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ACOUSTICAL RENOVATION OF THE QUEEN ELIZABETH THEATRE, VANCOUVER: SPATIAL SOUND IN A WIDE ROOM

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ABSTRACT

After a delay of more than a decade, the renovation of Vancouver's Queen Elizabeth Theatre is finally underway. In the summer of 2006 the building, which houses the 2900 seat main auditorium and the 800 seat Playhouse Theatre, was cut in two, leaving a 75 mm wide acoustic joint to control sound transmission between the two venues. The next two phases of the renovation will be carried out in the summers of 2007 and 2008. The work will deal with a number of acoustic and noise control concerns but one of the primary issues is the nature of the spatial sound. The Queen Elizabeth Theatre opened in 1959, long before the importance of spatial sound was identified. It is typical of its age: a very wide room (32.2 m) with a low ceiling. In order to maintain seating capacity, the overall width of the room will be preserved. Designs previously presented by the author have been significantly revised to improve spatial and reverberant sound. Revisions include a terraced seating area in the stalls, removal of the ceiling to increase room volume and overhead lateral reflectors hung in the exposed truss level space above the audience.

HISTORY

The Queen Elizabeth Theatre (QET) is a seminal building in the history of North American theatre design. The 1956 design competition was won by a group of young architects working out of their basement. That team would go on to design most of Canada's large post war auditoria. Eventually taking the name Arcop Architects, its progeny form the senior core of Theatre Projects' North American office and the architects for this renovation: Proscenium Architects + Interiors. The design included seating along the side walls – affectionately known as the "ski slope" – and a rarity at the time. It is seen by some as the first nascent step in the return to the Italian horseshoe shaped plans that were so popular in the 18th and 19th centuries. The acousticians included a young Russell Johnson, making one of his first major contributions to auditorium design. In the Johnson oeuvre, the QET comes in a close second to the Tanglewood Music Shed, which opened only a few weeks before.[1]

A renovation design was developed in 1997-98 and has been reported by the author in References [2] and [3]. The struggle through that process led to a greater appreciation of Height to Width ratios. Scale and computer model studies suggest that rooms with low Height to Width Ratios, i.e. wide and flat, have proportionally shorter Early Decay Times (EDT), i.e. the EDT/RT ratio is significantly less than 1. By narrowing the room with floor to ceiling "fins" at the side wall boxes, EDT/RT ratios were increased from 51% to 75%. The 1998 design also changed the existing single balcony room into a three balcony opera house geometry, replacing the "ski slope" with side wall boxes. The front half of the ceiling was flattened but the rest was left in place. Then the design lay dormant for eight years.

In 2006 the design was re-assessed and found to be wanting. Although EDTs had been improved, there was concern that they would not be long enough. There was also concern about Strength (G) and, of course, spatial impression. Computer models of the existing room and the 1998 design were developed and from these a series A/B auralisations were generated. It became apparent that the 1998 design would either have to be changed or be complemented with an electronic enhancement system.

