ACOUSTIC DESIGN OF THE CONCERTGEBOUW BRUGGE

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1 INTRODUCTION

The design competition for a new concert hall in Bruges (Brugge) was won by the architects Robbrecht en Daem in the spring of 1999. It was opened with a performance to the King and Queen of Belgium in February 2002, less than three years later. The building is the centre piece of *BRUGGE 2002*, where Bruges is the European city of culture.

The brief was for an auditorium which could hold the full spectrum of music performances. The priorities were established, with both symphonic concert and opera being the main uses. The city of Bruges and the region of Flanders have a rich tradition of cultural activities. Music events in Bruges are held in the many churches, rather than in large venues. The Flemish Opera currently perform in the opera houses of Gent and Antwerp, but not in Bruges. The Concertgebouw is intended to provide the opportunity for the performance of larger scale Flemish music, particularly to encourage new music. It is not intended that the building should join the international circuit of concert halls or opera houses. The seating capacity was set at between 1200 and 1400.

The Concertgebouw building has no resident company, but operates as a touring house. In addition to the main auditorium, it has a chamber music hall seating approximately 350, and two rehearsal rooms.

2 THE AUDITORIUM CONCEPT

In multi-purpose venues, a number of techniques can be used to vary the acoustic response of the hall. Examples of these are, briefly:

1. Provide a large acoustic volume and reduce the reverberation time for other uses with variable absorption systems;
2. Provide an acoustic volume suitable for most uses and adjust the acoustic response with electronic assistance;
3. Provide an acoustic volume suitable for most uses and add in some additional reverberant volume for symphonic concert use.

As the auditorium was to produce an excellent natural acoustic for symphonic concert use, Option 2 was not pursued.

Option 1 is employed in many auditoria where the principal use of the space is orchestral. Other events tend to use amplified sound, so variable absorptive treatment is adequate, although not ideal. Where the natural acoustic is required, but with less reverberance than a symphony hall, the variable absorption leads to an undesirable loss in loudness. Key sound reflecting surfaces are obscured, resulting in a reduction in clarity and other acoustic qualities. The overall range, between the most reverberant and least reverberant conditions, is also limited, by the amount and type of absorption that can be included in the space.

When auditoria are designed this way, they often have the ‘capability’ for staged events, but do not include a full flytower and wing space. The high priority for opera at the Concertgebouw dictated that this option would not be suitable.

2.1 The Coupled Volume Solution

The third option starts with an auditorium volume that is most appropriate for opera or chamber music use. Additional reverberant volume is then coupled to the auditorium to increase the reverberance for symphonic or choral use. The main advantage of this, is that the useful sound reflecting surfaces in the auditorium do not have to be covered with sound absorbing material. The range of reverberance is also extended from an opera RT, up to a symphonic RT. The reverberance can also be reduced to an RT suitable for use with a sound system.

There is a natural conflict between the use of an auditorium for opera and for concert, other than the acoustics. The opera is usually a ‘show’, designed to be viewed and experienced from the front. There are two distinct spaces, one for the performer and one for the audience, with limited overlap between them. For an orchestral concert, the music is made within the auditorium, ie the performers and the audience share one space.

The coupled volume, required for the concert condition, could be located in a number of different areas around the auditorium. In theory, distributing the additional volume evenly through the space would facilitate its aural integration into the acoustic of the auditorium. Alternatively, locating the additional volume behind the performers has the effect of putting them more centrally in the space. This way, the performers share the greater acoustic volume and the increased reverberance with the audience.

The decision was made to build an auditorium and conventional stage and flytower. The orchestra would then play on the stage and forestage, surrounded by an orchestral shell, but coupled to the empty backstage area to provide the increase in volume and reverberance. The stage would be closed off from the flytower, to limit loss of sound energy to above.

This concept is unusual in European halls. It is used in North America, where multi-purpose halls and an end-stage format are more common. Examples are the Pikes Peak Centre in Colorado Springs and The Centre in the Square, Kitchener, Ontario.

