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Front cover:
The auditorium of the new Glyndebourne Opera House.
(Photo: Martin Charles)

Back cover:
The central courtyard in Phase 2 of Lloyds Bank headquarters, Bristol.
(Photo: Peter Cook)

Engineering an opera house: the new Glyndebourne

Stas Brzeski Derek Sugden John Thornton John Turzynski

1. Glyndebourne in 1934: Organ Room (left), Theatre (right).

Introduction

The new Glyndebourne Opera House opened on 28 May 1994, the 60th anniversary of its predecessor, with the same opera, *The Marriage of Figaro*. The original building, constructed by Sir John Christie in the grounds of Glyndebourne House (Fig.1 above) near Lewes in East Sussex, was not only too small for current demand, but suffered from poor acoustics and sightlines, had inadequate ventilation, and sub-standard back stage facilities. By 1987 his son, Sir George Christie, had begun to plan a new Opera House; after approaching nine architects and asking two to develop proposals, he appointed Michael Hopkins & Partners early in 1989. Arups became involved in all aspects of the engineering and acoustics design apart from theatre equipment and production lighting.

The brief called for an increase in seats from 830 to 1150 and an improvement in technical standards. Sir George Christie was quite clear, however, that music, theatre, and an intimate atmosphere took precedence over technology. He did not want a building where the technology became an end in itself.

Clarity and integration

The design of an opera house is complicated. The problems of long spans over stage areas and the support of balconies and flytower are obvious, but there are many more: the form and detail of the auditorium must give good sightlines and create the required acoustic; the fabric must provide good acoustic isolation; and the ventilation system should be inaudible. Also, theatre and lighting equipment have very specific needs. (These are the technical criteria; the architectural planning, too, has its own demands).

Apart from the requirement that only one season should be lost during construction, Glyndebourne presented another challenge: how to relate to the House and gardens, and maintain those qualities which make 'Glyndebourne' unique.

The concept

Whatever success the design has stems from the simplicity and clarity of the overall concept of the building, which works for all disciplines at all levels. The diagram may seem obvious but a study of other theatres soon reveals that its clarity is exceptional. Such simplicity is not easily achieved and relies on the complete integration of architectural, engineering, and acoustic design. Instead of trying to reduce the impact of the new Opera House by fragmenting it, like Glyndebourne House itself, the Hopkins' chose to create a single compact building and then reduce its visual bulk, both by cutting into the hillside and through the detail of the design.

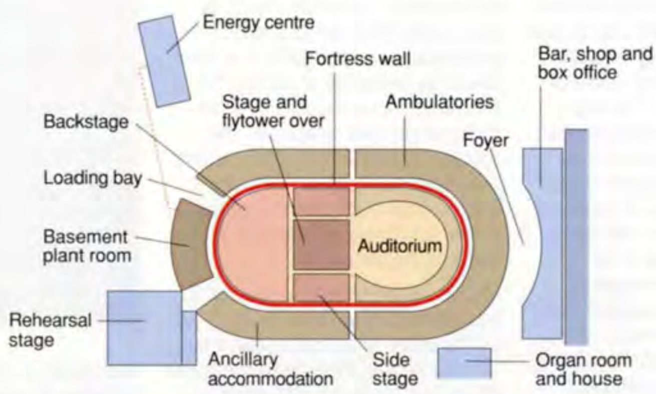
The design is a natural consequence of choosing a horseshoe-shaped auditorium for the intimate atmosphere it creates. The whole layout of the building is based on circular forms, which are used to soften its impact on the site. Recognizing that the auditorium and stage areas have the same requirement for acoustic isolation and generate similar widths, they are contained by an oval-shaped massive brick wall, the 'fortress wall'. At one end is the auditorium, at the other the back stage, and between lie the side and centre stages with the flytower above.

Around the fortress wall is wrapped the ancillary accommodation: dressing rooms, offices, and circulation space. Primary services distribution is located in this zone.

There is a basement. The area behind the proscenium contains plantrooms, stage equipment and dressing rooms, whilst in front there is a ventilation plenum beneath the auditorium, cloakrooms for the public, and plant rooms for the front-of-house areas. The back stage plantrooms supply air to the auditorium via two huge concrete ducts.

Noisier plant such as boilers and chillers are in a separate refurbished brick out-building.

The rehearsal stage too is outside the main envelope next to the loading bay, in which another stage can be built if necessary. The contours of the site are such that the rehearsal stage is almost completely underground, revealing its presence only by a low brick wall topped by a band of glazing and a lead roof.



2. Concept diagram.

3. The new Opera House looking westwards toward the South Downs.

Brickwork and the fortress wall

Glyndebourne House is a collection of mellow redbrick and stone buildings with gardens and lake, set in the Sussex Downs. The new Opera House not only had to relate to these physical characteristics, but also recreate the particular ambience which Glyndebourne has. In part this is created by the setting and the tradition of picnicking in evening dress in the gardens. It also lies, like the picnic, in the contradiction between sophistication and simplicity. In the old Opera House a complex art was performed at its highest level in a building which could best be likened to a large church hall. Some people were concerned that its acoustic qualities should not be lost but these in fact were poor with a dry sound and noise from aircraft using Gatwick.

Early in the design the architects considered using flint walling, a local material, but settled on brick as more appropriate. The hand-made bricks not only related its construction to the House, they also introduced a quality and scale of detailing which further reduced its impact and recreated the simplicity of the old building.

The fortress wall required mass to achieve its acoustic performance and, apart from under the flytower, the vertical loads are not particularly high, since above basement level the building consists of single-storey spaces with long-span roofs, or three-storey accommodation. This led to the idea of constructing the fortress wall out of load-bearing brickwork, double-skinned around the auditorium itself for acoustic isolation. It was then logical to add the enclosing accommodation as a dependent structure, in the way mediaeval cities built houses onto the outside of cathedrals and castles. This structural principle reinforces the architectural concept.

The Hopkins' work places great emphasis on the honest use of materials, but brickwork in large contemporary buildings is normally relegated to a cladding skin or a facing for precast units. This is betrayed in the bonding patterns, the use of the bricks in unlikely situations, and the location of mastic-filled movement joints. These are required by the expansion of brickwork and the lack of flexibility of modern cement mortars as much as by the need to absorb differential movements between frame and cladding. Nevertheless such joints would have undermined the visual integrity of the load-bearing structure and led to difficulties in detailing. They would also have been difficult to locate structurally and undesirable acoustically, so the older technology of lime putty mortar, which is more tolerant of movement, was adopted. The other distinguishing feature of modern brickwork, bonding patterns resulting from cavity construction, was avoided by building solid.

Auditorium, ancillary accommodation and roofs

Within the auditorium the balcony structures are of exposed precast concrete units stitched together by an in situ spine beam, balanced on a ring of columns, and restrained at the back by the fortress wall. (This follows the same structural principles as the Mound Stand and Compton and Edrich Stands at Lord's.)

The exposed thermal mass helps to smooth temperature fluctuations in the auditorium.

Outside the fortress wall, exposed precast slabs with an in situ topping are supported on precast beams which span between the fortress wall and brick piers. The outer ends of the beams appear through the walls and piers to make the construction legible and add detail to the brickwork. Brick spandrel panels span between the piers as flat arches carrying their self-weight. Precasting was chosen both for speed and for quality of finish; also, in the case of the accommodation structure, its form reflects the use of timber and cast iron in earlier brick buildings. The concrete mix was selected for its light colour and contained a mica-rich sand to give it sparkle. Precast panels were also used to form the ceiling over the auditorium and create the recessed lighting gallery. These elements play an essential role in the auditorium acoustics: apart from providing the mass necessary as part of the double-skinned acoustic enclosure, their sculpted form reflects and diffuses sound.

Above the precast units, the primary roof structure consists of radial steel trusses cantilevering into the centre from the perimeter where they are supported on the balcony columns and tied-down by the fortress wall. Above the trusses are double-skinned, lead-covered plywood panels. The mass of the lead and build-up of the panels is used for acoustic insulation. The trusses for the back stage are also radial, but in this case the centre of the system lies on the back wall of the flytower rather than over the space.

Continued on p.9

5. Main entrance (Organ Room in Glyndebourne House is on the left). ▶

Bricks and mortar

The bricks had to be similar to those used in Glyndebourne House, as well as satisfying engineering requirements, and their selection involved considerable research. The final choice was a Selborne hand-made, re-pressed brick, made from gault clay extracted from a deposit mined for many years. They are a modified imperial size, 220 x 106 x 60mm, to match those in the walls of the House. Compressive strength is 27.5N/mm^2 with an irreversible moisture movement of 0.37mm/m — classified as low by CERAM Building Technology. Water absorption is 14.3%.

The facing bricks have a textured surface produced by coating with sand before firing. Both these and the common bricks are made of the same clay and have the same mechanical properties, thus avoiding problems of differential movement between facings and commons bonded together or in adjacent leaves of cavity walls.

Knowledge about the manufacture, use and behaviour of lime mortar, chosen to avoid the need for movement joints, is not widespread, and an investigation was carried out, including a visit to The Lime Centre in Hampshire to gain practical experience. Lime for mortar is produced by burning chalk or limestone (calcium carbonate) in a kiln at about 900°C to produce calcium oxide. Two types of lime are used for mortar: lime putty or dry hydrate. The former was employed at Glyndebourne for its good water-retention properties, workability and availability. It is produced by hydrating or slaking the lime (calcium oxide) with water to produce calcium hydroxide. The reaction is exothermic, vigorous and potentially dangerous. The putty is stored under water, the longer the better, for increased plasticity and bonding properties.

Modern cementitious mortars (which incorporate unhydrated dry lime) set by the action of hydration with water. The mortar sets throughout the depth of the joint and, like most cement-based compounds, is accompanied by shrinkage.

In contrast, true lime mortars set by the action of carbonation at the exposed surfaces of a joint. Atmospheric carbon dioxide is absorbed into the mortar and the calcium hydroxide present is converted back to calcium carbonate in a lengthy process known as induration. The depth of setting is relatively shallow, and the core of a mortar joint remains plastic. It is this softness that permits the masonry to absorb stresses caused by movement. Any cracking that does occur is small and distributed along and across a wall. In effect, movement joints are created at every bed and perpend joint.

The lime putty was delivered in tubs, and the mortar mixed on site using gauging boxes and mortar mixers: the proportions were 1:2:9 (white PC : lime putty : sand).

◀ 4. Brickwork detail on arch.

Bricklaying commenced with the construction of sample panels for the approval of bricks, joint profile, blending and colour. This was a useful testing ground to establish working procedures for the main building.

The cross-bonded flat brick arches span up to 2.9m between skewbacks built into the piers. They are 334mm thick and 536mm high, are unreinforced, and incorporate a rise of 25mm. They support their own weight and a brick spandrel panel above. The bricks for each arch were made from a single column of clay. Each brick had a unique number, and complete arches were delivered on a single pallet.

Although the arches are relatively lightly stressed there was concern that they might be prone to movement and, with negligible tensile strength, exhibit unwanted cracking. A load test was carried out, both to answer this question and to assess the comparatively weak mortar.

An arch was constructed at CERAM's laboratories using the chosen bricks and lime putty mortar in the agreed bonding pattern. The arch was buttressed in a similar manner to those on the building, and was loaded in a predetermined sequence. Strains and movements were monitored at relevant points such as springing point, extrados centreline and intrados centreline. The arch withstood the applied load without undue distress and with displacements close to predicted values.

The maximum length of continuous brickwork on the building is just under 100m around the front of the Opera House. In other areas, perforations in walls for doors or other openings reduced this length. The potential long term irreversible moisture expansion of the bricks has been estimated as about 24mm, which does not account for moisture movement which occurred over the months the bricks were stockpiled in the open. This strain was considered acceptable, taking into account the restraint that was provided by the floor slabs and beams.

The use of load-bearing brickwork with lime putty mortar on a building of this scale has not been seen for many years. The investigations, tests, and trials were an essential part of developing the design and understanding the techniques required for construction. In the end, though, the design depends on engineering judgement.

The acoustic

The brief

Sir George Christie's brief was simple and direct, but very difficult to achieve: he asked for a sound which combined the clarity of the old house with a 'resonance' that would flatter the orchestra and singers. Like many acoustic briefs it illuminated two fundamental criteria which are virtually mutually exclusive. Throughout the history of opera there has been an argument about whether words or music are of primary importance; the French with their literary tradition favoured the words, whilst the Italians were more concerned with melody, harmony and timbre.

This dichotomy is still with us today and its resolution, achieving that delicate balance between words and music, was the starting point for the geometry of the Opera House as a response to Sir George's brief.

Setting the standards

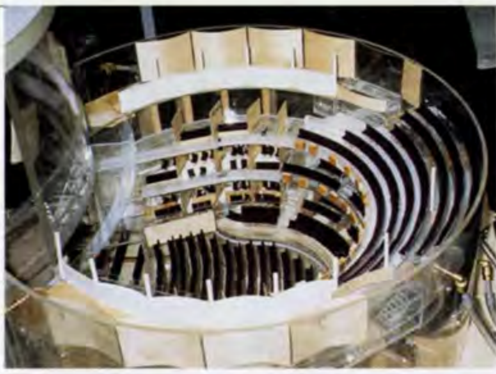
At the earliest stage, after the Hopkins' appointment but before that of the theatre consultant, some discussions took place whilst the auditorium still had the vestigial fan-shaped form of the John Bury brief*.

