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Auditorium acoustic design: 30 years, 15 projects

Rob Harris

Arup Acoustics, Winchester, United Kingdom

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ABSTRACT

The acoustic design practice Arup Acoustics celebrated its 30th anniversary in 2010. This paper reviews 15 of the auditoria projects acoustically designed by Arup over this period. Specific acoustic design considerations are discussed for the projects and the projects are used to track the development of auditorium acoustic design over the last 30 years. Equally, recent new challenges to acoustic designers are identified, as are aspects of auditorium acoustic design which have not developed sufficiently over the study period.

INTRODUCTION

This paper summarises 15 of the most significant new hall design projects completed by Arup Acoustics on its first 30 years of operation. (Snape Maltings concert hall pre-dates the 30 years but is included as the acoustical success of the project lead to the foundation of Arup Acoustics.)

For each project an image and key data (including the name(s) of the lead auditorium acoustic designer(s)) are presented, together with points of particular interest, including the development of room acoustic design techniques. For more detailed information the reader is referred to the references.

THE 15 HALLS

Snape Maltings Concert Hall (1970, Derek Sugden) [1] [2]

Architect: Arup Associates

Figure 1

Seats (N): 824 V/N 9.9m^3 RTocc 1.9s

Form: Rectangular with steep rake and a truncated pitch roof

Variable absorption: None

Arup Associates were the architects for the successful conversion of this historic industrial building to a concert hall for Benjamin Britten and Peter Pears. The steep rake and early reflection pattern contribute to a strong sound.

Arup Acoustics has used the truncated pitch form roof cross-section in other recital spaces, including the smaller Jacqueline du Pre hall at St Hildas College Oxford. 40 years later, a smaller recital hall, also designed acoustically by Arup Acoustics (Raf Orlowski) [Architect: Haworth Tompkins], opened on the same site in 2010. This shared many of the characteristics of the main hall, including the pitched roof, ‘natural‘ timber finishes and a steep audience rake.

Lingotto Centro Concerti e Congressi

(1994, Richard Cowell, detailed design and completion by Muller BBM) [3]

Architect: Renzo Piano Building Workshop

Figure 2

Seats (N) 2000 V/N ~11.5m^3 (concert mode) RTocc 2.0s

Form: Shoebox

Variable absorption: Variable height ceiling + side curtains

This rectangular hall was inserted into an existing courtyard in the architecturally and cinematically *('The Italian Job')* famous Fiat factory. Fortuitously the courtyard had appropriate dimensions for a shoebox form concert hall.

Lingotto (and Glyndebourne) were the first music auditoria projects modelled by Arup using 1:50 scale physical models. Of particular interest was the effect of the adjustable height ceiling on the room responses. The adjustable ceiling, consisting of 6 movable panels, can be lowered for when the hall is used for conferences. The ceiling panel height variation is 5.6m. The model study investigated the effect on the volume coupling of the dimensions of the gaps around the panels and the location of sound absorption placed on the upper sides of the panels.

The construction stage consultancy was undertaken by Muller BBM.

The Anvil Basingstoke (1994, Richard Cowell) [4] [5]

Architect: Renton Howard Wood Levin

Figure 3

Seats (N) 1400 V/N 10m^3 RTocc 1.85s

Form: Plan is gentle fan + parallel walls + reverse fan

Variable absorption: Adjustable curtains at high level + removable lightweight proscenium

This regional concert hall and general entertainment venue had a strictly limited budget. The structure is exposed within the hall to limit the overall height of the building and use is made of elements to fulfil more than one function, for example the ventilation bulkheads provide cue-ball early reflections.

The hall is wider at the top to provide reverberance whilst keeping the hall narrower at seating level for early reflections – a technique used again for Oslo Opera House.

Early lateral reflections are provided by angled, large radius convex panels. The rear wall is also convex in plan to reduce the level of late reflections back to the platform (the hall is used for both orchestral and amplified events).