3 AUDITORIUM DESIGN

The main design parameters were set as follows:

Auditorium Mode	Mid-frequency Reverberation Time, s	Mid-frequency Clarity, C80, dB	Loudness, dB re 10 m in a free field
Concert	1.8 – 2.0	> 0	> 0 at 15 m from the source
Opera	1.4 – 1.5	> 2	> 0 at 15 m from the source
Amplified	<1.3		

TABLE 1: Design Parameters for the Occupied Auditorium

The design target for the background noise level in the auditorium was NR 20.

The acoustic volume of the auditorium, with and without the coupled rear-stage volume, was set to achieve the target ranges of reverberation time.

3.1 Design of the Variable Performance Area

To understand the design of the auditorium, it is most appropriate to begin with the stage or platform area. The stage floor is maximum 18 m by 24 m, served by a fully operational flytower with powered flying system. There are two forestage lifts, which can be lowered to form an orchestra pit or to take additional seating, reducing the stage depth to 19 m. For orchestral concerts, the lifts are raised, to form the orchestra platform. This brings a large proportion of the orchestra into the auditorium.

The proscenium is 14 m high and 18 m wide (the full width of the stalls) in order to provide the largest opening feasible between the stage and the auditorium. For opera performances, the proscenium is reduced in size by a portal frame.

When the hall is used for concerts, the orchestra is surrounded by an enclosure which is made up of individual towers, and is adjustable in size. Figure 1 shows a section through the performance area for the two main configurations, concert and opera. The enclosure is discussed in more detail below.

Behind the orchestral enclosure, the upper volume of the flytower is cut off from the reverberant rear-stage area by a horizontal ceiling. This is a single piece plywood ceiling, supported on a steel structure. When not in use (during opera), the ceiling is rotated into the vertical and stored against the rear wall of the flytower, at high level.

Above the orchestra are two concert ceiling panels, suspended in the flytower. These also cut off the upper flytower from the platform area, as well as providing a reflecting surface above the performers in concert mode. During opera, they are lifted vertically and stored in the flytower. There are also two fixed ceiling reflector panels above the orchestra on the forestage. Each of these ceiling panels is made of plywood on a steel frame, is gently convex curved from front to back, and ribbed to maintain stiffness. The enclosure formed by the ceiling panels is shown in Figure 1. The forestage ceiling panels help to join the stage to the auditorium, both visually and acoustically, providing an even pattern of sound reflections from the performers to the stalls.

The concert ceiling and upstage ceiling do not completely seal off the flytower from the stage. Gaps between the panels allow some energy up into the flytower. It is likely that some cloths and the house curtain will generally be stored in the flytower. There is also 150 m² of fixed sound absorbing material on one wall of the flytower. Together, these limit the build up of reverberant sound energy in the upper flytower, and prevent late sound energy returning to the performers below.

In the backstage area there is provision to hang theatrical cloths to control the reverberance. Although this is designed to be a reverberant volume, a completely empty backstage results in a very unbalanced distribution of absorption, when contrasted with the relatively sound absorbing auditorium.

The orchestra pit is designed to accommodate an orchestra of upto 75 or 80 players. Three quarters of the pit area is in the open, which is a good compromise between allowing the orchestral sound to flourish, without too much separation of the stage from the audience. It also helps to maintain vocal/orchestral balance. The width to depth ration is 2.85:1. The rear wall of the pit is covered with reversible sound reflecting/absorbing panels for noise control under the overhang. The pit rail can be acoustically solid or transparent, to help adjust the orchestra balcance in the stalls. The pit front wall consists of sliding panels, either forming a solid wall or opening the pit to a sound absorbing seat store.

3.2 Auditorium Design

The first challenge, in shaping the auditorium, was to propose a plan form which would successfully accommodate the visual and acoustic needs of both concert and opera. This is made simpler by the limit on the seat numbers to between 1200 and 1400 people. The opera requirement has resulted in most of the audience being seated in either the stalls or two large balconies, all facing the stage. Tapering side balconies then bring the remainder of the audience closer to the stage, close to but never surrounding the performers. The plan at stalls level is shown in Figure 2.