This did not inhibit the setting of geometrical standards to achieve the preferred acoustic. Auditoria for music, whether concert halls or opera houses, invariably fall short of the volume per seat necessary to achieve the appropriate reverberation time (RT); defined as the time taken for a sound to decay through 60dB, RT is still considered the prime criterion for measuring the quality of sound within an enclosed space. Its value at different frequencies is also very important to the quality of the sound. It is directly proportional to volume and inversely proportional to the absorption of all the surfaces.

Volume decreases as the architectural concept is developed and detailed! In addition, clients and architects find ways of increasing seat numbers as the design and sight-line analysis develops.

Initially, $8m^3$ per seat was the volume fixed to achieve the preferred RT; for clarity, a maximum 17-18m between balconies was set to ensure strong early side reflections; whilst for acoustic and visual intimacy, the furthest seat was to be a maximum of 30m from the stage riser.

The quality of any acoustic is immeasurably enhanced by a quiet background. To achieve this a double skin wall and roof construction of sufficient mass with the appropriate cavity was specified, together with an air-conditioning strategy that would ensure a background noise level of PNC15 — approximating to the threshold of hearing.



6. Acoustic scale model showing convex reflectors installed for impulse testing.

7. Auditorium roof showing use of structural ribs for sound diffusion and 'jelly-mould' sound diffusing form of vertical precast sections.

8. Derek Sugden firing a .38 revolver during initial acoustic tests in December 1993.

Design and analysis: the 1:50 scale model

As the design developed, it became clear that Hopkins' auditorium would not include any 'carpets and curtains' and a minimum of absorbent secondary fixings, so the volume per seat could be relaxed a little. However, the $8m^3$ per seat did decrease to just below $7m^3$ per seat as expected, indicating a mid-frequency reverberation time of 1.4 secs. Anthony Whitworth-Jones, the General Director of Glyndebourne, placed great emphasis on clarity. He considered the Coliseum in London and the Bayreuth Festspielhaus with RTs of 1.5-1.6 secs to be too reverberant. Both these auditoria, but particularly the Coliseum, lack short powerful side reflections. With the short powerful side reflection, an RT of 1.4 secs - still somewhat more reverberant than most opera houses — was considered to be appropriate.

With the geometry and seating finalized, a 1:50 scale model was constructed in Arups' Model Shop, with the first roof and ceiling scheme.

Four were tested before the architects were convinced about a design, which incorporated a 'flat dome', a common feature of many opera houses. Sound waves focus in a similar way to light, and this design avoided the focusing problems associated with many earlier schemes. The model was also essential in exposing focusing from the drum at high level. This was corrected by the introduction of convex panels. Slotted lift-off panels were also introduced to allow the inclusion of small areas of absorption to deal with certain focusing and to allow for a limited degree of fine tuning.

Extensive work was carried out in the model to define the final geometry of the balcony fronts — fundamental in achieving, after the direct sound, the strong early reflections which provide intimacy, clarity and envelopment. The detailed geometry was resolved in the model to achieve this without focusing effects. The profiles reflect sound down into the stalls at the sides, with a subtle change in profile towards the back of the auditorium, and are slotted to provide acoustic transparency where focusing would occur.

To ensure an orchestral sound of some richness and warmth, a 20-25% increase in RT at low frequencies is needed. This is quite uncommon in most opera houses, where orchestras sound dry and rather 'boxy'. It was most rewarding that Hopkins' design of the auditorium without an architecture of second and third fixings was fundamental to achieving this aim. The soffits are of exposed concrete, the main floor is a stiff composite layer with a minimum thickness of 40mm, and all the balcony fronts are of very rigid solid pine, with a geometry that adds to their structural stiffness and so ensures a minimum of bass-absorbing resonance. This was a most important aspect of the acoustic design.

There was extensive acoustic input into the seat design in addition to the close work with the mechanical engineers to achieve the specified noise attenuation. The seats were tested in a laboratory with and without auditors. Following the first test, adjustments were made to certain aspects of their construction to achieve the specified absorption coefficients. These modifications were confirmed in a final test.

Predictions and measurements

Measurements in the model predicted a mid-frequency RT of 1.4 secs, with 1.7 secs at 125Hz. A test concert with full audience was held on 28 March 1994, where measurements gave an average mid-frequency reverberation time of 1.25 secs with 1.65 secs at 125Hz. The clarity index was high throughout the auditorium and the impulse traces were of 'text book' shape.

The orchestra pit

One of the central problems for an acoustician in the design of an opera house is the balance between pit and stage sound. The orchestra pit of a modern opera house must be able to house and adapt to a wide repertoire, from the orchestras of the Renaissance operas of Monteverdi and Cavalli, through Haydn and Mozart, to Verdi, Wagner and Richard Strauss, and on to Birtwistle and beyond.

In the last 200 years the orchestra has changed out of all recognition and the instruments have become enormously powerful. Conductors have a love affair with that great lush sound favoured by many recording engineers and producers. The power of the human voice may have increased somewhat, but there is no comparison with the size and power of a modern orchestra.

The brief for the orchestra pit was not precise about the maximum number of players. There is a tradition at Glyndebourne which encourages young singers, and to achieve the delicate balance between stage sound and pit sound with a large modern orchestra, a maximum distance of 3.6m between the orchestra rail and the stage riser was agreed. It was always the intention to place the more powerful instruments of a modern orchestra on descending rostra under a limited cantilever section of the stage. The final structural scheme, together with the abandonment of a proposal for sliding proscenium boxes and subsequent change in geometry of the sliding bridges — part of the original John Bury brief — resulted in a decrease to the overall length of the pit. To compensate for this, the distance between the orchestra rail and stage riser was increased to 4m.

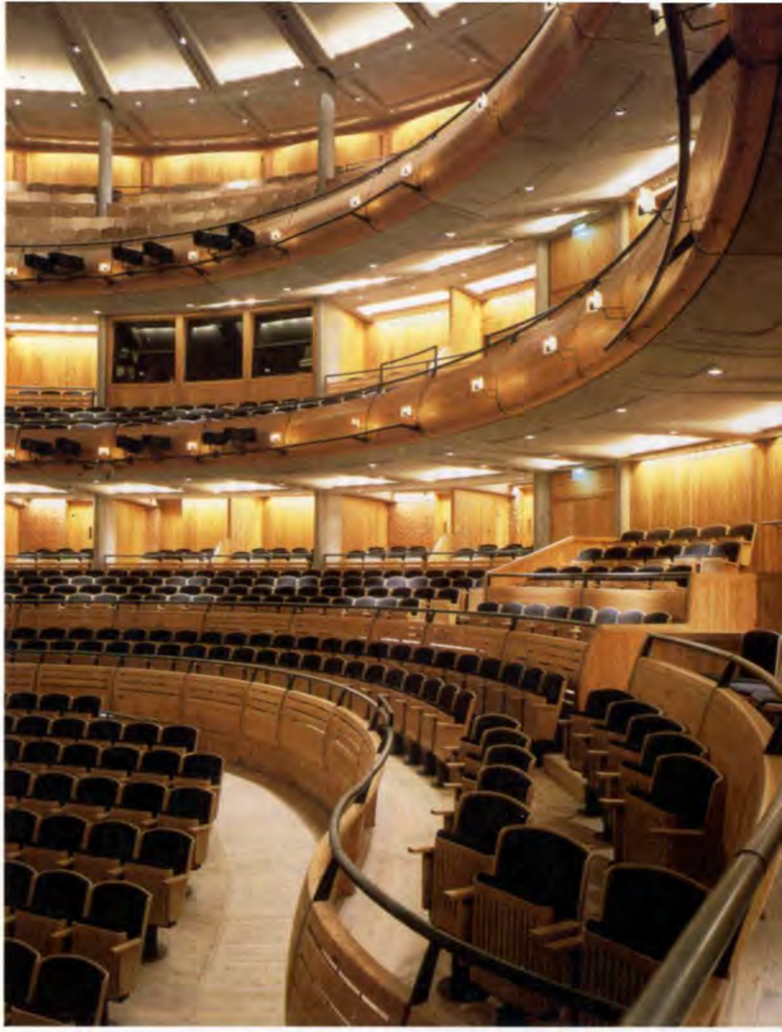
Following the test concert, the London Philharmonic Orchestra, with c.75 players on modern instruments, tested various configurations of the orchestra for *Figaro* and *Peter Grimes*, under conductors Bernard Haitink and Andrew Davis. The rostra geometry, particularly at the back of the pit, was resolved both for sight lines and comfortable seating.

The other Glyndebourne band is the Orchestra of the Age of Enlightenment, about 50-strong, who play on original, and thus less powerful, instruments. In view of this, it was desirable that all their players should sit forward of the stage riser, but with the growing demand of orchestral players for increased space and the presence of the safety net this was not possible. However, with the adjustable pit lift slightly below the preferred stalls level the OAE can be accommodated with the brass and woodwind placed under the safety net or edge of the cantilever.

Coda — art or science

Acoustics is often referred to as a 'black art', but it is no more nor less an 'art' than any other branch of engineering. Engineers, like architects, work from precedent, but primarily from intuition, using calculations as a guide to what they want to do, and with detailed analysis as a supporting tool. Acoustics does perhaps differ, in that the choice of an acoustic is highly subjective, whereas the overall stability of a structure is not a matter of taste or opinion. A quiet background, however — one of the most important qualities of a great acoustic — is not a matter of opinion, although even on this subject we can argue how quiet we should make an auditorium. This aspect of acoustics, the setting and achievement of sound insulation and sound attenuation, was one of the great success stories at Glyndebourne. Rob Harris of Arup Acoustics observed that it was the first auditorium we have measured that achieved PNC15 at the first test with no modifications or 'tinkering' necessary.

* John Bury was the theatre designer and consultant who prepared the drawings for the competition brief. He had designed a series of Glyndebourne productions for Peter Hall, including *Figaro*, *Fidelio*, and *Carmen*, and had been auditorium consultant to the original Edinburgh Opera House.



9. The auditorium.

10. Semi-circular backstage area.

Auditorium ventilation system

Choice of system

The design of the ventilation system for an auditorium is distinguished by two key features: the large concentration of occupants within a relatively small proportion of the overall volume, and the absolute importance of the system's acoustic performance.

The decision to ventilate the auditorium by a displacement system supplying air at low level under the seats and extracting at high level was natural and intuitive. Systems supplying air from above must overcome the natural upward airflow resulting from buoyancy forces generated by the heat of the audience. Falling fresh air becomes mixed with rising hot air so that heat and odours are recirculated to the occupants. In contrast, displacement ventilation complements the natural air flow pattern. Cooler, fresh air supplied from below replaces stale rising air so that the occupied zone is constantly purged with conditioned air and local recycling is eliminated. There is no need for higher air velocities to overcome the natural air movement, so there is less likelihood that noise will result. A benefit of the resulting increased cooling efficiency is that air is supplied at higher temperatures than required for ceiling supply systems, so refrigeration running costs are reduced.

11. Seating with acoustic absorbent base, mounted on integrated air supply pedestal.

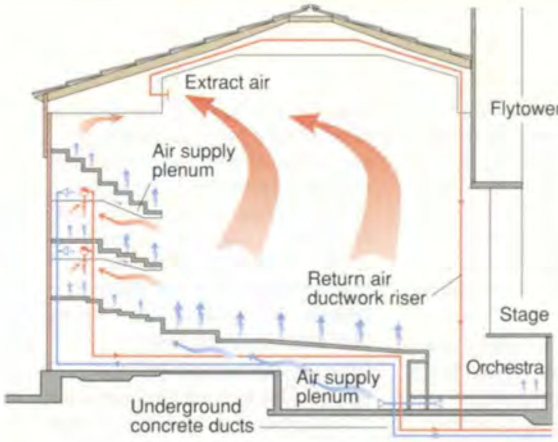
Early on, modelling studies were carried out in conjunction with Cambridge University's Department of Theoretical Physics and Applied Mathematics. A 1:25 perspex model of the auditorium, stage and flytower was inverted in a water bath, with coloured saline solutions of various densities used to represent hot air movement. The choice of a displacement ventilation system was confirmed and important data obtained for subsequent use in the design.

System design

To meet the PNC 15 noise limit, plant is located at a distance from the auditorium and, in addition to extensive attenuation, very low air velocities have been used in all distribution systems to avoid noise generation. The ventilation system is integrated with the building fabric wherever possible. Four 50m long, 2m x 2m concrete ducts buried in the ground beneath the backstage areas connect the ventilation plant to the auditorium. Air is injected into large plena beneath the floors of the stalls and each of the circles, and enters the auditorium through air supply outlets integrated with the seating support pedestal. The orchestra pit is similarly supplied, but with a flat grille served by a separate plenum connected to a branch of the main system. The exposed structural concrete within the auditorium provides a substantial thermal cooling store which smooths temperature swings by absorbing and releasing heat energy.

Choice of air outlet

Various auditorium air outlet types were considered, both integrated with the seat support and separate. Each outlet was tested to prove its air flow and acoustic characteristics and examined to ensure that it could be accommodated within the space available. More unusually, two further criteria peculiar to Glyndebourne were imposed : the ability to allow seats to be removed to locate cameras for video broadcasts, and the resilience of the performance of the outlet to the Glyndebourne tradition of placing coats under seats.