The orchestral reflector has to be regularly tilted vertically for storage during non-orchestral events and is relatively lightweight, providing primarily high frequency ensemble reflections.

Glyndebourne Opera House

(1994, Derek Sugden and Rob Harris) [6] [7] [8] [9]

Architect: Michael Hopkins & Partners

Figure 4

Seats (N) 1243 V/N 6.3m^3 RTocc 1.25s

Form: Circular

Variable absorption: None

The theatre consultant's and architect's concept for the new Glyndebourne auditorium was based on the concept of 2 interlinked circles – one inscribing the performers and the other the audience. This lead to a significant challenge, namely the creation of a non-concave acoustic geometry within a circular architecture.

Because of the curved geometry of the auditorium, it was decided not to use computer simulation, but to concentrate on scale modelling at 1:50 scale. This was the last major auditorium project by Arup Acoustics not to employ computer modelling and the last larger opera house (> 1000 seats) to be designed without the benefit of both computer and scale models.

The acoustic design uses a combination of sound reflecting, sound diffusing and acoustically-transparent components to overcome the complexities of the concave geometry. A great success of the room is the way that the architects have incorporated the complex acoustic demands into a very pleasing architecture.

Visual and acoustical intimacy are assisted by the 'semi-Wagnerian' pit, which has a relatively deep overhang relative to the open pit area. It is questionable whether this solution would be accepted by the major orchestras which play at Glyndebourne if this house was being designed in 2010.

Bridgewater Hall (1996, Rob Harris) [10] [11] [12]

Architect: Renton Howard Wood Levin

Figure 5

Seats (N): 2400 V/N $10.6m^3$ RTocc 2.0s

Form: Hybrid

Variable absorption: None

Bridgewater Hall is one of the few modern ‘hybrid’ halls, which go beyond the shoebox and vineyard forms. It retains the parallel from of the shoebox to provide strong lateral reflections, particularly to the stalls seats, while the upper levels are divided into seating sections at different heights to introduce additional wall surfaces close to the audience. For efficient use of the volume, the lower chord of the structure is elegantly expressed as rods and nodes within the volume. This technique of minimising overall building height by exposing the structure within the acoustic volume was also used in 2 of other 15 projects, namely the Anvil Basingstoke and Oslo Opera House.

This was the first project by Arup Acoustics to use computer modelling (DOS version of ODEON), in addition to a 1:50 scale model.

Bruges Concertgebouw

(2002, Rob Harris, Robert Essert and Helen Butcher) [13] [14]

Architect: Paul Robbrect en Hilde van Daem

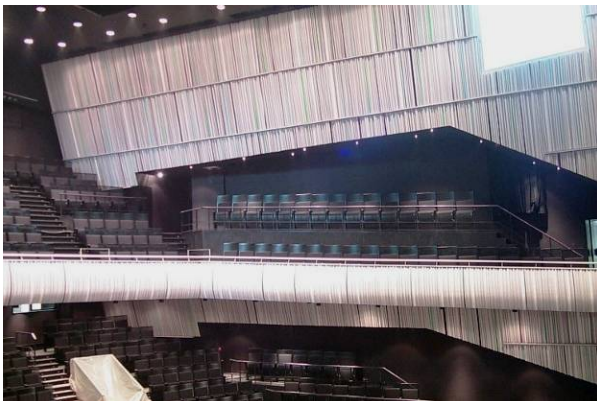

Figure 6

Seats (N): 1200 V/N $8.9m^3$ RTocc 1.9s

Form: Complex – fan at low level, canted walls to give reverse fan at high level

Variable absorption: Vertical banners + horizontal drapes in front of walls

The brief for this hall was unusual in that symphonic music and fully-staged opera were given equal priority. (In practice fully-staged opera performances are rare because of production costs). The acoustic solution for the symphonic mode was to go beyond a conventional concert shell, instead using the whole volume of the stage as part of the acoustic volume. The ‘shell’ elements are partially acoustically transparent. Hence they provide visual and partial acoustic enclosure but open up the full stage volume. The maximum proscenium opening is unusually high to couple the platform and auditorium volumes and fixed reflectors above the orchestra pit / forestage continue the line of the over-platform reflectors into the auditorium. The upper volume of the flytower (which would absorb sound) is closed off with a single hinged panel; this is stored vertically on the upstage wall of the flytower.