The acoustic aim was to maintain a tight effective width across the auditorium. In response to this, the architects came up with an auditorium cross section which is vertical near the stage and trapeziodal (narrowest at the top) at the rear. The side walls are warpped and the plan of the auditorium varies with height up the building. This allows a slight outward fan at stalls level, assisting in visual intimacy and good sightlines. At the top of the auditorium, the fan of the side walls is significantly reversed, enhancing lateral reflections of sound.

The long section through the auditorium appears that of a conventional opera house. However, the vertical separation between the balconies is based on aiming for the 1:1 ratio of height to depth for concert halls rather than the 2:1 ratio for opera houses.

The rake of the stalls seating was controlled to the minimum necessary for opera sightlines (6º), in order that the subsequent rake of the balconies could be limited. The result of this, and the plan form, is a compact audience seating area. The furthest seat is 29 m from the stage. The height of the ceiling above the stalls is 18 m and the average stalls width is 22 m.

The acoustic response of the auditorium was modelled using the ODEON software. This enabled optimisation of the sound reflecting surfaces. The balcony fronts and cut out soffits of the side balconies provide reflections of sound to the seats below. The side walls, sloping in plan and section, also direct the sound downwards and across the auditorium. The ceiling and rear walls are very gently convex curved to avoid harsh sound reflection. Small horizontal shelves were introduced at two levels above the forestage. These have been adopted as technical lighting galleries, but also provide vital cue ball sound reflections between the performers on the stage or in the pit, and the audience.

3.3 Variable Sound Absorption

Extensive areas of sound absorptive treatment are incorporated into the Concertgebouw, to limit reverberation for some events. The preference, as described above, is that most music is heard with no additional sound absorbing materials present in the auditorium. However, within the broad description of the orchestral concert or of opera, there are many different musical genre. While the acoustic may be optimum for the orchestral works of Beethoven or Tchaikovsky, those of Haydn or Shostakovich would benefit from less reverberance. Similarly with opera, the Italianate form requires more clarity and less reverberance than the Wagnerian. The variable sound absorption provides scope for this.

On each level of the auditorium, there are heavy wool curtains, which can be pulled along the side and rear walls. Above the second balcony, there are double layers of vertical banners, which retract into the roof void. At the forestage, there are two sets of double layered banners that drop the full height, from the ceiling to the stage. All of the banners and curtains are under motorised control.

When less reverberance is desired for concert or opera, some of the high level banners are revealed. This adds some absorption, without covering too many of the important sound reflecting surfaces in the lower part of the hall. When a sound system is in operation, the rear and side wall curtains are revealed. These absorb the sound which would otherwise be strongly reflected back to the stage. All of the banners and curtains can be used when the reverberation must be minimised for amplified sound.

3.4 Sound Diffusion

The most striking visual element in the auditorium is the profile of the side walls and balcony fronts. It is desirable to make the internal surfaces of an auditorium sound diffusing, to blend the musical sound and improve the timbre. However, it is often one of the most difficult areas for the acoustician to tackle, within the language of modern architecture. A strongly diffusing interior has particular advantages in a hall which has variable acoustics, limiting otherwise stong sound reflections. In this auditorium, it was particularly important to make those surfaces not covered by variable absorption sound diffusing.

The solution was to form deeply profiled plaster panels, which then covered all of the side walls and the balcony fronts. As the side walls are warped vertically, they do not form the structural or sound insulating walls of the auditorium. Vertical, 200 mm thick concrete walls form the structural envelope of the auditorium. The plaster panels are then mounted on a steel frame within the space.

Although the panels are not providing significant sound insulation, they were specified with a minimum surface mass of 145 kg/m² to limit their sound absorption at low frequencies. The thickness of the panels varies between 75 mm and 150 mm. The panels are stiffened with steel ribs, to increase their bending stiffness.