12. Auditorium ventilation principles.

On completion of the tests and studies, the integrated seat pedestal air outlet was chosen. A detailed simulated load test at an acoustic laboratory followed. A block of 24 seats with air supply pedestals was built above a plenum pressurized by a fan. A lamp bulb was placed on each seat to represent the heat generated by the audience, and detailed air temperature and velocity measurements were taken, as well as further acoustic measurements.

System tests

The heat load test was repeated on site at full scale during commissioning trials. Lamp bulbs and convector heaters were distributed throughout the auditorium to simulate the heat generated by a full house — equivalent to about 1250 domestic 100W lamps. Sufficient theatrical lights were rigged and operational to represent the heat given off by production lighting during a performance. Temperatures were recorded at various locations and tracing smoke used to examine the flow of air throughout the auditorium and stage area. The results showed an acceptable correlation with the predictions of the earlier scale model test.

The real proof came with the first use of the auditorium for a public performance, at the 28 March 1994 test concert, which lasted approximately 90 mins. Temperature measurements compared favourably with the design predictions and reports from members of the audience and orchestra were positive. The acoustic performance of the system has been confirmed both by measurement and by its inaudibility to the human ear.

Conclusion

Testing at successive stages in the design, construction, and commissioning process underpinned initial design assumptions, confirmed detail design parameters and, finally, proved satisfactory system performance. The successful outcome confirms the importance of testing in situations where attention to detail is paramount in achieving the end result.

13. Fabric canopy, designed by Arups, over the foyer entrance.

▶ *Continued from page 4:*

The trusses span from the fortress wall to a semicircular torsion beam hung from the flytower roof, the semicircle being used to create a skylight. The side stage roof trusses simply span from flytower to fortress wall.

In these areas the acoustic requirements are less than over the auditorium so the ply and lead roof is the only skin, thus allowing the steelwork to be seen from below. The roof of the rehearsal stage also consists of exposed steelwork with lead/ply panels. Like other parts of the design the steelwork continues the contrast of simplicity and sophistication, the design being based on simple back-to-back angles and tie rods. The sophistication lies in the organization and the refinement of the details. The roof over the accommodation uses timber and steel flitch beams to introduce a more domestic scale.

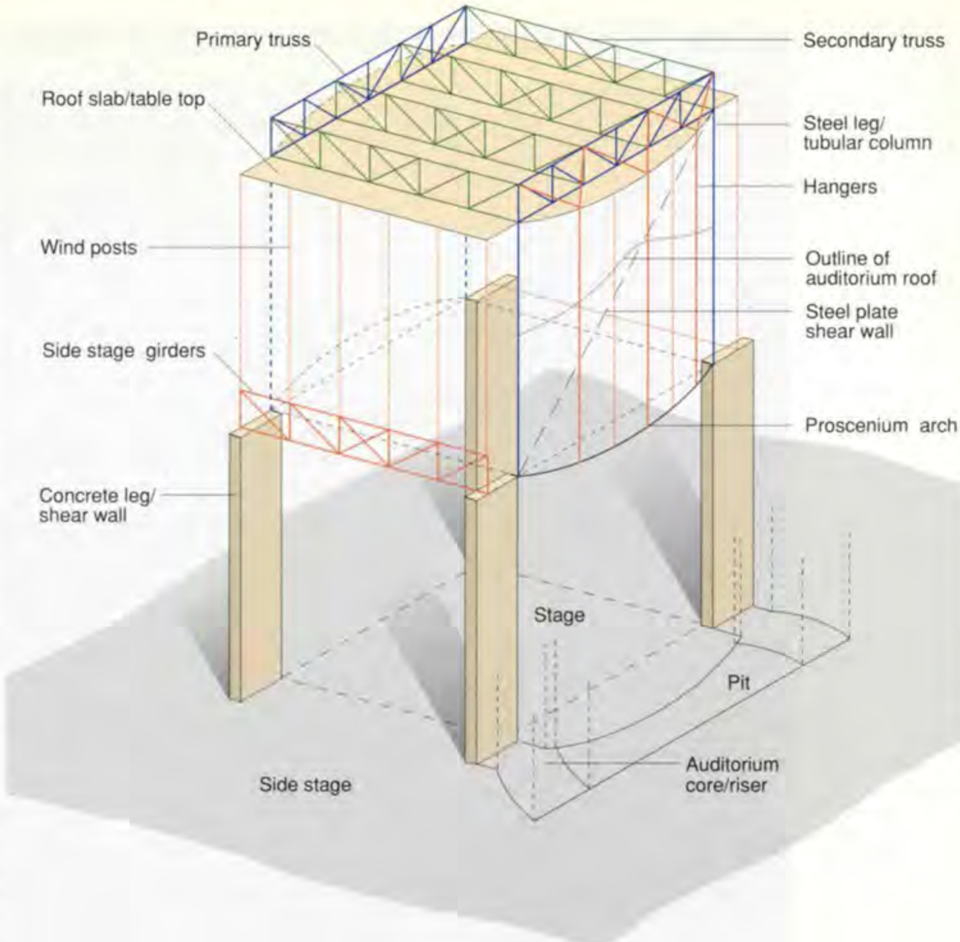
The exposed brick, the finely detailed precast concrete, the reclaimed pitch pine balcony fronts and panelling, and the bare timber floors have a tactile quality which creates a particularly restful atmosphere in the auditorium. This is enhanced by the apparent absence of services, not easily achieved in a building without applied finishes. Air is supplied through perforated seat pedestals, lighting is recessed into the precast concrete, and conduits are cast-in. The back-of-house areas were detailed with the same attention; great care was taken over the co-ordination of services, brickwork and concrete, conduits were cast-in wherever possible and final routing was simple. A fairly robust approach was adopted for the actual detailing and selection of fittings.

Flytower

The largest single piece of structure and the most conspicuous element of the building is the flytower, its size following inevitably from that of the stage and the height of the proscenium. Originally it was to be elliptical and of brick construction, but as the design developed the shape changed to a rectangle with curved front and back walls. As well as softening the shape, the curves create spaces for the curtains, a staircase, smoke extract plant, and dimmer rooms. However, the curved torsion beams required to support these walls were very large and would have been an unacceptable intrusion into the auditorium above the proscenium. The design was changed so that the walls were suspended from roof top trusses, which also helped speed construction. A grillage of exposed steel trusses is carried by four steel columns supported on concrete shear walls, two of which form the proscenium. The grid floor and stage equipment are suspended from the grillage as well as the front and rear walls which are formed of lead-clad timber panels and precast concrete units; similar side walls are supported by storey high trusses.

The House in the garden

Part of the attraction of Glyndebourne is strolling around the grounds before the performance and during the intervals, one of which is long enough for people to eat in the restaurants or picnic in the grounds. This, and the fact that the season takes place in the summer, creates opportunities which a more conventional situation cannot. The dining room is in a separate simple brick building, while outside the auditorium the walls of the circulation areas consist only of the piers with balustrades between. This helps reduce the solidity of the façade as it looks out to the House and gardens. Another softening device is the PVC-coated polyester canopy (left: Fig.13) which links the building with the bar, shop and box office attached to the original dressing room block which was retained. This creates additional circulation space sheltered from the English summer.



14. Flytower structure.

Construction

Construction started in March 1991 with an enabling works contract to divert existing site services. After the close of the 1991 season work began in earnest with the demolition of as much as possible of the existing building without affecting the operation of the main part of the opera house in the 1992 season. Work then proceeded on the structure behind the proscenium until after the 1993 season when the rest of the old opera house was demolished.

Before work started there had been concern over the problem of removing 33 370m^3 of excavated chalk through the narrow country lanes. This was solved by a slight modification to the topography of one of the adjacent fields. The Christies seemed to delight in the 10m deep hole, literally outside their back door, as a sign that their project was under way, but it cannot have been easy for them to live with a large, complicated, fast construction project in their garden.

The choice of load-bearing brickwork for a project to be built in a very short time might seem perverse when speed is normally associated with steel frames. However as a simple labour-intensive activity it is well suited to working in many areas at the same time. Moreover, the extensive use of precast concrete helped speed the work. Other key factors were the simplicity of the ventilation system and the fact that almost all structural components were self-finished, which minimized the fitting-out time.

Glyndebourne is a special building both in the quality of its design and the feeling that it will be there for a long time. Many people have remarked on the enthusiasm of those who worked on its construction. Perhaps it was these things which generated the enthusiasm or perhaps it was just that men could see the skill of their hands in the finished building, something increasingly rare as construction becomes an assembly process and finished surfaces are machine-made.

Timetable

Architectural appointment:	February 1989
Scheme design approval:	December 1990
Start on site (Phase 1A):	27 July 1991
Start on site (Phase 1B):	5 August 1992
Completion and handover:	31 December 1993
First night:	28 May 1994

Credits

Client:
Glyndebourne Productions Ltd.
Architect:
Michael Hopkins & Partners
Consulting engineers:
Ove Arup and Partners Jeremy Brasington, Pat Clowry, Barney Jordan, Rob Kinch, Clare Murphy, Steve Peet, Caroline Ray, Mervyn Rodrigues, David D Smith, John Thornton, John Turzynski (structural)
John Berry, Stas Brzeski, Martin Greenblat, Carolyn Gallehawke, Nigel Tonks, Graeme Walker (mechanical)
Joe Patel, Alex Perkins, Chris Taylor, Andy Worsick (electrical)
Bob Bassah, David Carroll, Tony Minchinton (public health)
Bob Cather, Chris Murgatroyd (AR&D), Nicos Peonides (Controls)
Chris Barber (Arup Fire), Adam Chodorowski (Arup Geotechnics)
Vaughan Sutton (Transportation)
Acoustic consultant:
Arup Acoustics Derek Sugden, Rob Harris, Raf Orlowski, Helen Thornton
Theatre consultant:
Theatre Projects Consultants
Cost consultant:
Gardiner and Theobald
Construction manager:
Bovis Construction Ltd.
Illustrations:
1, 15: Courtesy Glyndebourne Archive
2, 12, 14: Dennis Kirtley
3, 5, 9-11, 13: Martin Charles
4, 6: Peter Mackinven
7: Ove Arup and Partners
8: Richard Davies

15: 1994 programme

Cape Town's Olympic Games bid

Mark Bostock   Des Correia   Cliff McMillan   Ugo Rivera

1. Table Bay Harbour: Waterfront and central business district.

Introduction

During the past few years certain people — among them Sam Ramsamy, President of the National Olympic Committee of South Africa (NOCSA) and Raymond Ackerman, a prominent Cape Town businessman — became aware of the prospect of an African city being favourably considered by the International Olympic Committee (IOC) to host the 2004 Olympic Games. Africa is the only continent never to have had the Games on its soil, and political events there in the early '90s, including South Africa's rejoining the international community, have created some enthusiasm for the suggestion.

South Africa's three largest cities, Cape Town, Durban and Johannesburg, started preparations to bid, so NOCSA decided on a formal competition between them. One South African city could thus be chosen with full national support to compete for the Games.

Cape Town City Council produced an audio-visual presentation outlining the benefits and opportunities of hosting the Games, and formed an interim committee including sporting representatives and businessmen. It was decided to commission a formal feasibility study, and professional firms were invited to make submissions. Some 40 teams did so, including one led by Arups, and this was selected in September 1992 to assist the Cape Town Olympics 2004 Steering Committee in establishing the feasibility of hosting the Games. (This formal client body now comprised the broadest possible cross-section of interests in the Western Cape — sporting, community, business and political.) If hosting was found to be feasible, the next step would be to secure NOCSA's nomination.

Arups' role was to manage the entire bid process: prepare the sports plan and capital expenditure estimates, deal with the consultation process for the technical proposals, and carry out an economic benefit analysis. The Feasibility Study, completed on schedule between October 1992 and April 1993, concluded that it was feasible for Cape Town to host the Games and that in fact the city could put together an irresistible bid to the IOC in 1997. Arups were subsequently also employed to prepare the technical bid documentation for NOCSA, and to present the technical and economic case.

NOCSA had indicated that it would make its decision by mid-1993. During the course of the Study, however, it changed the bidding process and a decision was eventually only made in January 1994. To involve NOCSA more in the cities' proposals and to allow the latter to demonstrate their capabilities, each had to host a NOCSA Council meeting in 1993 and make a presentation to it — Cape Town in April, Durban in August and Johannesburg in November. The technical bids were submitted at the end of November and the final presentations were made on decision-day: 29 January 1994.

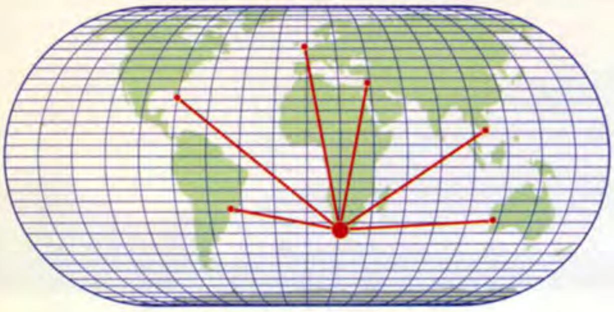
This extension of the period placed particular strain on Cape Town's financial resources and its consultants, partly because it was the one bid to be entirely private sector-led and funded, but also due to the timing set by NOCSA. Having disclosed the depth of their thinking in April, Cape Town had to maintain the momentum and lead for another eight months.

