sound Insulation:

Measures that could be undertaken to improve the sound insulation were limited by the fact that the building shell could not be substantially altered, due to listed building constraints. The glazed roof was in need of repair, and was replaced with a new roof comprising two timber panel skins separated by an airspace. All windows were fitted with secondary glazing. Sound lobby entrances were formed into the auditorium from the new underbalcony foyer. Fire escape exits were required from the auditorium directly into the adjacent street. The fire authorities would not accept sound lobbies in this location, so special acoustic doors were installed.

The sound insulation of the hall has been considerably improved although occasional noisy vehicles are intrusive.

2.8 Ventilation System:

Supply air is distributed via an external, heavily lagged, perimeter duct, and extract air drawn via a single opening, at high level to the side of the stage. Listed building constraints prohibited ductwork distribution within the ceiling of the hall, and the proximity of the plantroom limited the space available for attenuators. Planning constraints limited the cross-section area of the perimeter duct. In view of these constraints, and also so that there would be some masking of extraneous external noise, the design aim for ventilation system noise was set as NR25. This has been achieved in the majority of seats, with the exception of rear balcony seats where the criterion is exceeded at low frequencies. A study is underway to investigate means of improving the noise level at these positions.

3. ACOUSTIC TESTS

3.1 Reverberation Time:

The reverberation time with the hall in concert format but unoccupied is tabulated below.

Octave Band Centre Frequency (Hz)	63	125	250	500	1k	2k	4k	8k
RT (Feb 88) (sec)	(1.78)	1.73	1.78	1.74	1.60	1.40	1.22	.85

Whilst it would be desirable if the reverberation time at mid and high frequencies were greater for large orchestral works, the result is consistent with a moderately reverberant hall with reasonable warmth of tone, and adequate tonal balance. The fall in RT above 2000Hz would be associated with a lack of brilliance for the furthest listeners.

3.2 Early Decay Time:

Values at of EDT at non-overhung seats were close to the RT indicating good diffusion. The ratio of the Mean Early Decay Time to RT for these seats is as follows:

Oct Band Centre Freqency (Hz)	125	250	500	1k	2k
Ratio of Mean EDT/RT	.94	1.01	.99	.96	1.0

As is normally found, the EDT was short at mid-frequencies at overhung seats.

3.3 Early-to-late Index:

Values at mid frequencies are shown in Figure 2, plotted against source-receiver distance. The values fall within the usual range of ±2dB. The values at 2kHz were consistently higher than those at 1kHz. The RT at 2kHz is somewhat shorter than that at 1kHz, and this seems to affect the late sound.

3.4 Early Lateral Energy Fraction:

Values (mean 125Hz - 1kHz) are tabulated below for seat position:

			Source/receiver distance (m)	
Stalls	L12	0.19	9.3	
	R 5	0.27	14.9	
	W12	0.25	18.1	
	XB3	0.26	23.3	
	XF6	0.22	26.3	(Overhung by balcony)
	XK10	0.13	28.1	(Overhung by balcony)
Balcony	CC11	0.27	29.3	
	GG5	0.13	32.2	
	OO9	0.13	37.8	
	VV5	0.16	43.1	

Values in excess of 0.20 were obtained in the stalls area as expected, indicating strong lateral reflections. However, not many lateral reflections appear to reach balcony seats, and it is postulated that wall reflections to the balcony are obscured by the wall profiles, and roof beams, which also cause the ceiling to act as a highly diffusing surface. The measurements were carried out on one side of the auditorium (stage left), and it is possible that the front of balcony fire escape on this side also obscures lateral reflections.

The overall mean value is 0.20, which is favourable when compared with other halls.

3.5 Sound Level with distance:

Figures 3, 4 and 5 show values of early sound level, late sound level, and total sound level with respect to source-receiver distance.
The dotted points in the figures represent the expected values according to the theory presented in reference [2]. The values measured in the stalls indicate that these seats are behaving as expected.

In the case of Early Sound, low levels were measured in the balcony. In seats near the front of the balcony, direct sound is obscured by a glass screen which has been erected as a safety barrier, but acts as an effective acoustic barrier! Weak early sound was also measured at other balcony positions, and possible reasons are given above (section 3.4). Balcony seats and those overhung by the balcony had quiet late sound.

3.6 Impulse Responses:

Impulse response measurements for the majority of seats were acceptable. In front balcony seats it was clear that the direct sound was weak.

4. CONCLUSIONS

The construction of a new concert hall within an existing building shell, which cannot be altered, inevitably forces many constraints on the design. The design had aimed for the best practicable acoustics, given these constraints. Comments from the users of the hall have been favourable.

