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THE ACOUSTIC DESIGN OF THE REFURBISHED ROYAL EXCHANGE THEATRE, MANCHESTER

Joan Faria Arup Acoustics, St Giles Hall, Pound Hill, Cambridge, CB3 0AE, UK

1. INTRODUCTION

The refurbished Royal Exchange Theatre opened in December 1998. The theatre was first opened in 1976 to stunning visual effect; it was as if a high tech 'spacecraft' formed of glass and steel had landed in a vast Victorian cotton exchange. The architects were Levitt Bernstein Associates, with acoustic consultancy provided by DK Jones of the University of Nottingham [1].

Between 1996 and 1998, the theatre was refurbished. The other members of the design team from the 1970s were retained but Arup Acoustics was appointed as acoustic consultant.

In this paper an overview of the acoustic prior to refurbishment is provided, together with details of the refurbishment and measurements carried out upon completion.

2. THE THEATRE PRIOR TO REFURBISHMENT

The Royal Exchange Theatre Company leases several floors of the Royal Exchange Building in central Manchester from Prudential Property Management. The rest of the Royal Exchange Building houses retail (at street level) and offices.

In October 1995, Arup Acoustics was commissioned to carry out a series of room acoustic measurements and listening tests in the theatre (known as the 'Module'). The Theatre Company was considering refurbishing the Module and the tests would serve two purposes:

- the Theatre Company would have a record of the Module acoustics for reference;
- any improvements to the acoustic that could be made during refurbishment could be identified.

The format of the Module was (and still is) theatre in the round, with 740 seats. The theatre is seven sided in plan, with each seating level rotated by half a side with respect to the level below. The heptagonal form means that there are no parallel wall surfaces which could cause flutter echoes. When the Module was first built, the fire authorities required that the audience could see if the surrounding Exchange Hall caught fire, and thus the Module had to be visually transparent (the walls are formed from 12 mm glass).

The challenge of the design of a theatre in the round is to achieve good speech intelligibility in a situation in which the actors' backs will always be turned to some of the audience, with no useful sound reflective surfaces around the stage area. Good speech intelligibility was achieved at the Royal Exchange Theatre by minimising the distance between the audience and the actors, by control of reverberance and by ensuring that there were useful sound reflecting surfaces close to all seat locations.

Key results of the measurement carried out in October 1995 are presented in Table 1.

Parameter	Unoccupied	Occupied
Mid-frequency RT	0.80 s	0.70 s
Mid-frequency EDT	0.60 s	0.50 s
Low-frequency RT (125 Hz)	1.20 s	0.95 s
Clarity index, C_{50}	5.7 dB	4.2 dB
RASTI	0.66	-
Level difference between Exchange Hall and Module (high level louvres open)	D_w25 dB	
Level difference between Exchange Hall and Module (high level louvres closed)	D_w28 dB	

TABLE 1: Key acoustic parameters prior to refurbishment
All average of 500 Hz and 1kHz octave bands, except as specified

Subjectively, speech intelligibility was judged to be good at all locations within the Module, even when the actors' backs were turned. The close proximity of the audience to the actors created a sense of great intimacy. The theatre was not sufficiently reverberant for music recitals, although strength and clarity were judged to be high. Mid and high frequency acoustic absorption was provided by the audience, seating and carpeting. Small acoustically absorptive panels provided reflection control in locations where limited areas of parallel walls were unavoidable. The glass walls and the metal roof decking provided low frequency absorption.

At the top of the Module were louvres which were designed to provide a variable link between the Module and the Exchange Hall so that the reverberance of the Hall could be excited by loud events in the theatre or used for sound effects. The measured mid-frequency reverberation time in the Exchange Hall was 4.8 s. The louvres sealed poorly when closed and a double decay was clearly audible in the theatre when excited by loud speech or music. The ability to control the use of the Hall reverberance had been lost. Seals around doors and between adjacent glazing panels had also become worn and ineffective over the years. Noise within the Exchange Hall was clearly audible in the Module during performances.

It was concluded that the room acoustics of the theatre were excellent for drama, but that the reverberation time was a little short for music recitals. The major shortcoming was the poor sound insulation of the theatre envelope.