City Recital Hall, Sydney

(2002, Rob Harris and Peter Griffiths)

Architect: Peddle Thorp Walker

Figure 7

Seats (N) 1238 V/N $8.8\ m^3$ RTocc 1.75s

Form: Rectangular

Variable absorption: Vertical movement banners and sound absorbing panels

This room is large for a recital hall, a fact driven by the arts economics of seat revenue against performance costs, particularly for guest ensembles from Europe and other continents.

Angled balcony fronts provide early lateral reflections and significant sound scattering is incorporated ‘naturally’ into the architecture.

A useful performer’s balcony replaces the visual focus often provided by a pipe organ.

Wales Millennium Centre

(2004, Rob Harris and Jeremy Newton) [15]

Architect: Percy Thomas Partnership

Figure 8

Seats (N) 1950 V/N 6.7m^3 RTocc 1.3s

Form: Modest fan, mitigated by wall shaping

Variable absorption: Extensive vertical banners + absorbing shutters for control rooms

This auditorium was designed as a balance between an opera theatre (the WMC is the home of Welsh National Opera) and a lyric theatre for major amplified touring musicals and a multi-performance genre programme. The overhead panels are partly solid, to provide useful early reflections to seating areas, and partly acoustically-transparent, to ensure that the upper volume contributes to reverberance. The theatre has a large, flexible orchestra pit. Tracking towers each side of the proscenium (a technique also employed in Oslo Opera House) allow the effective acoustic width to the sides of the pit to become narrower when the proscenium opening is reduced. The profiled glass reinforced gypsum wall panels provide effective high frequency sound scattering.

The Operaen Copenhagen

(2004, Rob Harris and Jeremy Newton) [16]

Architect:Henning Larsen Architects

Figure 9

Seats (N) 1450 – 1633 V/N 7.4m^3 (max) RTocc 1.4s

Form: Horseshoe

Variable absorption: Motorised twin vertical fabric banners

The most remarkable fact about the construction of the new opera house in Copenhagen is its speed of realisation: from writing the concept brief to completion in 3 years 9 months. This was the only project to date for which Arup has used a 1:25 scale model instead of a 1:50 scale model. After the study was completed it was concluded that overall there seemed little advantage in the larger scale, with potential accuracy improvements offset by practical complications.

The auditorium walls are constructed of multiple layers of board with timber lining.

Scandinavian orchestras have strict policies with respect to limiting sound level exposure of musicians. The Det Kongelige Teater pit orchestra will not play under an overhang and demand significant ‘free space’ in the pit in front of loud instruments, eg the brass. This results in a considerable separation of the singers from the audience. Given that the singers are also performing on a very large stage, design emphasis was placed on achieving a good stage / pit balance. This is assisted by an overpit sound reflector (a characteristic of all Arup-designed opera houses). This provides both a reflector for mid-stage and upstage singers and an ensemble reflector for the orchestra.

The design was assisted by an Odeon computer model and a 1:25 scale physical acoustic model.

The Sage Gateshead

(2004, Raj Patel and Robert Essert) [17]

Architect: Foster and Partners

Figure 10

Seats (N) 1650 V/N 12.5m^3 RTocc 1.8s

Form: Variable-height shoebox

Variable absorption: Adjustable height ceiling panels + motorised drapes in upper volume + motorised horizontal movement curtains in front of visible walls

The brief for the Sage unusually placed equal importance on mid-scale classical and symphonic music (as the home of the Northern Sinfonia) and local folk music traditions. The key acoustic design elements were therefore moving ceiling panels which can vary both the effective room volume and the early reflection pattern.