The overall reverberation time is consistent with a moderately reverberant hall with reasonable warmth and adequate tonal balance. There is good diffusion of the sound field.

In the stalls area there are good lateral reflections, and other measures indicate good acoustic quality in these seats. Balcony seats tend to have reduced lateral energy, and it is suggested that this is due to obscuring of wall reflections by the wall profiles, and roof beams. The balcony also has a shallow rake, and a glazed screen has been introduced at the balcony front with the result that direct sound is weak. Loudness at the rearmost seats in the balcony is poor.

ACKNOWLEDGEMENTS

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REFERENCES

[1] M R Schroeder: Number Theory in Science and communication: Springer - Verlag, Berlin 1984

[2] M Barron and L-J Lee: Energy relations in Concert Auditoria: accepted for publication in JASA.

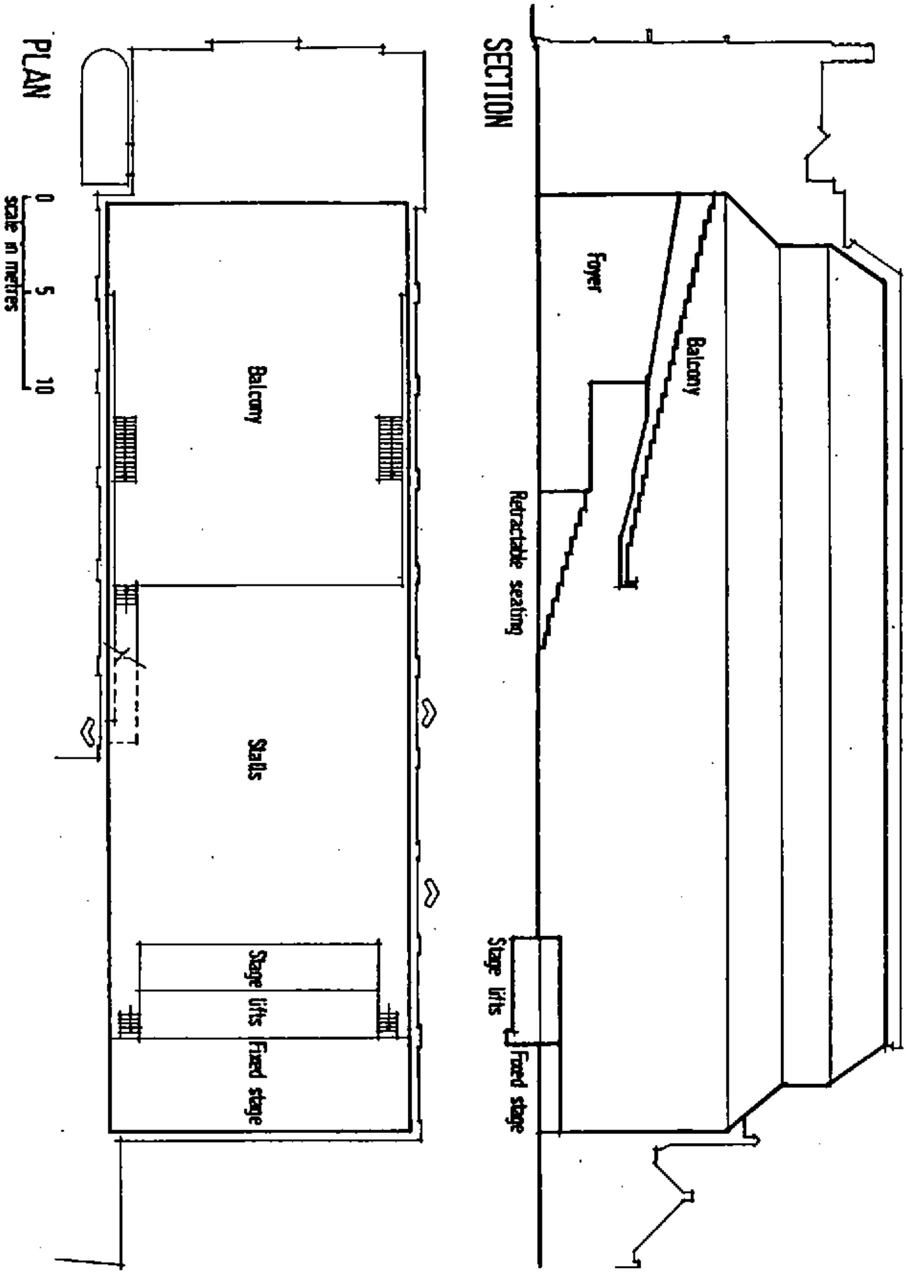
PLAN
SECTION
scale in metres
0
5
10
Balcony
Stalls
Stage lifts
Fixed stage
foyer
Balcony
Retractable seating
Stage lifts
Fixed stage