3. THE BRIEF

Lottery funding had already been secured for the refurbishment of the theatre when, in June 1996, an IRA bomb exploded in Manchester causing devastation to many buildings, including the Royal Exchange building. The Theatre Company found temporary accommodation in Campfield Market, but the refurbishment programme was significantly compressed by the Theatre's desire to be back in their permanent home. The aim was to reopen the theatre in the Exchange Building in just eighteen months, in December 1998.

Aspects of the Client's brief which affected the acoustics included:

- addition of a new, 100 seat, flexible Studio Theatre in an area formally occupied by a workshop;
- improved Module sound insulation;
- refurbishment of the Module seating;
- improved technical facilities within the Module, including modifications to the flying systems;
- modifications to the air conditioning system in the Module;
- improved rehearsal facilities.

Additionally, foyer space in the Exchange Hall would be rationalised and additional workshop space would be provided in an off site building.

4 ACOUSTIC DESIGN ISSUES

4.1 Theatre Module

Based on the measurements carried out in the Module in November 1995, the acoustic design philosophy was to maintain the good room acoustic for speech as far as possible, whilst providing a modest increase in reverberance for music recitals. Prior to refurbishment, the Theatre Company had reported that there was a flutter echo between the stage floor and the roof which was distracting to actors; it was important that this defect should be removed during refurbishment.

The proposals to update the flying system involved the installation of a grid over the stage which would be accessible from above. The effect of this was to raise the height of the roof by approximately 600 mm. This increase in volume would provide the desired small increase in reverberance, whilst the installation of a grid with equipment located on it would provide diffusion which, it was judged, should remove the flutter echo. As a precaution, zones on the underside of the roof were identified where small patches of absorption or diffusion could be placed after completion if this was found to be necessary.

The client wished to retain the ability to use the reverberance of the Exchange Hall for sound effects, but wanted more control over when this effect would occur. Arup Acoustics proposed an electroacoustic system to feed the signal from the Module into the Exchange Hall and play back the response in the Module, because this would avoid the need to weaken the sound insulation envelope of the Module. The client, however, wanted to feel that the two acoustic volumes were physically connected and so a system of opening roof doors was devised. The doors can be opened or shut by winches which are located on top of the Module roof structure to connect the Module with the Exchange Hall.

The design aim was to provide a sound level difference of approximately D_w 35 dB between the Module and the Exchange Hall by means of improving the sealing between panes of glass, replacing worn door seals and replacing the old louvres with new roof doors.

4.2 Studio Theatre

The Studio Theatre was conceived as a flexible, 'black box' space which could be used in a variety of formats, including theatre in the round, promenade and end stage. Seating is not fixed and is provided on a series of rostra. The plan shape of the former workshop area was not dramatically

altered, but the plan area of the theatre can be reduced by closing sliding doors, or increased by opening the doors to include the foyer area in the theatre volume. Part of the theatre, above the central area of the floor, is double height to accommodate flying.

The stage area is not fixed and thus there was no scope to provide useful sound reflecting surfaces near the actors. The acoustic design was therefore to limit the dimensions of the theatre (to control the distance between the actors and the audience) and to control the reverberance. The ceiling in the double height flying space is too high to provide any useful reflections, so absorption in the form of 100 mm mineral wool with a metal mesh facing was applied to it. The rest of the ceiling is sound reflective. The sliding doors are formed of perforated metal with a mineral wool infill; at the Client's request they do not serve a sound insulating function.

The theatre overlooks Old Bank Street, a pedestrianised street on which there are high noise levels in the evening due to local nightlife. The Theatre Company wished to retain the windows on the Old Bank Street façade. These were provided by the building freeholder and were double glazed, but with poor perimeter seals. An additional layer of 12 mm laminated glass was added, with a 200 mm airspace between panes. Blackout shutters were formed of a sandwich construction of timber and mineral wool to provide additional sound insulation.

There is a 100 mm concrete floating floor in the Studio Theatre to reduce noise transmission from retail areas below. Common columns and façade elements are clad with an independent dry lining to reduce flanking transmission.