Environment, location and features

'The fairest Cape' is famous for its natural beauty: for Table Mountain (Fig.1), for the beaches around the Peninsula, for the wine farms within 100km of Cape Town, and for the famous 'fynbos' (the local generic name for the shrubberies of this floral kingdom). It is a tourist paradise that has not realised its potential internationally because of South Africa's political isolation. All indications are that tourism will increase dramatically over the next 10 years, and that the Olympic Games will be a major stimulus to this. Because of the Cape's special environmental qualities and the strength of the ecology movement in Cape Town, the Steering Committee is committed to an Environmental Charter.

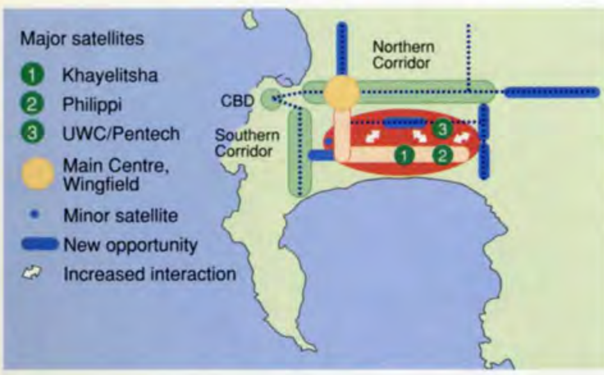
This will ensure that any development, for tourism, industry or the Games, will be co-ordinated within its framework so that impact on natural assets will be controlled.

The city is the centre of the second most powerful province economically in the new dispensation in South Africa — a focus for likely investment and industrial growth. It is a desirable city: people want to live there, it has a trainable potential workforce, and there are well-developed educational facilities including three universities and two technikons (major technical colleges). It has a well-developed primary road network and rail infrastructure, plus good transport and communication links to the rest of Africa and other continents. Being in the European time zone would be an



◄ 2. An international destination.

3. ► Feasibility study.

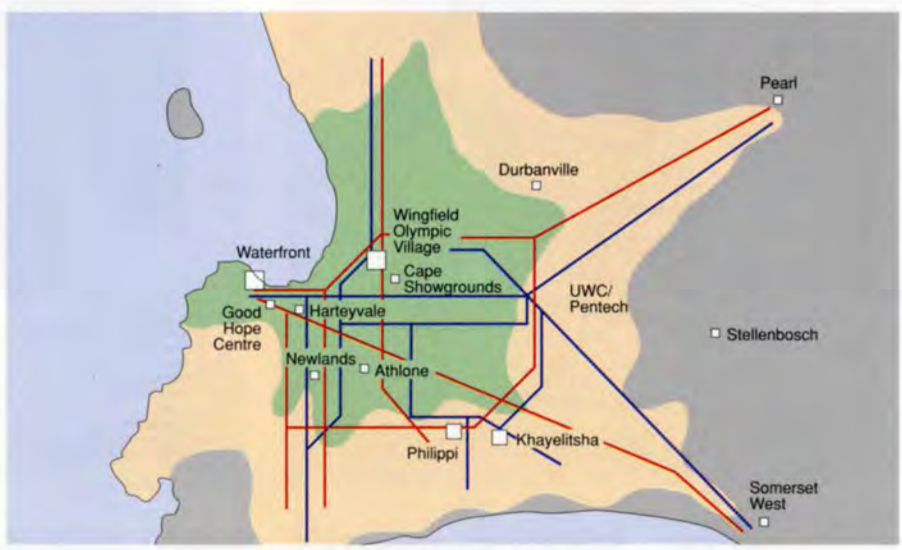


◄ 4. Needs and opportunities.

5. ► Transport.

advantage for the 2004 Olympics because all the summer Games between 1980 and 2000 will have been in the Eastern or American zones except for Moscow and Barcelona. It is endowed with outstanding medical facilities, including South Africa's first sports medicine faculty. So far as sport itself is concerned, Cape Town has a strong tradition which includes hosting international events like the Argus Cycle Tour (with 20 000 competitors, the largest event of its kind in the world), the Two Oceans Marathon, the Cape-to-Rio Yacht race and athletics, rugby and cricket events.

Finally, it is a centre with a rich history, a liberal political tradition, and cultural diversity, which has led to its inhabitants being described as the rainbow people', and hence the proposal dubbed the Rainbow Games'. Cape Town's tradition of relative peace and stability contrasts with the violence affecting most of South Africa in recent years, and naturally political stability and peace are prerequisites to staging a successful Olympics in South Africa.



6. Cape Town's Olympic plan.

A developmental strategy

From the outset the Steering Committee recognized that the bid process should be based fundamentally on a sound developmental strategy if the concept was to enjoy the vital support of the community and the future Government. This meant that:

- It had to be African and community based.
- It needed to address income redistribution and empowerment.
- It had to be feasible.

The objective was to capture the synergy that exists between the Olympic requirements and the regional needs, opportunities and potential, and at the same time to utilize the Olympic ideals, linked to a national vision, to create an approach that would be unique and irresistible (Fig.3).

The Cape Town metropolitan region comprises two zones of historical affluence and development, one running north-south down the peninsula and the other east-west from the central business district (CBD) (Fig.4). Between these, some 2M people — increasing rapidly as a result of inward immigration — live in relative poverty on the Cape Flats south-east of the CBD, many in informal settlements like Khayelitsha. To achieve the developmental objective, the Games had to be planned to bring benefits to these areas.

Cape Town's transport infrastructure (Fig.5) is at present focused on moving people to and from the CBD. (The 300 000+ morning peak capacity makes the commuter rail system Southern Africa's largest.) By locating the proposed Olympic venues near these road and rail corridors, it will be possible to provide the necessary transportation efficiency between them, and at the same time ensure that the Olympic planning process acts as a catalyst to co-ordinate the development of the system over the next 10 years, transforming it from its present CBD focus to a metropolitan-wide looped service, giving the people of the region greater mobility and access to employment opportunities. After examining more than 20 sites as possible Olympic venues, the Arups-led team decided to locate the main Olympic complex at Wingfield, with sub-nodes at Philippi, Khayelitsha and the adjacent University of the Western Cape and Peninsula Technikon campuses (UWC/Pentec).

These nodes will be strongly linked by the transportation system, enabling the Olympics to reinforce development already proposed there by existing initiatives. At the same time, all existing sporting facilities in the region would be utilized to their maximum, either as competition or training venues (Fig.6).

▲ 7. Olympic Stadium.

◀ 8. Wingfield Olympic Centre

▼ 9. Khayelitsha Sports Centre.

The Wingfield site offers everything a main Olympic complex could need: a 300ha, open, publicly-owned site which, without problems of congestion, can be planned for optimum Olympic use as well as for after-use, strategically located 12km from the city centre and in its growth path, and with a magnificent vista of Table Mountain.

Wingfield will have the world-class Olympic stadium for 80 000 spectators (Fig.7), and two indoor arenas, for which concept designs were prepared of state-of-the-art facilities that then could be transformed into a permanent multi-feature sports centre.

The compact arrangement of the proposed athletes' and media villages and media facilities, all at walking distance from the stadium and arenas, plus the potential to use the Olympic thrust as a catalyst to stimulate immediate mixed use development of the site to provide lasting benefits to the community, made the proposals particularly potent (Fig.8).

The facilities at Philippi and Khayelitsha will reinforce the proposed Western Cape Metropolitan Development Framework, delivering sorely-needed facilities to the Cape Flats communities. A football stadium and boxing arena, serving as a multipurpose indoor complex after the Games, are proposed at Khayelitsha (Fig.9), whilst Philippi will accommodate baseball and wrestling. Here, the Olympic structures will form part of a development node, with job creation as a primary objective.

The UWC/Pentec facilities will utilize existing management capacity, and the connections of those institutions with the communities to ensure that they will serve the grassroots sports needs on a long-term basis.

Guiding principles in the choice of all the venues were accessibility, use to the maximum of existing facilities, promotion of local sport development, integration into communities, and pre- and after-use. The training venues also present opportunities both to make maximum use of existing facilities and to introduce modest facilities into communities where need exists.

A few comments on certain of the proposed venues are appropriate. To avoid the cost of two new indoor halls for gymnastics and basketball, which require seating for 20 000 and 25 000 spectators, Arups proposed using the existing Newlands Rugby Stadium (Fig.10) by roofing it temporarily and partitioning it into two indoor halls.

Preliminary discussions with the rugby authorities on the implications of this have met with a favourable reaction, but the proposal will need further detailed consideration.

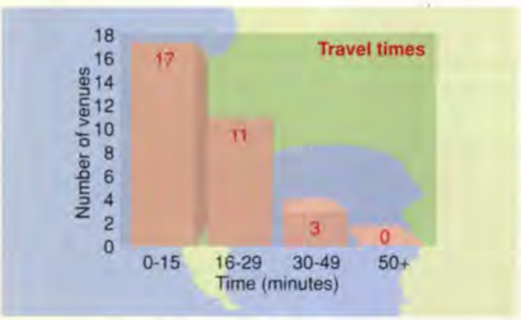
Proximity to the road and rail network ensures that 17 of the venues will be within 15 minutes' travelling time from the main Olympic complex at Wingfield, and virtually all within 30 minutes (Fig.11). This will ensure a compact, efficient, Games plan.

The strategy has built-in flexibility to review the siting of venues as the detailed Olympic planning proceeds.

The equestrian cross-country event will be held at Vergelegen, one of the Cape's most beautiful wine estates.

It is worth noting that the Cape is the only area in Africa likely to be declared immune from African Horse Sickness within the next few years, thereby avoiding the problems which any other African city would create for this particular competition. Yachting will be in Table Bay harbour against the backdrop of Table Mountain (Fig.12), whilst the proposed venue

10. ▶ Newlands Rugby Stadium.

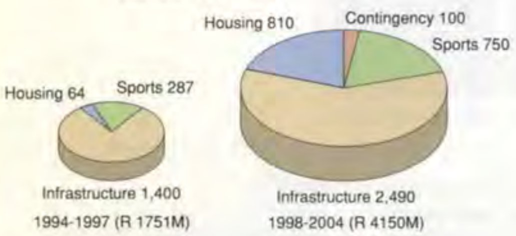


11. A compact Games plan.

12. Yachts in Table Bay Harbour.

	Rand(M)
Olympic costs	
Housing	874
Sports	1037
Infrastructure	220
Sub-total	*2131*

	Rand(M)
Non-Olympic costs	
Infrastructure	3670
Contingency	100
Total	*5901*



13. Capital costs.

for rowing and canoeing is on the Berg River at Paarl, about an hour's drive from Cape Town — a location relatively free from wind.

Finally, as far as football is concerned, it is proposed to take as many matches as possible to the enthusiastic fans throughout South Africa, at venues such as Durban, Johannesburg and Port Elizabeth, with one of the pools and the finals in Cape Town.

Timing and climate

Many considerations influenced the choice of late September to early October for the Games. This timing, the same as Sydney's for the 2000 Games, suits world television requirements, athletes' international schedules, and domestic priorities such as academic holidays.

It also offers the unique advantage of spring in the Cape, with its famous wild flowers.

The small coastal strip stretching a few hundred kilometres from Cape Town is one of the world's six floral kingdoms, with an exceptional variety of flora.

This timing is optimal climatically, coming at the end of the rainy Cape winter and before the summer south-east winds prevail. 30 years of climate records for that time of year were analyzed, and it was concluded that the climate will be satisfactory for both athletes and visitors, with mild temperatures, ideal humidity, relatively long daylight hours, little rain and sea level altitude.

Records show that windy days can occur within the period of the Games, but the probability of acceptable limits being exceeded is low.

The main stadium, where wind effects on athletics records could be an issue, will be designed to minimize the effect.

Accommodation

The accommodation plan is designed to provide a suitable range for all the estimated 208 000 visitors expected on any day of the Games. The famous Victoria & Alfred Waterfront will provide the IOC and other Olympic dignitaries with a setting in Table Bay harbour unequalled in the world. Cruise liners will be used to the utmost for other VIPs and corporate sponsors.Currently it is proposed that 25 000 beds in 27 vessels will be accommodated in the harbour, but on the advice of those experienced in the corporate sponsorship trends of the Games internationally there are plans to increase this by utilizing other harbours and anchorages.

The large range of holiday homes and guesthouses throughout the Western Cape, together with the Cape's tradition of hosting visitors in private homes, will be exploited to the utmost. The projected increase in tourism over the next 10 years will enhance the accommodation stock significantly. Also, because of the timing of the Games, the large stock of education residences in the Cape will also be available.

One of the Olympic villages at Wingfield will accommodate 15 000 athletes and officials and the other 15 000 media people. These are envisaged as private developments and will serve as well-located and crucially-needed housing afterwards.

Costs and finance

The costs associated with hosting the Games are divided into those of bidding, the operating budget and the capital expenditure programme.

Bidding is estimated at R60M (£18M) (1993 figures). The economic analysis concluded that tangible benefits would flow from this process alone, making the bid worthwhile even if the Games were not secured in 1997.

These economic benefits arise primarily from the tourism boost fuelled by the publicity associated with the bidding process. This will translate into additional business, new construction projects such as hotels and a convention centre, generating additional jobs.