The profile of the panels is a series of troughs and ribs. Each of the troughs or ribs varies in width and in depth. In section, either horizontally or vertically, the ribs are slightly curved. The combination of these features serves to scatter sound over a significant frequency range.

The panels were pre-cast in 300 mm wide elements. Six different moulds were made, each of which could be turned upside down to create twelve variations in the panels. These were then mixed along the walls to create the maximum variability of profile.

3.5 Orchestral Enclosure

The orchestral enclosure is shown in scheme in Figure 1 and in detail in Figure 3. It completely surrounds the orchestra in plan and covers a height of 11m at the rear up to 14 m at the front. The lower 7 m is of solid construction, divided into vertical towers. The upper section is acoustically open, allowing the coupling of the sound between the performance area and the backstage area. The towers of the enclosure have to be readily moveable by hand. It was thought that 14 m was too high a tower to manoeuvre, so the visual screens of the upper sections are stored in the flytower.

The towers are approximately 1 m by 1.5 m and trapezoidal shaped in plan. The rear wall of each tower is solid plywood. The front 'wall' is a very open timber lattice, which mimics the vertically ribbed diffusion in the auditorium. Sound travels through and is diffused by the timber lattice, then is reflected off the solid rear wall. There are three horizontal shelves spaced up the height of the tower which provide reflections of the sound back down to the players.

There are solid flaps between panels which may be closed to complete the solid shell and give the players more support. Alternatively, they can be open to let more of the sound energy through the enclosure to the reverberant backstage. Loose sound absorbing panels are provided for the towers. These can be hung inside the tower to provide local sound absorption for the louder instruments.

3.6 The Acoustic Characteristics of the Auditorium

Detailed analyses of the acoustic parameters for the many different formats of the auditorium are beyond the scope of this paper. They will be reported in a future paper. A number of interesting characteristics and initial conclusion will be presented here.

Arup Acoustics have been able to experience and measure the acoustic response of the auditorium in a number of different forms. Variations between a choral concert and an amplified jazz quartet have all been successful acoustically. The variability in reverberation time is as designed. In addition, values of musical clarity (C_{80}) have been higher than expected for both concert and opera modes.

In the concert mode the perception of the sound is very warm with a rich timbre. These arise from a long reverberant response at low frequencies and the high level of sound diffusion. The EDT is significantly lower than the reverberation time (T30) and the late sound (audible at a stop chord) is perceived by the trained ear to come from the direction of the platform. Loudness throughout the auditorium is good.

The sound on the platform is significantly affected by the conditions of the enclosure towers and the amount of sound absorption in the backstage area. This allows the conductor freedom to experiment, to find the optimal layout of the performers and enclosure.

In conclusion, the auditorium successfully fulfils the design aims of providing an auditorium for the enjoyment of both opera and orchestral music. The variability for other events and between different genre has been very successful, providing the city of Bruges with a very versatile performance space.