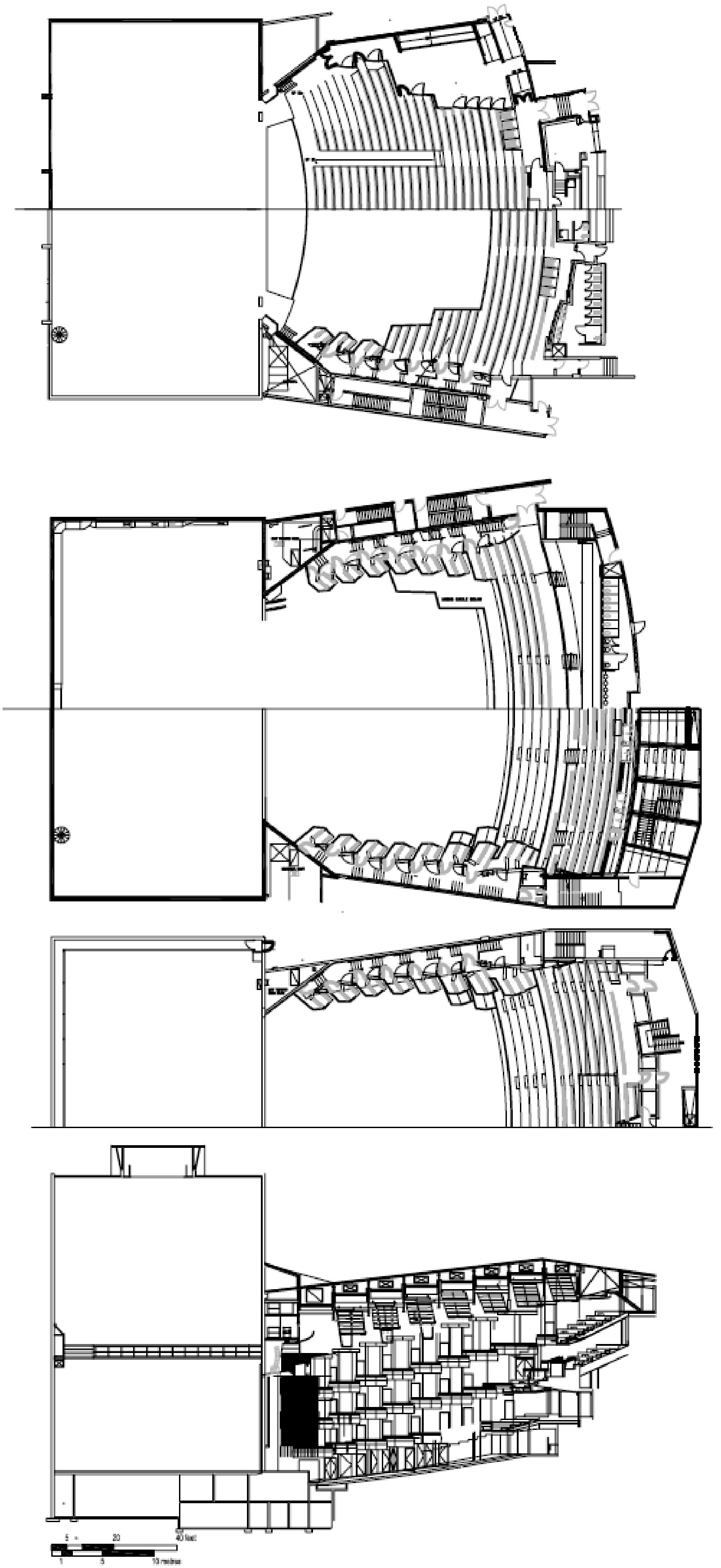

Figure 1 Composite Plans and Longitudinal Section of the Queen Elizabeth Theatre renovation design starting with the Stalls level plan at the top then moving progressively upwards into the balconies.

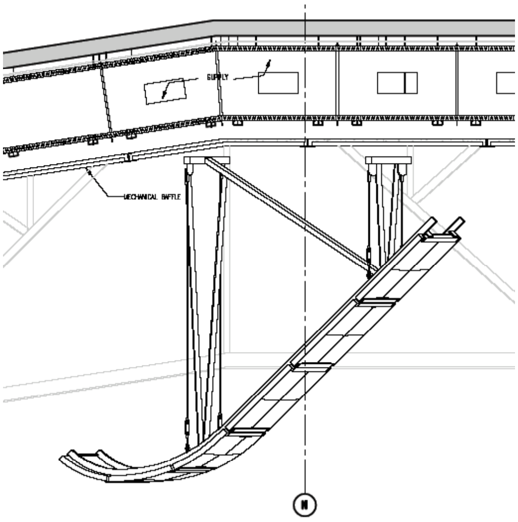

Figure 2 Detail of one of the lateral reflectors in the ceiling truss space. Above the reflector is the ventilation system's Supply Air plenum.

SPATIAL SOUND DESIGN

With a width in excess of 32 m, the need to address spatial sound seems obvious. Two key design elements deal with the issue: lateral reflectors high above the room in the truss space and a terraced, laterally reflecting floor plan. Design precedents for the former come from the Michael Fowler Centre in Wellington, New Zealand[4]. The floor plan makes reference to the recently renovated Jubilee Auditoria in Calgary and Edmonton[5], the Metropolitan Art Space Concert Hall in Tokyo[6] and, of course, the Berliner Philharmonie[7]. Plans and sections are shown in Figure 1. Drawings of the original building can be found in Reference [8]

Where the 1998 design left most of the existing ceiling in place, the new design removes it completely, effectively raising the height of the room by 4.8 m. This part of the construction, and anything else that requires scaffolding, has been carried out over the summer of 2007. The trusses are now exposed. Duct work has been re-designed to slower velocities, air being delivered through plena that are tight to the underside of the roof deck. The design goal for the ventilation system is PNC-15. The undersides of the plena are 38 mm corrugated steel deck (for diffusion) filled with a 38 mm topping of concrete (to maintain warmth). Tucked inside the trusses are seven pairs of lateral reflectors. A detail of one is shown in Figure 2.