The proposed operating budget for the Games shows an operating revenue of US$1.25bn (£830M). This has been based on careful analysis of the budgets of other cities which have hosted or bid for the Olympics over the last 12 years. Although projection of costs and revenues 10 years hence must be treated with caution, allowance has been made for prevailing trends; for instance, some reduction in US television revenues is expected, though European and Japanese revenues appear to be increasing.

A lower provision for revenue from ticket sales has been assumed because of the need to encourage local attendance.

The budget indicates an operating surplus, most of which will be ploughed into the development of the Olympic facilities.

Capital expenditure

The estimate of gross capital expenditure over the 10 years leading up to the Games is R5.9bn (£1100M). The largest item in this is infrastructure — roads, railways and airport — followed by the sports facilities and the villages. The infrastructure expenditure will be on projects necessary for the development of the region, most of which have already been proposed independently and will enhance the new Government's reconstruction and development programme (Fig.13). The impact of the Olympics is to ensure their co-ordination and in some cases to advance the expenditure in time. The Olympics process is an extremely powerful force for co-ordinating capital expenditure across the region, involving local authorities and provincial and national agencies such as the rail, road and airport authorities. The power of this co-ordinating effect is already evident and has been particularly significant in the political and policy vacuum which has existed in South Africa. These benefits will continue to be significant over the next few years while the new provincial and local authority structures come into effect.

The proposed expansion of Cape Town's airport, very small at present because of regulations only recently removed with it being accorded international gateway status, will increase its capacity to approximately 11M passengers per year by 2004. This is in line with the airport authority's projections for demand-driven growth arising from increased tourism and business activity.

It is proposed that approximately R1.8bn (£330M) of the capital expenditure would have to be under construction or committed by late 1996 to ensure a credible South African bid to the IOC. Most of this expenditure will be on necessary infrastructure projects. About R300M (£55M) of it will be for sports facilities, the priority being those which will best fulfil community needs. This will ensure that by late 1996 six of the proposed Olympic venues will be virtually up to Olympic standards, 21 will be under construction or fully committed, and only six will be bid- dependent. The latter will include the most costly, like the main stadium, and those facilities which least meet immediate community needs. In this way, it is proposed to produce a bid which will be totally convincing to the judges and IOC officials and demonstrate Cape Town's commitment to the necessary infrastructure and facilities.

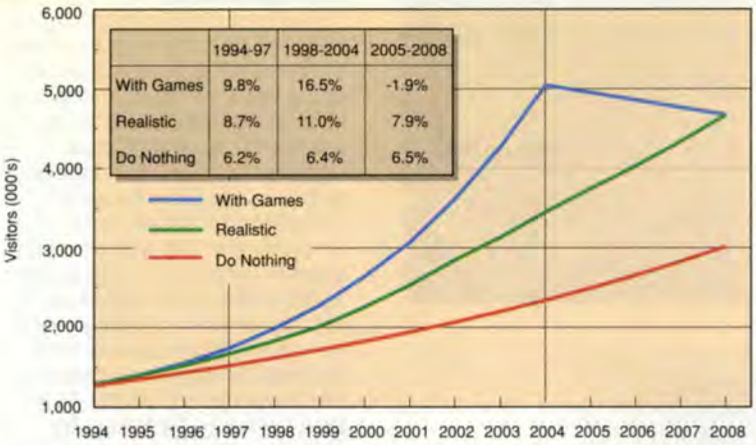
Economic benefits

The key to the economic benefits to be derived from Cape Town hosting the Olympics is the unique synergy that exists between Cape Town's tourism growth potential and the Olympics. The Olympics will help to drive tourism growth by projecting the world class assets of Cape Town as a tourist paradise for a decade as it emerges from the period of international isolation. Also the tourism growth will generate the demand which will drive the development of hotels, tourist facilities, the airport and transportation. Growth scenarios with and without the Games were based on inputs from many players involved with tourism. A 15% compound annual growth rate is indicated for that with the Games, which is probably a conservative estimate. Economic benefits derive from the difference between this growth and what might happen if no concerted campaign was mounted and without the benefit of the Olympics (Fig.14).

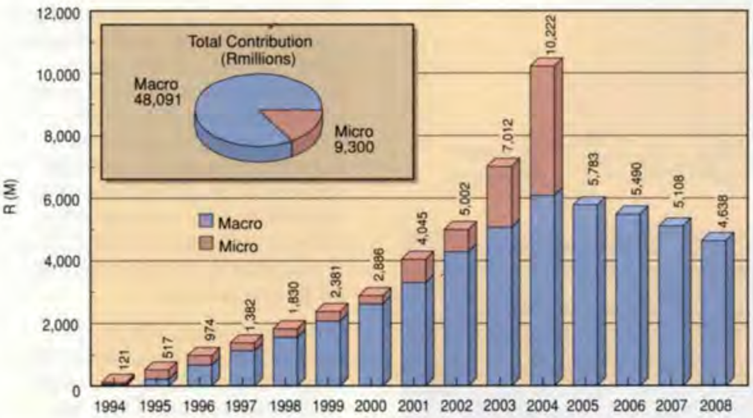
They serve to accelerate the growth which might otherwise occur with a well-managed tourism strategy. Evidence from other Olympic cities shows this benefit continues several years after the Games, with tourism in the couple of years after higher than in the Games year itself.

The economic benefits derived from direct and indirect spending by visitors accrue not only to the Western Cape region but to the national economy. Arups estimated the gross resulting economic benefits to be R48bn (£10bn) (Fig.15). Even the State is a winner: it is calculated that revenues from taxes and other sources amount to R8bn (£1.5bn) over the period — this in return for a gross capital expenditure of less than R6bn (£1.1bn).

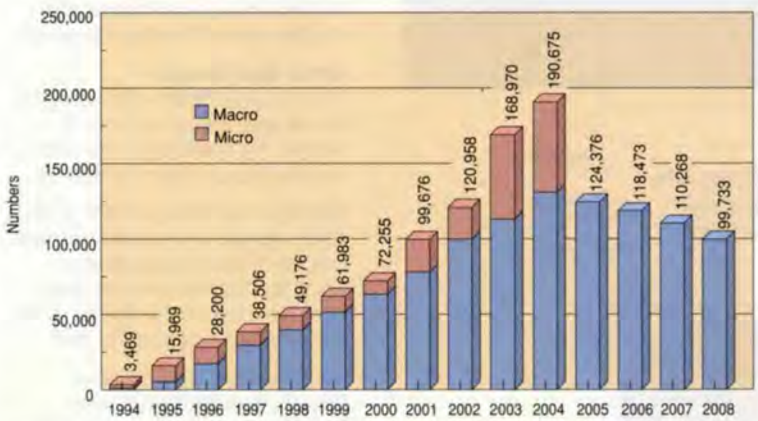
Extremely important is the job creation potential of this increased economic activity. South Africa faces high and drastically increasing unemployment which is unlikely to be alleviated in the medium term even with improving economic growth, because most formal businesses and industries do not generate significant job opportunities. Construction and tourism are the industries with maximum potential to generate new jobs at modest cost, and these are the beneficiaries of the Olympics and the tourism development. Arups estimate up to 200 000 new jobs will be generated by 2004. Fig.16 shows the progressive growth over the 10-year period as a result of the Olympics.



14.
The tourist growth scenarios.



15.
Annual gross economic contribution.



16.
Annual employment.

Community involvement
Arups' work involved an enormous amount of community consultation. This was especially necessary because of the unique political climate in which the bidding process to date was undertaken. The priorities of communities are for basic facilities which will improve their quality of life — shelter and social infrastructure for education and health. It has been necessary to demonstrate to these communities, who may suspect that the Olympics represents an unnecessary expenditure of public funds on potential white elephants, the benefits to be derived in terms of reconstruction and development. That this process has been largely successful is a commentary on the validity of the Feasibility Study and the tenacity of those involved with the bidding process. It involved Arups in many hours of presentations and consultations.

Public and community support for the bid is demonstrated in several ways. Apart from the immensely wide cross-section of interests in the Steering Committee, the list of Patrons, many of whom have been actively involved in the bidding process, represents a Who's Who of South Africa's leadership and personalities. The formal endorsements included in the bid document are from a large cross-section of South African interests.

The sponsors who funded the bid are national and international companies, household names in South Africa, who showed commitment to Cape Town's bid despite their business interests in the other cities involved.

Conclusion
The announcement on the evening of 29 January 1994 by Sam Ramsamy of NOCSA's nomination of Cape Town as the South African city to bid for the 2004 Olympic Games represented a great triumph for those involved.

The reasons for Cape Town's selection are many, but the following were probably decisive:

- the magic of Cape Town's image as a world class city capable of hosting the Olympics
- a compact technical Games plan which should enable Cape Town to demonstrate to the IOC its ability to host the Games efficiently
- the unique synergy between tourism and the Olympics which enable economic benefits to accrue which justify the support of business and Government for the Games
- the developmental strategy which will ensure community support for the Games and its compatibility with the reconstruction and development programme.

The process of preparing the IOC bid has already started and Arups are deeply involved, although the precise role is still being defined.

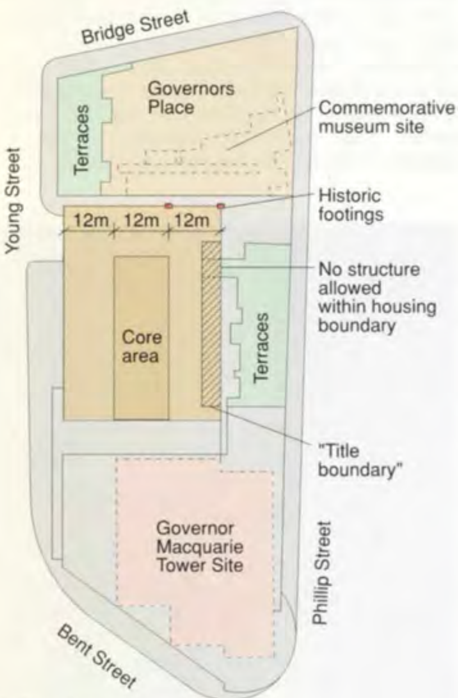
The bidding structure is being established, potential sponsors have been approached to support the bid, and discussions have been held with the Minister of Finance and other prominent ministers and officials, aimed at obtaining the crucial support of Government as early as possible.

Credits
Client:
Cape Town Olympics 2004 Steering Committee
Leader of Bid Team:
Ove Arup Incorporated Mark Bostock, Des Correia, Michael Lewis, Cliff McMillan, Ugo Rivera, Siza Zware, Jim Read (communications), James Burland, Michael Lowe, Dipesh Patel, Graeme Smart (urban design), Andrew Allsop (wind studies), Jane Osborn, Ivone de Figueiredo (administration and report production)
Other Team members:
M.L.H. Architects & Planners, Hawkins, Hawkins & Osborn, Price Waterhouse Meyernel
Marketing and PR consultants:
Corporate Image
Sub-consultants:
Prof. David Dewar (regional development needs), John Donaldson (sports events), Pierre Tredoux (tourism), Reg Patterson (community and sports development), Prof. Tim Noakes, Dr. Jocelyn Kane-Berman, Dr. Alan McMahon, Dr. Denys Reitz (sports medicine and health facilities), Prof. Richard Fuggle (environment), Schalk van der Merwe, Eric Peltz, Cdr. Tom Laidlaw (security and public safety), André Odendaal, Gordon Metz, Tony Karon (cultural opportunities), Dave Lindenburg (venue costs)
Illustrations:
1, 10, 12: Cape Town City Council
2-5, 11: Allessandro Bottega/Trevor Slydel
7-9: Arup Associates
13-16: Rob Evison/Dennis Kirtley

Governor Phillip Tower, Sydney

Bill Thomas   Neil McClelland

Introduction
In 1982 the New South Wales State Government called for proposals to develop a vacant block of land in the heart of Sydney's financial precinct, overlooking Sydney Cove and the Opera House. The site once contained the first Government House of Australia, also the first permanent building in the colony. It had been built in 1788 by Arthur Phillip (1738-1814), the first Governor of NSW, and had subsequent additions to satisfy nine Governors, one of them the infamous Captain Bligh of The Bounty. Surprisingly the land remained undeveloped after demolition of the old premises in 1846.



1. Site plan.

2.

A design — with which Arups were involved — was accepted for the site, but community pressure was brought to bear for an archaeological investigation. To the delight of the conservationists and embarrassment of the bureaucrats, the stone footings of the first Government House and additions were discovered. This naturally threw any plans to develop the site into disarray, and close to a decade passed before a competition was held for a commercial development, adjacent to the original site and containing a museum of the history and foundations of the first European development in Australia. Together with the successful architects, Denton Corker Marshall, Arups again became involved, this time as façade engineers as well as structural and civil engineers.

The building
The commercial development, aptly named Governor Phillip Tower (GPT), is a 64-level landmark office building, soaring 250m above its foundations to join the tallest on Sydney's imposing skyline. It has 38 office floors, typically 38m x 52m with a floor height of 4.05m, giving a total nett lettable area of approximately 55 170m^2, serviced by four banks of lifts for medium, medium high, high, and sky rise zones. The tower contains three double-height floor plantrooms at levels 30, 51 and 62, whilst below street level there are 10 basement floors extending under the full width of Young Street for 650 car park spaces and plant facilities.