Although barely noticeable, the walls are all bowed (ie convex in plan), in structural bays, with a radius of approximately 42m to allow diffusion of sound down to very low frequency. The timber modelling of the surface treatments vary from 12mm to 200mm to allow mid-high frequency sound diffusion.

The concave plan orchestral risers (more common in North America than in Europe) are removable to provide a flat platform for non-orchestral events.

Nytt Operahus i Oslo

(2008, Rob Harris and Jeremy Newton) [18] [19]

Architect: Snøhetta

Figure 11

Seats (N) 1375 V/N 8.7m^3 RTocc: 2.05s (max)

Form: Horseshoe

Variable absorption: Fabric banners + curtains

Den Norske Opera sought a reverberant acoustic for their new opera house, but a city planning requirement limited the height of the Store Sal (main auditorium) to 20.5m. The acoustic solution was for a 'T' shape transverse section, with increased auditorium width at high level. This approach proved to be highly successful: the narrower lower part of the room ensures a good early reflection pattern and the upper volume ensures high reverberance.

The potentially sound-focussing concave wall is mitigated by a 'wavy wall' concept, initially introduced for acoustic reasons but enthusiastically adopted by the architect. As in Copenhagen the walls are timber bonded to board; Arup used Boundary Element Modelling to ensure adequate room bass response without excessive expenditure on unnecessary layers of board.

Similar in concept to the overhead panels in the Wales Millennium Centre, the central lighting feature is partially sound absorbing and partially sound reflecting.

The orchestra pit is highly flexible acoustically, with a modular acoustically-transparent or solid pit rail and tracking, rotating (absorbing or reflecting) panels at the rear, which can close off the overhang. Very similar solutions were installed in the Operaen Copenhagen, Wexford Opera House and the Grand Canal Theatre.

The acoustic design benefited from computer modelling, ambisonic auralisation of the computer model output and a 1:50 scale model.

Wexford Opera House (2008, Jeremy Newton)

Architect: Keith Williams Architects

Figure 12

Seats (N) 781 V/N 6.2m^3 RTocc 1.1s

Form: Horseshoe within a rectangular box

Variable absorption: None

This compact auditorium replaces an earlier, very small opera theatre, on a restricted city site. Wexford Opera traditionally features high clarity and intelligibility and the room form and limited reverberance continue this tradition.

An acoustically important aspect of the original theatre was the large forestage that extended beyond the proscenium arch over the orchestra pit. This brought the stage action closer to the audience and helped to provide a good stage to pit sound ratio. As the Wexford Festival supports young vocal talent, the new auditorium has a similar arrangement. The design is flexible, with a double-decker orchestra pit lift allowing the orchestra to play either underneath the forestage or on top of the forestage at the same depth as the rest of the pit. The latter configuration creates an increased open area for the orchestra pit as found in modern (larger) opera house design.

The visual impact of the (relatively) large volume is reduced by suspending the lighting bridges inside the room. These are elegantly integrated into the architecture, clad in aluminium. The sound reflector above the orchestra pit is at an acoustically preferred height of 9.9m above stage level. To reduce the expanse of clear wall above the proscenium opening, the visual ceiling continues beneath the reflector as aluminium clad mdf strips, spaced to allow the sound to pass through them and reflect off the surface that they obscure.

Elisabeth Murdoch Hall, Melbourne Recital Centre

(2009, Raf Orlowski and Andrew Nicol) [20]

Architect: Ashton Raggatt McDougall

Figure 13

Seats (N) 1000 V/N 9 m^3 RTocc 1.9 s

Form: Shoebox

Variable absorption: Vertical banners

The most striking feature of the hall is the routed patterns in the Australian hoop pine timber finish, developed by the architects in response to the request from the acoustician for sound scattering surfaces. In addition, whole wall and ceiling panels are stepped in and out to provide medium scale sound diffusion.

A stepped ceiling above the performance platform provides strong acoustic reflections, improving the musicians' ability to hear themselves and facilitating greater musical ensemble.