These reflectors went through several generations of design prior the final version shown here. They started out as four large, flat and rather awkward looking reflectors located towards the back of the room, providing lateral energy mostly to the balconies. Please see Figure 3. Later on they developed into the elliptical plan shown in Figure 4 but the individual panels still remained flat. Concerns about image shift generated by the flat panels suggested a need for diffusion. Diffusion would also spread the sound out, increasing the zone of coverage. The question was how much diffusion was enough and how much was too much. An early scheme provided diffusion in the form of a three layer fractal, 2-dimensional Quadratic Residue Diffuser (QRD). This was questioned by the architects on aesthetic grounds. Acoustically, there was also concern that the 2-D QRD provided too much diffusion and that lateral energy levels received by listeners would be too low. These concerns were corroborated by Jerry Hyde, who kindly shared some of his experience with the design of the lateral reflectors at the Michael Fowler Centre.[9]

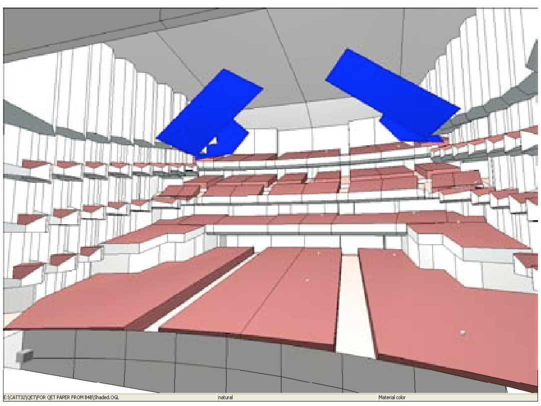

Figure 3 An early version of the overhead reflector design. The colours are for the model, not the room.

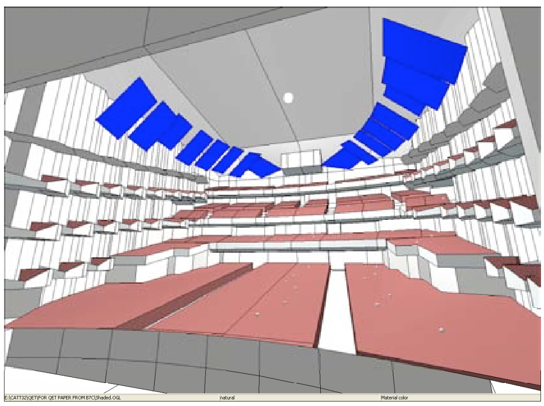

Figure 4 The penultimate design of the lateral reflectors showing the elliptical plan.

The size of the reflectors was dictated partly by truss spacing and partly by headroom constraints on the top balcony. Reflection coverage zones were easily determined using CATT Acoustic 8.0. Aiming the reflectors was easy; determining where to aim them was not. Should a reflector aim for seats on its side of the room or the opposite side? Aiming for the opposite side of the room meant a larger zone of coverage but, because the room is so large, the reflections were arriving rather late; between 60 and 70 ms in the stalls. If a reflector was aimed towards the same side of the room the reflections arrived earlier but the angle of incidence became more vertical than lateral. The decision, once again, was informed by the Michael Fowler design. A quick method of images study of an AutoCAD version of the drawings[10] confirmed that the reflectors should indeed be aimed to the opposite side of the room.

Providing lateral energy coverage to the stalls level was rather easy, primarily because the reflectors were so far away. On the balconies, especially the top balcony, the reflectors were closer and the zone of coverage was correspondingly smaller. The elliptical plan compounded the problem, limiting the reflection zone to the centre of the balcony. The problem was solved with two more design improvements. The side walls of the lighting gondola were sloped to direct sound to the back corners of the balcony. Then, in an eleventh hour optimisation, the bottoms of the reflectors were curved into the “J” shape shown in Figure 2. This will scatter some of the incident sound to directions behind the reflector. Having developed this for the balcony, we realised that it could also be used on the other reflectors to scatter sound to the side wall boxes.

The final question pertaining to the lateral reflectors originated from the multi-purpose nature of the building. Would these lateral reflectors have a deleterious affect on loudspeaker clusters and, if so, should they be rigged to be moved out of the way when required? The sound system designer’s experience is that loudspeaker clarity correlates with its spatial image. If the image is small, the loudspeaker will be clear. After much consideration, computer model reflection studies, auralisations and an on-site experiment with a similar reflector configuration at Vancouver’s Orpheum Theatre[11], it was decided that the reflectors could remain fixed in place.