Sound separation between the Studio Theatre and the Module was critical to avoid simultaneous performances from causing disturbance. The Studio Theatre is at Exchange Hall floor level, only 5 m away from the Module envelope. The Exchange Hall floor could not support high loads (indeed, the Module itself is supported from columns in the Exchange Hall rather than resting on the floor) so masonry walls were not possible. Instead, a 300 mm twin frame dry wall construction was used, with the inner leaf supported on the floating floor of the Studio Theatre and the outer leaf supported on the Exchange Hall floor.

5. ACHIEVED RESULTS

An acoustic test evening was held for an invited audience in the Module and the Studio Theatre in November 1998. The audience in the Module was approximately 85% of full capacity. The test evening comprised:

- performances of drama, cabaret, and a piano recital in the Module;
- a drama performance in the Studio Theatre;
- lectures from Royal Exchange Theatre Company staff;
- impulse response testing, using a dodecahedron loudspeaker and MIDAS analysis software.

The results of the measurements carried out in the Module and the Studio Theatre in November 1998 are presented in Table 2.

Parameter	Theatre Module		Studio Theatre	
	Unoccupied	Occupied (approx. 85% capacity)	Unoccupied (no seats)	Occupied
Mid-frequency RT	1.10 s	1.00 s	1.10 s	0.70 s
Mid-frequency EDT	1.05 s	0.75 s	1.05 s	0.50 s
Low-frequency RT (125 Hz)	1.05 s	1.20 s	0.95 s	0.75 s
Clarity index, C_{50}	+0.6 dB	+3.1 dB	0 dB	+6.4 dB
STI (500 Hz – 2 kHz)	0.62	0.67	0.60	0.77

TABLE 2: Key acoustic parameters after refurbishment

The unoccupied measurements in the Module were carried out when some bench seats at stage level were not yet installed. The stage was not set. It is expected that values of RT and EDT would be lower and values C_{50} and STI would be higher than measured if all seating was in place and if the stage was set.

The Module measurement results show that there has been a controlled increase in the mid-frequency RT, but that speech intelligibility is still good. The increased reverberance will provide improved acoustic conditions for chamber music.

Subjectively, speech intelligibility in the Module is very good, even though the theatre is noticeably more reverberant than it was before refurbishment. The former flutter echo is not audible to actors or audience. The former double decay from the Exchange Hall is only audible when doors to the Exchange Hall are intentionally left open, and intrusive noise from the Exchange Hall is no longer disturbing. For music recitals, the sound is loud and envelopment is good.

The acoustic conditions in the Studio Theatre vary significantly with occupation due to the lack of fixed seating. With an audience, the RT is well controlled and speech intelligibility is excellent.

6. DESIGN TEAM

Acoustic Consultant: Arup Acoustics
Architect: Levitt Bernstein Associates
Structural Engineer (Theatre Module): Ove Arup & Partners
Structural Engineer (rest of building): Broadhurst Partnership
Services Engineer: Max Fordham and Partners
Theatre Consultant: Theatre Projects Consultants
Project Manager: Lassetter Williams
Construction Manager: Mace Limited

7. REFERENCES

DK JONES (1978), Acoustics of the Royal Exchange Theatre, Proc Institute of Acoustics 4, 14-9-1 to 14-9-2.