For this project extensive use was made of auralisations to inform design decisions. This included presentations of chamber orchestras, string quartets and solo instruments.

This hall uses classical acoustic design concepts but is realised as highly distinct, contemporary architecture.

Kings Place Recital Hall

(2008, Rob Harris and Helen Butcher)

Architect: Dixon Jones

Figure 14

Seats (N) 420 V/N 8.4 m^3 RTocc 1.7s

Form: Double cube

Variable absorption: Motorised horizontal movement curtains around all 4 sides in upper part of room (2 curtains each covering 2 walls) + concealed hand-winched drape around platform surround + hand-operated curtain in front of control room at rear at stalls level

This hall is based on dimensions close to the 'double cube' which has been historically successful fro recital spaces. A narrow gallery all around the hall provides an additional cueball refection for the stalls audience, additional seating and convenient installation space for temporary audio visual equipment (one of the 2 resident orchestras, the London Sinfonietta, makes frequent use of electronic and reproduced sound and video). The ceiling is a modern variant of the classical hall coffer, providing sound scattering over a range of frequencies.

As in many of the featured halls, timber surfaces are given prominence. This reflects the positive response of performers and listeners to halls with a timber finish.

When extended into the room, the large area of variable absorption halves the reverberance and subjectively reduces the acoustic height of the room for jazz, world music, conference and similar uses.

Grand Canal Theatre (2010, Jeremy Newton)

Architect:Studio Daniel Libeskind and Arts Team (theatre architect)

Figure 15

Seats (N) 2169 V/N 5.5m^3

RTocc 1.3s (estimated from 1.5s unoccupied)

Form: Lyric theatre fan

Variable absorption: None

The primary function of this major touring theatre is to present large scale musicals and other amplified events. As the most appropriate theatre in Dublin for the presentation of opera and ballet it was decided to provide sufficient reverberance for successful performance of these art forms.

The upper volume, required to achieve the enhanced reverberance, is screened visually using acoustically-transparent metal mesh panels. Reflectors beneath the lighting bridges provide additional overhead reflections. The walls are profiled to provide a mixture of scattering and sound reflections (offsetting the natural fan shape). The controlled room response means that very high amplified sound quality can be achieved without a variable sound absorption system.

CONCLUSIONS

Over the past 30 years Arup Acoustics has completed many major acoustic design projects, including the 15 summarised above. Design tools have moved reasonably satisfactorily from hand calculations through computer modelling (first DOS and now Windows based) to modelling plus auralisation. Auralisation enables the client and the design team to listen to the proposed design and compare it with models of existing halls of known reputation. Recent advances in multi-source and walk-through modelling and auralisation are exciting and today Arup would not contemplate developing a design without listening to it.

The need for scale modelling is arguably reduced as computer modelling accuracy improves, but many major projects wisely retain both prediction tools.

Less progress has been made on the understanding of the relationship between subjective response and prediction and measurement parameters. Many of the parameters (and the design philosophy they represent) have remained largely unchanged over the 30 years. Relatively few new parameters have been introduced or widely accepted, an exception being 1-IACC. Little work has been reported ion the effect of sound level on the perception of temporal and spatial acoustic attributes. Performer acoustics (for both concert players and opera singers) remain inadequately understood, despite studies by Arup Acoustics and many others.

Opera house design has become more difficult for two reasons. Firstly, the increase in open pit size, driven mainly by noise exposure concerns but also the desire for a fine orchestral sound, which increases the physical separation of the singers from the audience. Secondly the very large stages within which singers must perform without the benefit of the side wall reflections which occur on smaller stages.

All of the auditoria have been designed with very low building services noise levels (generally Preferred Noise Criterion 15) and commensurate technical systems noise limits. In earlier projects, dimmer-induced filament noise in lamps was an issue. This was resolved by the development of more sophisticated dimmers, but a new problem has appeared to replace it, namely noise from cooling fans in luminaires (and motors in moving lights). In recent opera projects very low noise from stage machinery has been achieved, enhancing the drama from the stage.

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