The tower forms part of a total development, encompassing an entire city block bounded by Bridge, Phillip, Bent and Young Streets, in which there are five integrated elements: GPT itself, Governor Macquarie Tower, Governor's Place, the Commemorative Museum and the existing heritage-listed terraces along Phillip Street and Young Street.

The first office floor of GPT, at level 21, is 40m above Young Street, offering tenants superb city and harbour views. Beneath this level the tower sits on a series of zinc-clad blades over a magnificent entrance foyer finished in sandstone with a polished granite floor. Above the entrance foyer and between the zinc blades are three glazed roofs supported by delicate stainless steel cable trusses. Between GPT and the adjoining Governor MacQuarie Tower is a sandstone-clad loggia with three glazed entrance screens supported by vertical cable trusses.

The tower façade is a panellized strong-back system of polished granite, glass, and stainless steel fins with metal inlays. The latter define a three-storey square grid pattern which has been further accentuated by the distinctive stainless steel clad fins terminating above the tower roof.

Structure

The brief

It was an important aspect of the client's brief that both the Young and Phillip Street terraces and the important remnants of the footings of the original Government House remained undisturbed, with historical artefacts recovered from the site preserved in the Commemorative Museum. However, as well as preserving the site's history, the development of the new office building had to proceed on a sound commercial basis, with the following major requirements:

- Design and construct a state-of-the-art, quality building.
- Maximize the site development rights.
- Provide a nett lettable area of 1400m^2 per typical floor and maximize floor efficiency.
- Provide 12m of column-free space from the external façade to the face of the central service core to allow for optimum tenancy planning.
- Deliver the project in the shortest possible time.

The ideal building form would have had its three central façade columns striking through the Phillip Street terraces, but the brief's demands necessitated a scheme for a rectangular tower overhanging the housing. Despite the floor area, the service core ideally needed to be only 12m wide. The major challenges posed in satisfying this proposal were:

- to provide a structural system integrated within the architectural form to support an 8m overhang of the eastern façade over the Phillip Street terraces
- to develop a lateral stability system in the east-west direction to augment the very slender service core
- to provide, within the design, structural systems and techniques to help the builder achieve the shortest possible construction program.

Transfer structure

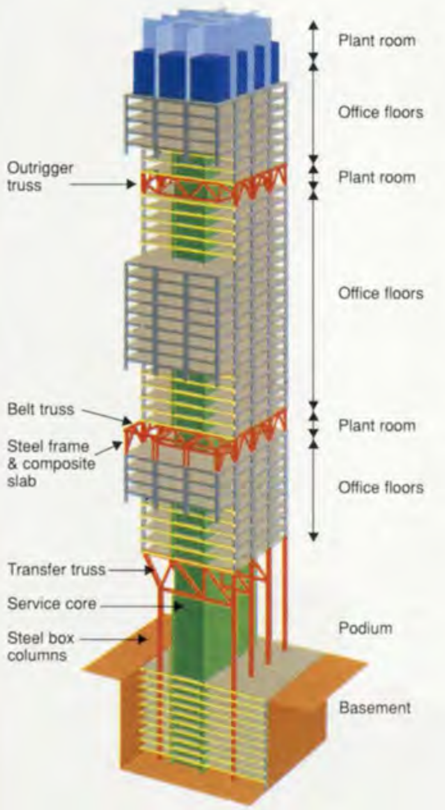
The most striking feature of the tower is the 8m overhang, but in addition the columns on the northern façade needed to be relocated transversely to avoid the important remnants of the first Government House footings. The transfer structure had to be located beneath level 21 to give the required clearance above the terrace housing, and be able to transfer a total weight of 12 000 tonnes. To minimize the material used and maximize speed of construction, steel was chosen in preference to reinforced or prestressed concrete.

Each of the four trusses is 36m long, 12m deep, and weighs 250 tonnes (Fig.4). Each was cambered 20mm and its tension members prestressed in two stages during construction to reduce absolute movements of the truss and hence minimize their effect on the façade. The trusses are supported on steel box columns 1.2m square which spring from foundations 70m below level 21 and freestand 28m tall within the foyer walls.

Preliminary investigation during the design of the transfer system showed that the trusses and supporting box columns needed to be independent of the core to avoid transfer of vertical forces from one element to the other, owing to differential vertical displacement. Further, under wind action, coupling of these elements would have resulted in large transfers of wind moment and hence axial forces from the core to the columns. To overcome these undesirable effects the trusses are located in slots and pass clear through the core. Specially manufactured bearings allow for rotational freedom and relative vertical movement at the connection between core and truss, whilst providing horizontal restraint to stabilize the truss chords.

Erection of the transfer trusses was seen as the most critical stage, and a study was carried out to determine the optimum time solution for assembly and erection of this steelwork. This document formed part of the structural steelwork tender package — for information only, the builder being ultimately responsible for his own erection procedures. It is interesting to note, however, that the eventual erection procedure was in principle the same, with the exception of cranage.

The transfer trusses were assembled on a temporary platform at street level. As soon as the service core and steel box columns were constructed to level 21, the trusses were winched up through temporary slots left in the core and rolled across to their final location, each truss being lifted in less than a day. A composite steel-concrete floor was constructed at level 21 which subsequently acted as a platform for starting work on the typical floors. This jump-start system saved 15 weeks on the construction programme.



3.

5.

3.
Structural scheme, viewed from the north.

4.
Transfer truss in workshop.

5.
Transfer trusses supporting typical floors over terraces (bottom left).

6.
Outrigger/belt truss connection at plantroom level.

4.

6.

Lateral stability system

Architectural planning requirements dictated that the service core be limited to the constant 12m width, east-west, over its full height. In the north-south direction it reduces in stages from 36m to 20m. For the building's overall height of 250m this resulted in aspect ratios of approximately 21:1 and 7:1. For the core alone to resist wind forces, a maximum aspect ratio of approximately 14:1 was required for the necessary strength and stiffness to control stress levels, drift and accelerations, so clearly the east-west dimension was inadequate for this height. The options considered to solve the problem were:

- Increase the width of the core.
- Provide a tube-in-tube system by modifying the façade with additional columns.
- Strengthen the core with outriggers connecting it and the façade columns.

The first two options were ruled out because they invalidated the brief and architectural requirements, so the third became the preferred solution to be investigated. To compensate for the core's slenderness, pairs of steel outrigger trusses span the width of the building coupling the façade columns and core. These are 6.5m deep, and are located in the plantrooms, independent of the floors, at levels 30 and 51. Each truss weighs 90 tonnes. The bending stiffness of the whole building footprint is thus mobilized to resist wind forces. All shear or horizontal forces are retained in the crosswalls of the core with the façade columns, providing a push-pull reaction. To mobilize effectively the external columns, 8m deep belt trusses cross the east and west façades and form part of the stabilizing system. Each truss weighs 135 tonnes.

The outrigger trusses were intentionally offset from the core crosswalls so as not to constrain the wall locations and hence affect the core planning. They pass through the core and are only connected to the major longitudinal walls through steel inserts cast-in to act integrally with the core structure.

The estimated long-term differential shortening between the perimeter columns and the service core is 30mm. Movements of this order, if not allowed for, would result in significant loads being attracted to the outrigger which as a result would become overstressed. To control this differential movement, flatjacks and steel wedges were incorporated at the junction of the outrigger truss to the belt truss column. This enabled the connection to be released and re-wedged at a number of stages during the construction period. Finally, the flatjacks were grouted up to form part of the permanent connection.

The choice of steel versus concrete for the system was investigated initially. Concrete outriggers would have had to be full height walls in the plantroom to achieve a stiffness comparable to that of a steel truss. Such a division in the plantrooms was too restrictive on the planning of the building services and was therefore ruled out.

Three-dimensional analysis of the building using the ETABS computer program showed that the combined core and outrigger system had the following effect when compared with the core acting alone:

- reduction of 40% in the tip deflection
- reduction of base bending moment in the core of approximately 20%
- change in the first mode of vibration to a lower amplitude excitation
- reduction in the induced wind accelerations to a less perceptible level.

Cladding

Arup Façade Engineering were appointed as cladding consultants for the project, with a brief to assist the architect and project manager with aspects of the cladding and to monitor the performance of the cladding subcontractor. This included the following tasks:

- Review design calculations and shop drawings for performance.
- Review testing of prototype cladding panels for air and water infiltration and structural performance.
- Carry out QA factory inspections of panel production.
- Carry out site inspections of panel installation.

A separate commission was also given to Arup Façade Engineering to help select the granite for the main tower.

This included site visits to a quarry in India and a close monitoring of the stone strength throughout production.

Foyer roofs and loggia screens

Arup Façade Engineering carried out full design and documentation to the level of shop drawings for the glazed roofs over the entrance foyer to GPT and the screens in the loggia between GPT and Governor MacQuarie Tower, together with their tensioned support systems.

Foyer roofs

The foyer roofs consist of three 10.5m x 10.5m bays. Each is supported by five cable trusses spanning from the building core to the main perimeter column lateral support beams. The truss consists of 23mm diameter duplex stainless steel rods kept apart by stainless steel struts. Stainless steel castings were used for the nodes connecting the cables, struts and glazing. Though they allowed for architectural expression, the use of castings did not prove to be expensive and, in addition, they solved the problem of in-plane cable crossover.

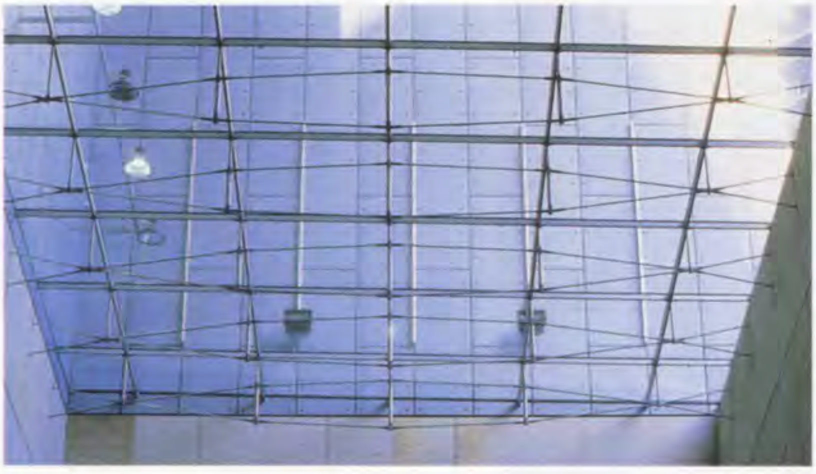
There is no triangulation of the middle truss panels, so deflections due to asymmetric loading are controlled by the prestress in the cables, the level being set so that no elements experience compression buckling under any load combination. The prestress also provides inherent stability so no lateral bracing is required.

The roof glass was designed using a non-linear finite element analysis package; subsequent testing confirmed the calculated deflections as well as the safety requirements of the overhead glass. The glazing consists of double glazed units with internal channel spacers, the channels enabling a partially captive but flush glazed system. The glass is set in a purpose-designed aluminium suite which allowed easy replacement of individual glass units.

The flimsy unstressed trusses were assembled at ground level in a lifting frame, the same one being used for each roof bay. The aluminium members were attached, all the glass apart from edge units was installed, and the almost-complete roof was lifted into position and the trusses stressed. Support deflections had been carefully calculated, as had the drop in the trusses when depropped. The actual deflections were as predicted.

▲8. Foyer with glazed roofs and cable trusses.

7. Plan showing glass roofs and screens.



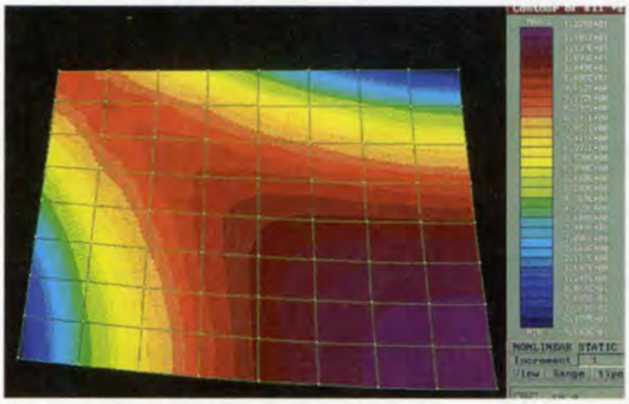
◀9. Close-up of foyer roof bay.

10. Loggia screen to exterior (Farrer Place).

11. Courtyard loggia screen.

12. Screen truss strut and connection detail, showing 19mm truss rods and 9.5mm glazing rod.

13. Cable truss node casting.



14. Stress distribution in foyer glass.

Loggia screens

The loggia area provides a common entrance space for GPT and Governor MacQuarie Tower. The two main entrance screens, 12m and 9m high and each 8.5m wide, have three vertical trusses, whilst the side screen, 12m high and 8.5m wide, has two vertical trusses. The vertical glass joints and truss nodes are at 2 m centres. The entrance screen trusses are of similar configuration to the foyer roof trusses, one of the design requirements being the re-use of the roof truss castings. Whereas the roof glazing has continuous support, the screen glazing is supported on corner patch fittings attached to the truss via a stainless steel cruciform casting, the only new casting for all of the screens. The screen trusses also have a 9.5mm diameter vertical glazing rod which takes the dead load of the glass. Again, the asymmetric loading is mainly resisted by a prestress in the 19mm diameter rods with some help from the vertical glazing rod (See Fig.12).