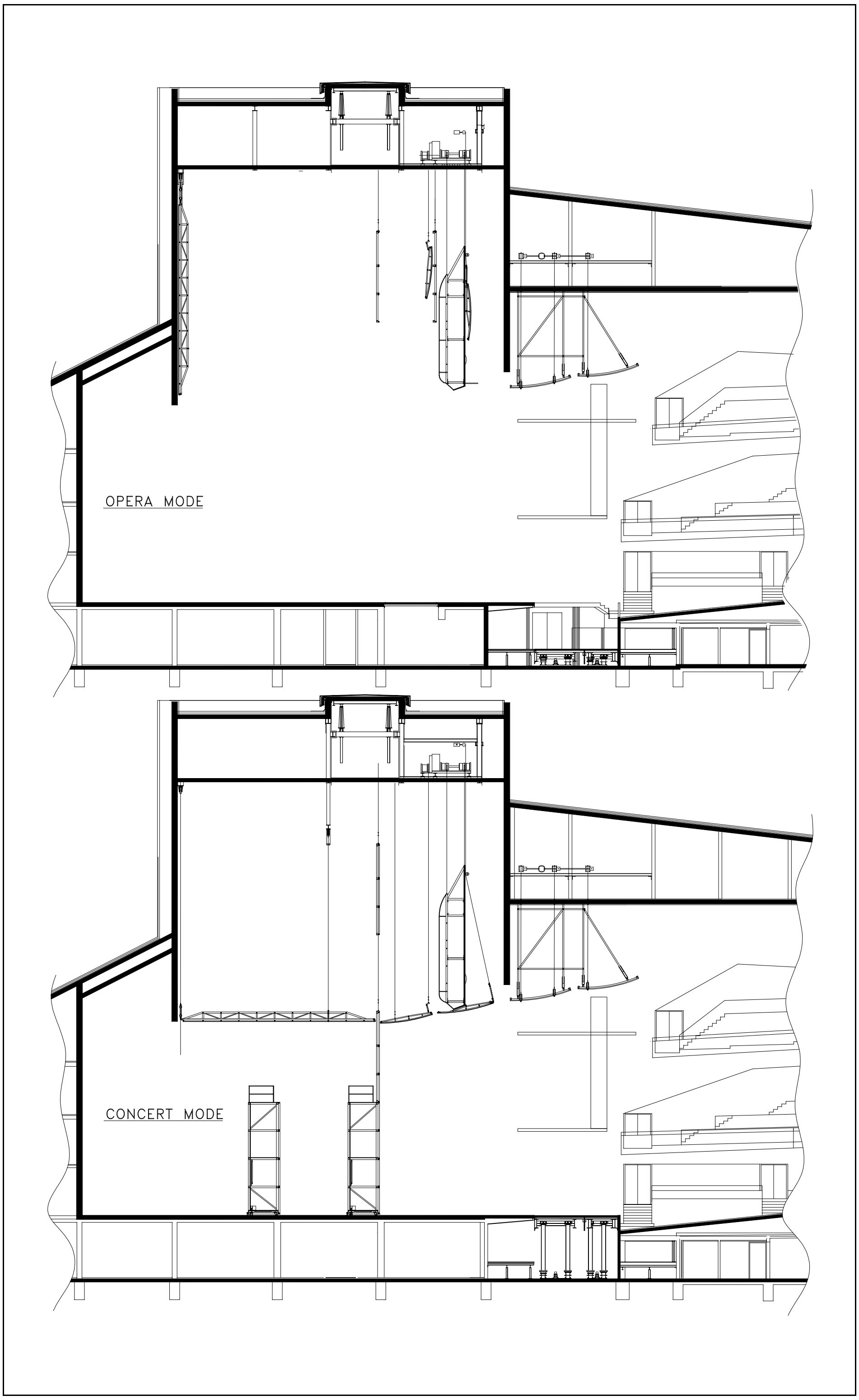

FIGURE 1 Section through Stage Showing Opera and Concert Formats

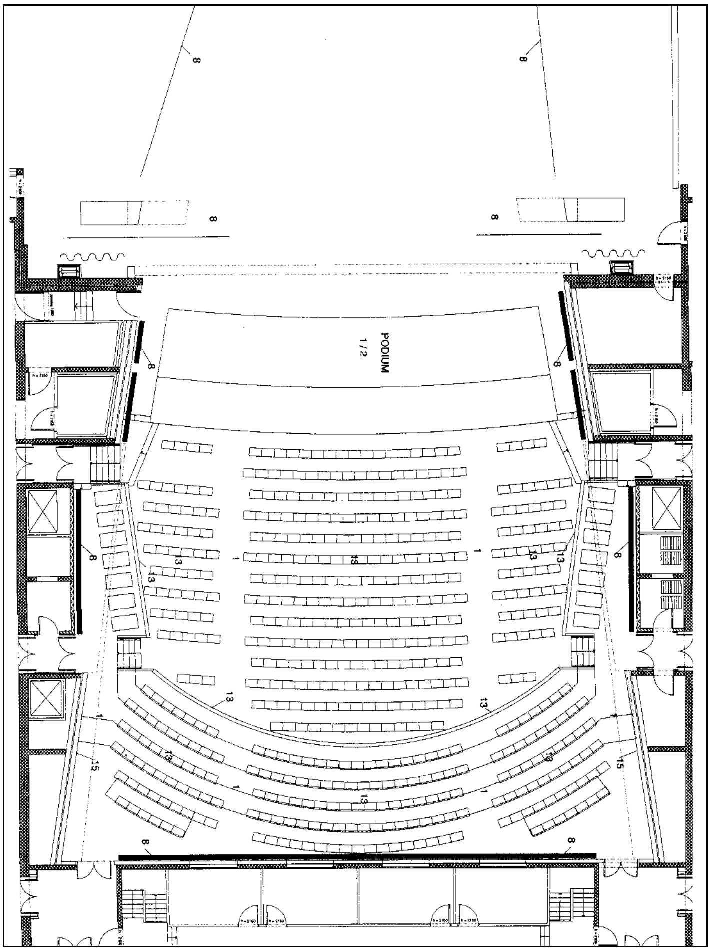