FIGURE 1

THE ACOUSTICS OF THE CORN EXCHANGE, CAMBRIDGE

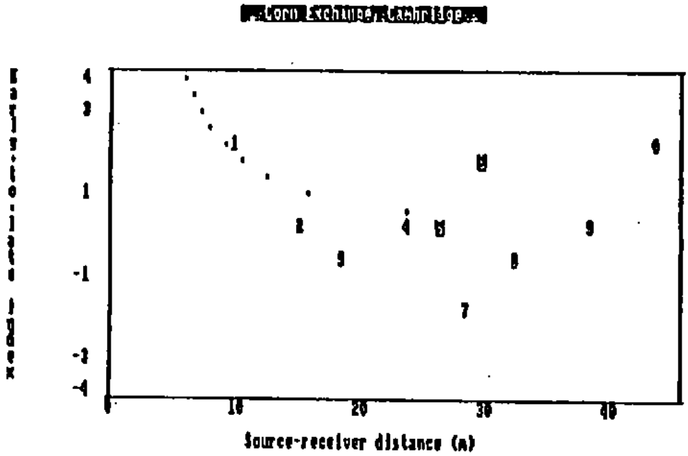

Figure 2 Early-to-late index

No.	Position
1	Stalls L 12
2	Stalls R 5
3	Stalls V 12
4	Stalls XB 3
5	Stalls XF 6
6	Stalls XK 10
7	Balcony CC 11
8	Balcony GG 5
9	Balcony OO 9
0	Balcony VV 5

Notes: All points are mid-frequency values.
Seats overhung by balconies are highlighted.

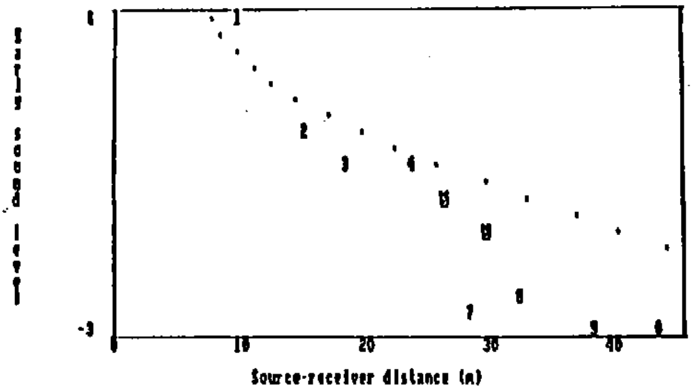

Figure 3 Early Sound Level

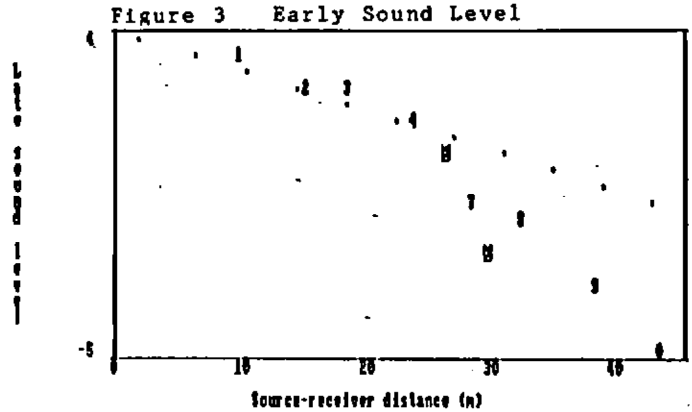

Figure 4 Late Sound Level

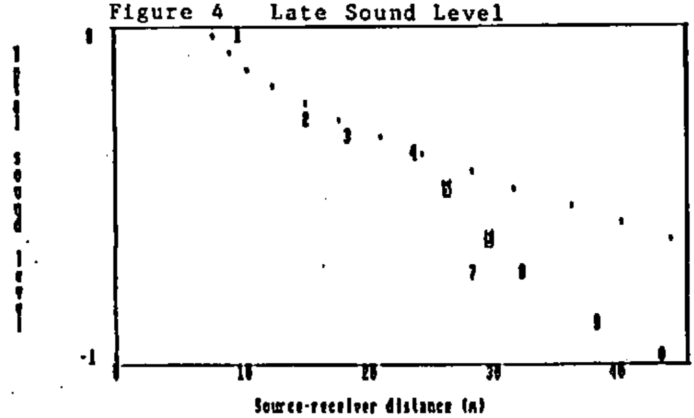

Figure 5 Total Sound Level