Local stresses around the glass patch fittings were checked using finite element analysis. It was found that standard proprietary glass patch fittings were unsuitable, as the characteristic high deflections of the cable trusses and the rigid connections of the proprietary fixings resulted in excessive local stresses in the glass at the fixings. Various combinations of compressible washers and gaskets were considered but they all proved unsatisfactory: the only solution was to use a true pin connection. This was a considerable problem as Arups were only asked to carry out this part of the design at the last moment and the castings were already under production. The solution was to use a standard pin joint that is common in mechanical engineering applications, and the pins proved to be easily obtained and inexpensive. All the trusses for one screen were assembled on lifting frames and simultaneously stressed. Careful analysis was again needed for the support deflections as a good knowledge of the support stiffness is crucial for calculating the required prestress. The predictions were complicated by the fact that all the truss supports were different, both between the screens and within the screens. The glass was installed once the trusses had been stressed, the glazing rods being prestressed to remove the glass weight deflections in the trusses.

Conclusion

The landmark GPT project was completed on budget and within the two years and nine months programmed construction time.

Experience on the project showed that for high-rise buildings up to 70 storeys where the service core alone is too slender to resist wind or earthquake forces, the introduction of outriggers to mobilize the total footprint of the building should be investigated. Two levels of outriggers appropriately located in the tower would generally suffice. It should be noted, however, that this solution may not be appropriate if extreme lateral forces such as those associated with typhoons exist.

A jump-start system can, under certain circumstances, result in significant time savings to the overall construction programme. The marginal increase to the structural cost is generally well off-set by the saving of the builder's preliminaries associated with the time saving and earlier rental returns.

The foyer roofs and loggia screens demonstrate that with careful analysis and design, innovative but relatively inexpensive glass roofs and screens of large area and high 'transparency' can be built.

Credits

Client:
State Authorities Superannuation Board
Architect:
Denton Corker Marshall
Structural engineers:
Ove Arup & Partners John Nutt, Bill Thomas, Chezy Tang, Chris Smith, Jim Forrest
Façade engineers:
Arup Façade Engineering John Perry, Tristram Carfrae, Neil McClelland, Mike Gwodz
Project manager:
Colin Ging and Partners
Builder:
Grocon
Curtain wall sub-contractor:
Permasteelisa
Foyer roof and loggia screen sub-contractor:
Hudson Pacific
Illustrations:
1, 4-6, 8, Photos: John Gollings.
2, 7: Dennis Kirtley.
3: Tristram Carfrae.
9-13, Photos: David West.
14: Neil McClelland.

1. Aerial view of Canon's Marsh.

Lloyds Bank, Canon's Marsh, Bristol

Stuart Mercer Terry Raggett Peter Warburton

Introduction

With the increasing office rents in Central London during the mid-'80s and the expiry of leases on several of their City offices, Lloyds Bank decided to relocate and group their retail banking activities together on a single site outside the capital. In November 1986 Arup Associates were appointed to design this new headquarters building on land at Canon's Marsh in the centre of Bristol. In May 1988, the two seven-storey tobacco bond warehouses that had dominated the site since the 1930s were demolished, so that construction could commence.

The brief

Offices for 1400 staff were required, plus various support facilities, all adding up to a gross area of 23 450m^2, with some 650 car-parking spaces. The development was required in two equally-sized phases, the first designed to stand alone in case the second was never built. To satisfy the demands of Lloyds Bank's organization and communication operations, and to respond to the dynamic changes then taking place in the banking business, a sophisticated, advanced technology building was needed, with a high degree of interior flexibility for either open or cellular office spaces throughout.

The site

Canon's Marsh is an area of flat, reclaimed, low-lying land, bordered to the north by higher ground where Bristol Cathedral stands, and beyond by Brandon Hill and Park Street with their dominant respective silhouettes of the Cabot and University Towers. The remainder is enclosed by the historic 'Floating Harbour'. The site itself covers some 5ha in a Conservation Area overlooking the confluence of the Rivers Avon and Frome. This forms the focal point of the old Dockyard, whose industries used to cover most of Canon's Marsh but had, with the advent of modern shipping in the post-war years, declined rapidly, resulting in semi-dereliction over much of its area.

2. Phase 1 and amphitheatre viewed across the 'Floating Harbour'.

Planning brief

Although various redevelopment proposals were made earlier, it was not until 1984 that the City Council produced a Planning Brief with a strategic plan for a comprehensive approach to the area's regeneration. This proposed that Canon's Marsh should become Bristol's main centre for the arts, leisure, and recreation, and envisaged the creation of a series of public pedestrian routes and spaces linking it both to the City and ultimately to the other side of the Floating Harbour via a ferry and a new bridge.

The Planning Brief did not support office-building in Canon's Marsh, but with little progress due to lack of public funds for the activities envisaged, the City recognized that a corporate building for a major company was the only realistic way forward, provided that certain undertakings on its impact and contribution to the area could be agreed. After extensive negotiations between Bank and City, as well as a public enquiry over the closure of Butts Road which divided the site, Arup Associates produced a development strategy including proposals for all the building forms plus public spaces along the quayside. Outline Planning Permission was granted in April 1987.

Amphitheatre

The design team considered it vital that the new development should not be restricted by ownership and road boundaries inherited from the area's previous dockyard function and that, wherever possible, the buildings should be sited and formed in response to the new regeneration opportunities. In particular, these included a progression of complementary civic spaces not evolved from the needs of the past but anticipating those of the present and future. To achieve successful external spaces on a site for which public expectation was high was thus paramount, and largely determined the building form for Phase 1.

The City wanted a major public assembly space on the quayside, at the key point of the Rivers' confluence, and so a 60m radius, crescent-shaped, open-air amphitheatre was provided, with the public's relationship to the waterside enhanced by lowering the harbour wall within the amphitheatre's limits. Stepped, precast concrete seating units are ranged along its outer edge, and a semicircular stage was formed at the original quayside level around a listed structure — the Weathervane Tower — at the focus of the crescent. Large ramps provide direct routes for both the disabled and public utility and emergency vehicles to the amphitheatre.

The City has ambitious plans for this space to be the main assembly point for spectators of waterside activities such as powerboat racing, concerts, music festivals, regattas, and firework displays. It is clear of obstructions so that large groups of people can congregate, and anchorage points are integrated with the paving to allow temporary structures such as seating stands and marquees to be erected for special events. The lowered level also provides safe access onto the ferry, a landing point established for official and ceremonial occasions, as well as floating pontoons to extend the usable level out onto the water for particular events.

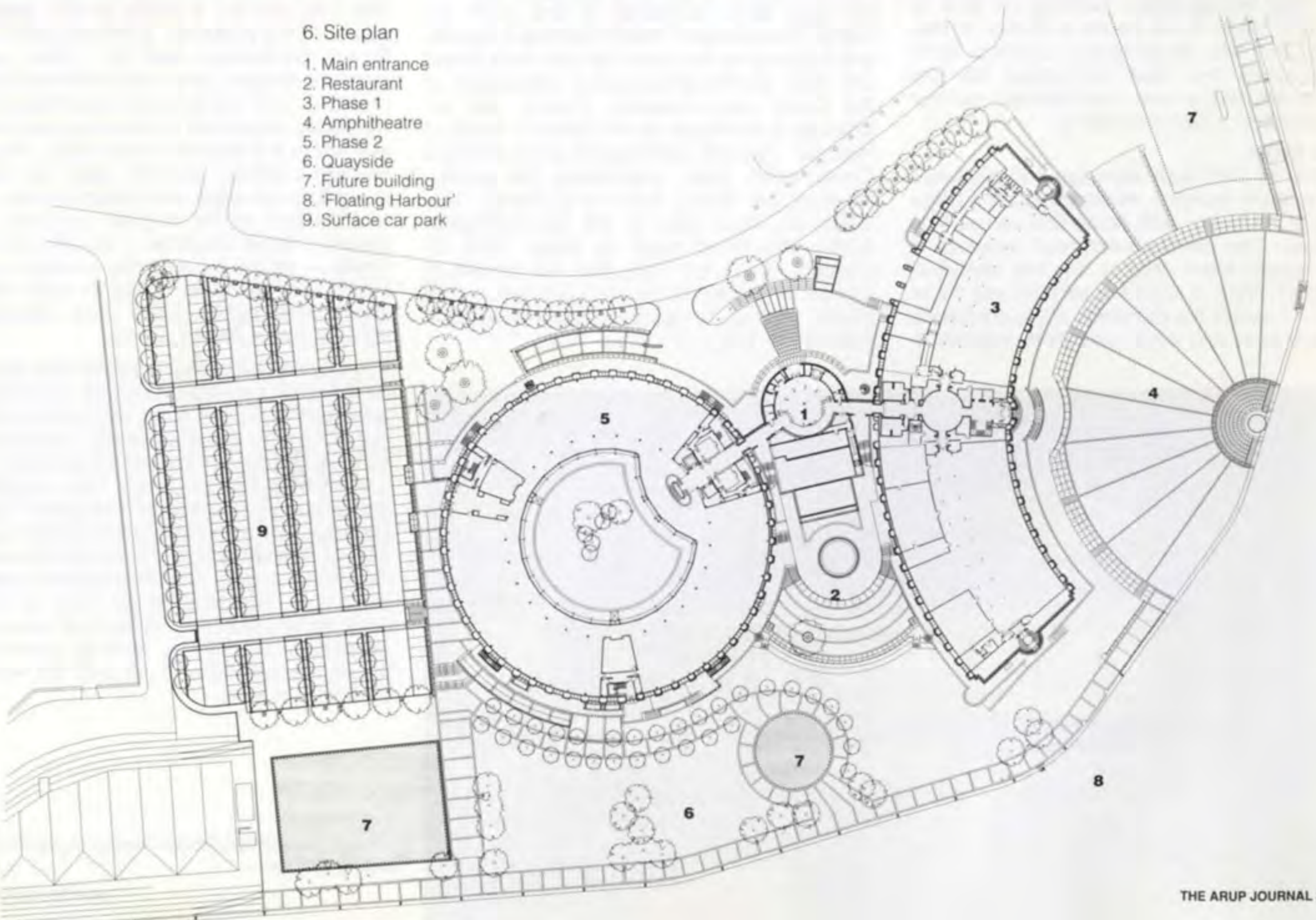
3. New view of the cathedral between Phase 1 and Phase 2.

◀ 4. Detailed elevation of Phase 1.

5. ▶ Phase 2 courtyard.

6. Site plan

1. Main entrance
2. Restaurant
3. Phase 1
4. Amphitheatre
5. Phase 2
6. Quayside
7. Future building
8. 'Floating Harbour'
9. Surface car park



Building form

To define and visually enclose the amphitheatre, Phase 1 is crescent-shaped. Although an unusual geometry for office buildings, this is an architectural form not uncommon in Bristol, most notably in Georgian terraces in Clifton and the City Council House. The Planning Brief stipulated opening up a new sightline of Bristol Cathedral across the harbour, as well as preserving all existing views. Between them, these factors determined the limits of the crescent form.

At the southern end, the Phase 1 building is within 20m of the dockside, a spatial restriction that provides a 'threshold' through which the public pass from the amphitheatre to the further series of quayside spaces.

A future building envisaged by the City on the space between the northern end of Phase I and the quayside will, in due course, provide a similar 'threshold' to the amphitheatre and so complete its visual containment.

The building is limited to three storeys, to keep within the height constraints laid down by the planning authority. To avoid deep office spaces, it is divided along its linear axis into two parallel office floors of 12m span, each arranged on either side of a full-height, top-lit galleria forming an internal street separating and serving the two office areas and containing all the secondary circulation.

The brief requirement for two distinct phases meant that the massing of a large single monolith could be avoided. Phase 2, although not so restricted by site boundaries or sightlines as Phase I, is circular in plan to complement its neighbour: the radial forms give a common yet distinctive identity to the two phases. They are set some 20m apart, with the main entrance located in this space in a single-storey structure, permitting a new sightline to the Cathedral. The converging convex forms create a generous approach and natural focus to the main entrance to the north, and an ideal location for restaurant facilities looking south onto the quayside.

Phase 2, also of three storeys, is some 80m in diameter, with primary internal circulation arranged around its inner perimeter serving 15m-deep office spaces on one side and overlooking an internal open landscaped court on the other. This green 'private' courtyard, over 40m in diameter, provides an important counterpoint to the hard-surfaced 'public' space of the amphitheatre, and is intended to ensure that Phase 2 is not considered by staff as the 'poor neighbour' to Phase 1.

The ground floors of both Phases are raised some 1.8m above the quayside level to avoid any possibility of flooding. The resulting terrace defines a natural line for the new boundary to the Lloyds Bank site and creates an effective and natural separation between the private functions of the office spaces and the public domain.

Phase 2 quayside

The present large quayside space in front of Phase 2 will accommodate two buildings under City ownership intended to promote and encourage the tourist and leisure activities in the area. A 250m^2 single-storey structure for a restaurant/fast food facility is envisaged at the eastern end, with a 2500m^2 two-storey building set alongside the existing 'A' shed sited at the west. An original proposal for extensive tree-planting in this open quayside area as a visual contrast to the amphitheatre, so enhancing the variety of spaces, was rejected by the City on the grounds that space was needed for public activities. The quayside area therefore has a series of areas defined by limited tree planting to enable the erection of marquees and seating for these major public events. Time will tell if this was the right decision.