FIGURE 2 Plan at Stalls Level

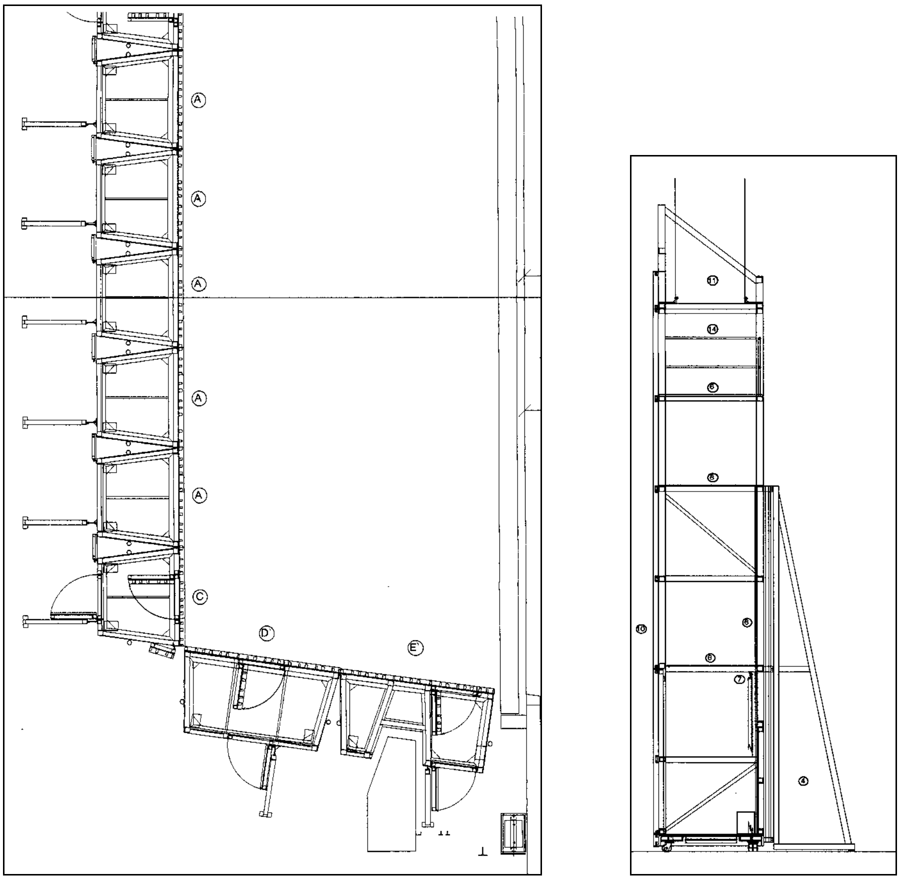

FIGURE 3 Plan and Section of Orchestral Enclosure