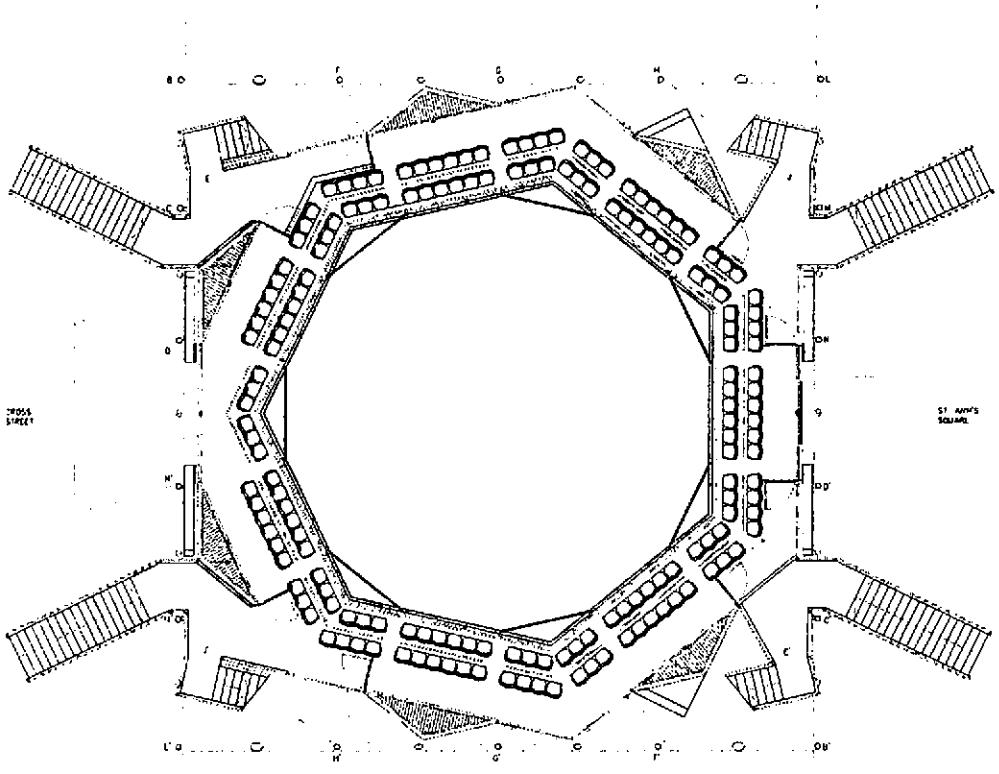

FIGURE 1: Plan of Theatre Module at first gallery level

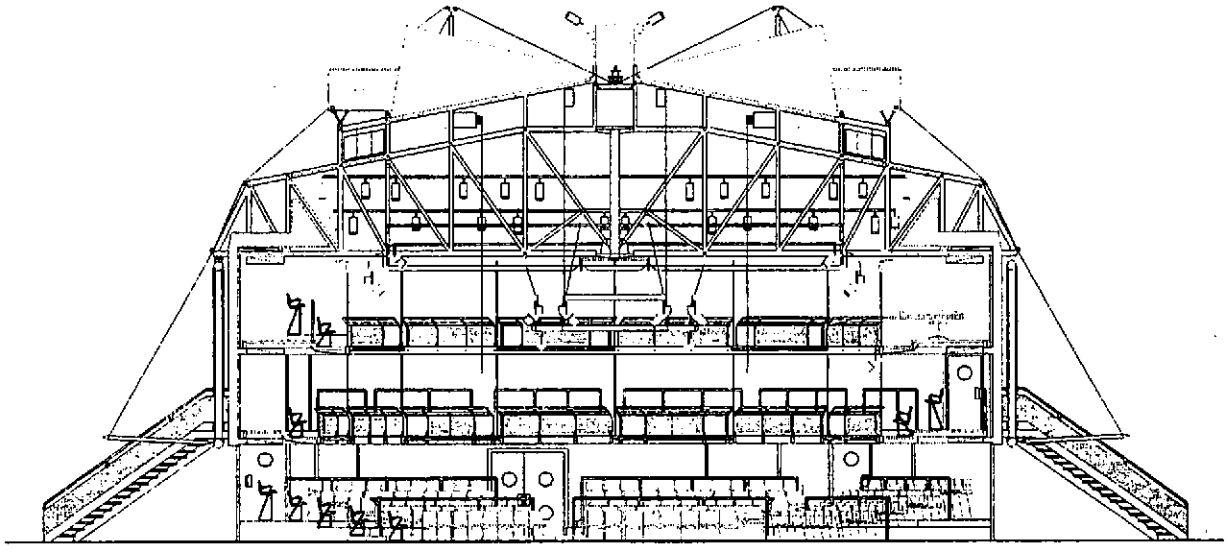

FIGURE 2: Cross section through Theatre Module