7. Main entrance hall.

Car parking/delivery

Harbour Way, a new road on the western edge of the site, provides access to a 325-space surface car park and connects Canon's Way to the existing 'A' shed as well as, ultimately, to future development on an adjacent redundant Gas Board site. A new north/south public walkway to and from the quayside runs between this car park and Phase 2. A secondary staff entrance on the latter's west side provides access from this walkway into the Phase 2 offices.

A further 217 spaces are provided in a circular car park beneath Phase 2, accessible on the north from a ramp by the main entrance. Lifts and stairs give direct access from this car park to the office levels above.

18 spaces of visitors' surface parking are arranged on both sides of the main entrance forecourt. A fully-enclosed, three-bay truck dock inside Phase 1, with immediate vehicle access off Canon's Way, serves both phases by means of an underground link to distribute goods and services. Phasing and costs of excavation in ground with a high water table made it impossible to put the truck docks anywhere other than near the main entrance.

However, the potential problems of such close proximity have been overcome by the complete enclosure of the delivery bays, careful design, and good management.

Internal circulation

Large buildings, particularly those with complex working communities like big corporate offices, should provide a spatial organization and comprehensible structuring of both primary and secondary circulation to create a sense of place and orientation as well as to foster a corporate community. Introducing spatial hierarchies within offices creates clear territorial boundaries and can thus overcome the greatest single objection to modern 'open' office interiors — the invasion of group and individual social territories by 'outsiders' wandering through on routes with no clear definition. These routes do not require the same sophistication of lighting, electrical servicing, air-conditioning, or sub-division capability as the office spaces. This provides an overall cost benefit for the office spaces, defining the working zones within which columns should be avoided if possible to provide maximum flexibility.

The main entrance hall, containing the waiting area, reception counter, and visitors' washrooms, is circular, with a central glazed roof lantern from which two radiating primary circulation routes originate. These give direct access to the respective main cores in each Phase. In Phase 1 this route follows the crescent form, with views focusing on the Weathervane Tower in the amphitheatre. In Phase 2, it follows the radial geometry of the plan with views directly into its open landscaped courtyard. Along these enclosed routes, three-storey high side-lit atria space signals the thresholds of the respective office buildings. The staff restaurant is accessible directly from the main entrance.

Phase 1's main service core, containing passenger lifts, service risers, and washrooms, frames the route, opening out to create a circular top-lit space at its intersection with the galleria. The circulation routes on the upper two floors take the form of galleries along the

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edge of the galleria with bridges across the space connecting to the staircase at the gable ends.

Similarly, the main service core in Phase 2 frames the axial route from the main entrance, but intersects with the secondary route on the outer edge rather than the centre of the building. Here, a three-storey conservatory contains a reception area with a staircase to all the perimeter circulation levels above. Two secondary cores housing service risers and stairs are located off this perimeter route. By variation in volume, light and outlook, the articulation of these circulation routes creates a natural progression from entrance to workstation, intended to make the overall building easily understood and efficient to use.

External façade

The extensive views across and beyond the Floating Harbour, as well as of Bristol Cathedral and Brandon Hill, suggested that the offices should be fully glazed, particularly above ground floor level, to satisfy the expectations of staff relocated from London. However, large areas of glazing on the outside were not considered appropriate, given the dockside landscape setting in the heart of a city whose most prominent buildings are in stone. This urban context, and the significant function of the building in forming major public spaces, necessitated an appropriate 'civic' quality in response to the surroundings.

Following the design team's similar approach for Legal & General's new building at Kingswood[1] — where a free-standing landscaped pergola screen was adopted as an extension of its rural context — an articulated masonry screen was constructed in front of the offices' glazed curtain wall, as an extension of the Lloyds Bank building's urban role. The same type of masonry screen was used to unify the façades of both Phases.

The screen sits on a 1.8m high Terrace formed in split-faced precast reconstituted granite blockwork with a matching precast coping, on a base of piers in rusticated St Maximin saw-faced limestone with Euville stone plinths. These piers are linked at first floor level by an interlocking series of precast lintels and column bases using white cement and Balladon aggregate and having a tooled finish. Through their depth and solidity, the piers provide an important visual weight to the screen at its base as well as being the 'threshold' separating the public quayside areas and the private office spaces. The ground floor internal height is 300mm greater to compensate for the more limited outlook at this level.

A two-storey high, double-column, similarly precast colonnade surmounts the piers. These are set at approximately 4.5m centres to provide scale and rhythm to the façade, which a curtain wall with its mullions at constant 1.5m centres to suit the internal office planning module fails to give. The twin columns impart an apparent transparency when viewed at right angles from the interior, giving the views sought by the staff, whereas the colonnade visually closes from oblique external viewpoints to create the illusion of a solid but articulated masonry wall, as sought by the planning authority and public opinion.

A lead-finished, timber-framed canopy is supported by a twin steel column-and-stay assembly, fixed to an acid-washed, precast concrete capital linking the tops of the double columns. This canopy provides solar shading to the upper office floor; its eaves, 12m above the quayside level, reduce the building's apparent scale as well as conforming to the height limitations stipulated by the planning authority. A precast parapet unit set back on the line of the main building completes the elevation.

An aluminum-framed walkway for maintenance access at second floor level also visually obscures the 1.5m high aluminium spandrel panels of the curtain wall and offers solar shading to the office windows below. Polyester powder-coated, aluminum, full-height, clear double- glazed curtain walling spans the two upper office levels, with Iroko timber-framed windows in the openings between the piers on the ground floor.

Although the overall development programme was extensive, the construction time available for the two individual Phases was very short. The prefabricated curtain wall element made it possible to enclose the building at an early stage to provide a weatherproof environment for services installations and interior fit out to proceed, while the more traditional construction of the colonnaded screen and masonry walls could continue at their pen pace and so achieve the perceived hand-made quality appropriate to the surrounding conservation area.

Structure

Canon's Marsh is an historic landfill site and has seen many cycles of industrial activity. The fill, generally 2-4m thick, contains remnants of these activities and so varies in quality and type. The underlying natural strata comprise a thinnish crust of firm to stiff clay above softer alluvial deposits which in turn overlay Keuper sandstone at about 12-14m depth.

The concrete-framed warehouses had been founded on the clay crust with massive spread footings. A much simpler and more predictable approach was chosen for the new buildings, which involved driving precast, 300mm square section piles into the sandstone. Small section piles were chosen to make it easier to avoid existing obstructions, and precasting overcame problems

8. Phase 1 galleria.

9. Route leading to Phase 2 from main entrance hall with courtyard beyond.

10. Phase 1 ribbed in situ reinforced concrete ceilings with precast cantilever walkways.

11. Phase 1 masonry details.

12. Meeting area, ground floor, Phase 2.

13. Phase 2 offices and precast cantilever walkways overlooking courtyard.

13.

from the high water table. The suspended ground floor was raised above flood level and constructed of precast units spanning about 11m between the pile cap strips.

The basement construction for the car park in Phase 2 comprised a 600mm piled raft, thickening to 900mm under the line of the principal office column structure. The potential problem of flotation under maximum flood conditions is counterbalanced by the dead weight of construction, with the tension anchorage of the precast piles providing a factor of safety for exceptional conditions.

The client had liked the concrete radial rib construction integrated with lighting and extract systems used at the Leslie & Godwin building, Farnborough[2], and this approach was developed further at Canon's Marsh, to optimize the structural opportunities presented by floor supply ventilation and the requirement for clear span space: nominally 12m and 15m for Phases 1 and 2 respectively.

In situ, post-tensioned radial ribs run between perimeter beams on circular concrete columns at 4.5m centres. The ribs were cast off high quality reinforced glassfibre moulds to provide a finished surface for painting. Multi-strand post-tensioning tendons were used, stressed in two stages and subsequently grouted to form a fully-bonded system. This avoided the need to camber the floors and the moulds, and allowed a faster turn round of moulds — and thus fewer of them, lower cost, and a quicker erection sequence. The tendons were designed to balance the loads imposed by the next level of construction, thereby avoiding the need for backpropping. Precast ribs were considered, but the inner city location inhibited their economic use. However, cantilevered precast walkway units do form the primary circulation balconies.

The shear walls of the Phase 1 cores were constructed in concrete with blockwork internal walls. This proved time-consuming and tied up resources. In Phase 2 the cores were constructed as structural steel cages with concrete accommodation platforms having a void-to-platform ratio of about 1:1. All but the external walls are fabricated from metal studwork and the link building between the two Phases is of in situ concrete.

Dock water

The heating and cooling system uses the dock water, the temperature of which varies from 19°C in summer to 0°C in winter. When the water is below 12°C it is used to cool the computer rooms. In summer, when the outside air temperature is above 18°C, it is used to reject condenser heat from the refrigeration plant. In spring and autumn, it is used as a heat source for the refrigeration plant evaporators so that the plant can operate as a heat pump. In winter, the heat pump coefficient of performance cannot compete with free heat from the cogenerators. Should the dock freeze over, gas-fired boilers meet demands.

The intakes are in deep water between the surface level refuse and the bottom sediment. At the suggestion of the local Dockmaster, a fully reversing design was installed: as the system is reversed, the strainer on the exhaust, which was the intake, is automatically flushed clean. To use the dock water, a way-leave was necessary to penetrate the dock wall and a licence to extract the water was needed from Avon River Authority.

Mechanical services

The major plantrooms in Phase 1 are located under the galleria space and at roof level above the central core. In Phase 2 they are along the outer edge of the underground car park and behind screen walls at roof level. Service cores at the ends of the office areas feed conditioned air into a 600mm raised floor plenum, from where it enters the space through adjustable twist air outlets. These can be relocated simply by transferring the floor tiles that incorporate them to suit any new office layout. Around the external perimeter, fan coil units in the floor void provide heating and extra cooling; flexible connections allow these also to be repositioned to suit new desk layouts. The units incorporate a damper which, during cooling, takes air from the plenum and directs it up against the glazing. Air is extracted through ducts integrated with the luminaires and passed to header ducts within the raised floor above, which connect to the main air risers in the service cores.

Air enters the office space at 18°C-22°C depending on the outside air temperature. Through the stabilizing effect of the exposed concrete troughs, conditions in the occupied areas are maintained within the comfort bands without the need for terminal unit thermal control. The machine office cooling loads, from 20W/m^2 average to 40W/m^2 peak, can be simply accommodated through provision of twist air outlets.

Heat recovery is provided between the exhaust air duct and the air intake in the plantroom. The kitchen, restaurant, and computer rooms have separate air-handling plants.

Electrical services

Two diesel generator sets in each Phase provide 100% standby power capacity, supplying heat and electricity to the building during the winter months. When tariffs are favourable, electricity is also exported into the South Western electricity system.

Continuous linear air-handling luminaires in the ceiling troughs between the ribs incorporate smoke detectors, emergency lighting, and sprinkler heads. These were specially designed for the office spaces and provide an average 450 lux at desk top level. This arrangement gives an even illumination on the sides of the ceiling rib and provides the desired cut-off angle of light from the luminaire to eliminate surface reflections at desk level and on VDU screens. Control is by a *Delmatic* system with individually programmable control cards in the spines of the lighting fittings. On both sides between the rib and the fitting, preformed, self-finished acoustic panels limit sound reflections into the office space. Office partition can be fixed to both the luminaire and the acoustic panels on the 1.5m internal planning module. By integrating the lighting, acoustic panels, and air extract ducts between the ribs, the cost and programme time for installing a conventional suspended ceiling was avoided.

The restaurant and main internal circulation routes are lit by low voltage dichroic lamps to emphasize the different quality and function of these spaces.

All power, data and telecommunications cabling for the office is run in the raised floor to a regular grid. Instead of using traditional outlet boxes in the raised floor, a special circular brass casting was developed for the controlled passage of cables into the central spine unit of the desking system. Trays incorporated into this spine allow cables to be neatly supported and adequately segregated from the floor void to the desk-mounted equipment. The service spines are concealed by panels that can be easily removed by service personnel.

Conclusion

The Lloyds Headquarters has brought a significant improvement to the prime site in the historic docklands and has acted as an important catalyst to the future development of this largely derelict area. The City of Bristol has now adopted a new strategic plan retaining a predominance of arts and recreation use but with a balance of commercial and residential development. It has the agreement of all interested landowners and a great deal of public support.

Finally it is interesting that, despite the reservations and objections of Bristol's conservation groups during the planning stage, a major opinion poll on the City's architecture undertaken by the BBC in summer 1994 established that Lloyds Bank is clearly the Bristol public's most favoured post-war building.

References

(1) BONNER, M. *and* FERGUSON, D. Legal & General, Kingswood: Architecture in landscape. *The Arup Journal, 27*(4), pp.3-9, Winter 1992-93.

(2) BONNER, M. *and* RAGGETT, T. Leslie & Godwin, Farnborough. *The Arup Journal, 20*(2), pp.2-8, Summer 1985.

Credits

Client:
Lloyds Project Construction Co. Ltd. for Lloyds Bank plc
Designers:
Arup Associates
Architects + Engineers + Quantity Surveyors
Landscape architects:
Peter Swann Associates
Management contractor:
Bovis Construction Ltd.
Illustrations:
1: Sealand Aerial Photography.
2, 5, 9: Peter Cook.
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