MULTI-PURPOSE ACOUSTICS

The Queen Elizabeth Theatre is, above all, a multi-purpose venue. Although much of the acoustic design was centred around the needs of Vancouver Opera, most of the bookings for the room rely on amplified sound. Thus the room has opposing acoustical requirements. The traditional solution, of course, is to provide the appropriate room volume for opera and when amplified productions are on stage, absorb the excess reverberation with adjustable acoustic banners. The client, whose knowledge of the building type was at once formidable and challenging, objected to curtains for two reasons. First – and for him foremost – they collect too much dust and are difficult to clean! Second, they don’t absorb low frequency sound. The client wanted something better than curtains. Discussions between the author and the architect led to a simple solution that addresses both of the client’s concerns.

Coupled volumes have long been used to modify the acoustics of a room, usually to extend the Reverberation Time. While there are many successful examples, some acousticians remain sceptical. What most agree on, however, is that coupled volumes can be used as very efficient low frequency absorbers. We informed the architect of this and a few days later he came up with a proposal to put a series of doors in the side walls, opening them up to the Sound and Light Lock (SLL) corridors that run down the sides of the auditorium. The SLLs will be lined with 100 mm thick glass fibre mounted in front of thin wood or gypsum board panels. The doors will be 55 mm thick wood. For opera, ballet, etc. these doors will be closed and will provide strong early lateral reflections. For amplified sound, the doors will be open, exposing the absorption material to the room. By eliminating the lateral reflections, this will also address the sound system designer’s concerns about the spatial image of loudspeaker clusters. Other absorption will be found on the back walls, in the form of moveable fabric covered panels, and in the ceiling, in the form of vertical roll-up curtains at the catwalks.

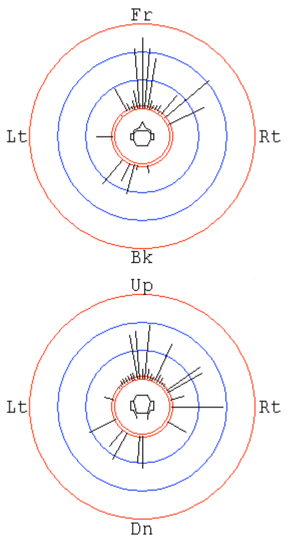

Figure 5 Computer model calculation for a seat in the stalls of the existing room showing the lack of laterally reflected sound.

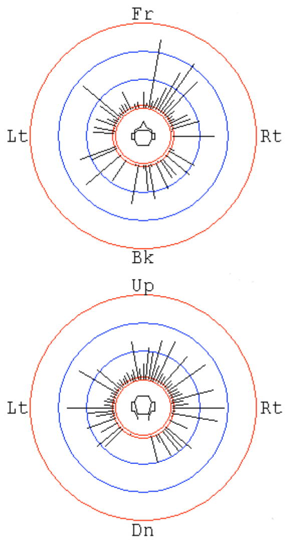

Figure 6 Computer model calculation for the same seat as Figure 5. Laterally reflected sound has been increased by the overhead reflectors and the terraced floor plan.

COMPUTER MODELLING

In the 1998 design, most of the work focussed on a 1:48 scale model study. The current design makes use of computer model studies exclusively. The author's experience is that scale models are more accurate than computer models[12]. For design however, computer models are a much more powerful tool, especially for the design of spatial sound. In an effort to improve the accuracy of the computer predictions, a model of the existing room was developed and calibrated to the full scale measurements. The model of the existing room was then used for comparative studies as the design progressed. There were 36 versions of the model in all and more than 900 auralisations. An example of one of the comparative studies is shown in Figure 5 and Figure 6. Figure 5 shows the level and direction of reflections received in the first 80 ms at a location near the back of the stalls, in the existing room. Figure 6 shows the same calculation in a version of the room similar to Figure 3. Lateral reflections have increased significantly, and it is evident that these are coming both from the side walls and the overhead reflectors.

OTHER ISSUES

If there was one overriding directive from the client it was to keep the room's seat count as high as possible. The resulting design is thus very wide with long balcony overhangs; two design elements that do not lend themselves well to good acoustics! The width of the room was overcome with the terraced floor plan and ceiling reflectors described above. The long balcony overhangs will be compensated for electronically.

A number of other modifications are being made to improve acoustics. The side walls are currently lined with thin wood panels that absorb low frequency sound. These will be removed and used elsewhere in the building. To improve acoustic warmth, all surfaces exposed to the auditorium will be massive, either 50 mm plaster or the equivalent weight.

Perhaps one of the most important improvements is what became known as "The Cut". The building houses two venues: the 2900 seat QET and the 800 seat Playhouse Theatre. In the summer of 2006, the QET – which ironically was a stand alone building up until 1962 – was separated from the Playhouse. Prior to The Cut, structure borne noise limited concurrent use of the two venues.

ACKNOWLEDGEMENTS

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