THE ARUP JOURNAL

APRIL 1984

THE ARUP JOURNAL

Vol.19 No.1 April 1984
Published by
Ove Arup Partnership
13 Fitzroy Street, London W1P 6BQ

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Front cover: 'The Old Vic', by Arthur Moreland, from 1930.
Back cover: Saturday night at the Victoria Theatre, by G. Durand
Illustrations from the Raymond Mander and Joe Mitchenson Theatre Collection

The Old Vic is back!

Architects:
Renton Howard Wood Levin Partnership

John Pilkington
Alan Foster

After a £2m. facelift, the Old Vic opened its doors on 31 October 1983 for the first time in two years. Canadian businessman, 'Honest Ed' Mirvish bought the theatre, site unseen, in August, 1982 for £550,000. He was convinced that the reputation of the 165 year-old theatre would be critical to the commercial success of the venture.

A comprehensive restoration programme has left little of the theatre untouched. The interior now resembles the designs of the 1880s, with the proscenium arch being moved back to allow stage boxes (which were moved in 1963) to be re-installed. The exterior has also been restored to resemble its 1818 facade. It complements the arched brick side walls which are the only surviving part of the original building. A columned canopy alleviates the appearance of the asymmetric entrance doors. The original canopy was made in timber, while the present one is in cast steel. The broken pediment has been surmounted with a coat of arms, dating from Queen Victoria's succession to the throne.

With the change from repertory to a touring theatre, it was necessary to extend the stage to accommodate a variety of entertainment. The stage is now some three times its original size, having been both lengthened and widened.

Throughout the restoration, the aim was to combine traditional decoration with the most modern facilities.

The construction work was completed on time and within budget, despite a number of major structural flaws which were uncovered as work progressed.

Fig. 1
Exterior of the Old Vic

Architectural history

Originally built in 1818 by Cabanel, The Old Vic Theatre has been altered frequently through the years.

The external walls were the only remaining visible parts of the structure. The auditorium form set by the shape of the balconies and the position of the proscenium arch dated from the major alterations carried out by J. T. Robinson in 1871. The decoration on the ceiling dome and the second tier balcony is thought to be the remains of the 1880 decoration that existed when Elija Hoole altered the foyer and auditorium into a coffee tavern and music hall for Emma Cons.

The facade and the foyers were radically changed by Frank Matcham & Co in 1928 to an austere neo-classical style, with complex circulation routes.

The proscenium zone and forestage that remained until 1982 were designed by Sean Kenny for Laurence Olivier and the National Theatre Company. It was the conclusion of several various styles and an attempt to break down the barrier of the proscenium arch.

The decoration of the auditorium was plain and a result of the 1960s' desire by directors that attention should be focused only on the stage. With balcony fronts and ceiling dome painted in a monochrome dull gold, the surrounding walls dark green and the proscenium zone a grey-green, the overall appearance was tired and run down.

The project team

It was in September 1982 that Renton Howard Wood Levin Partnership, in competition with other architects, submitted their proposals to restore the theatre to its late 19th century form and decoration but with extensive front of house and backstage improvements expected by today's audiences and performers.

The professional team of RHWL, Ove Arup and Partners as engineers and Gardiner and Theobald as quantity surveyors, were appointed in October 1982. From then until Christmas 1982, the concepts outlined in the original competition submission were developed. At the same time a survey of the existing building and services was carried out and the results of that survey used to develop the brief and detailed design.

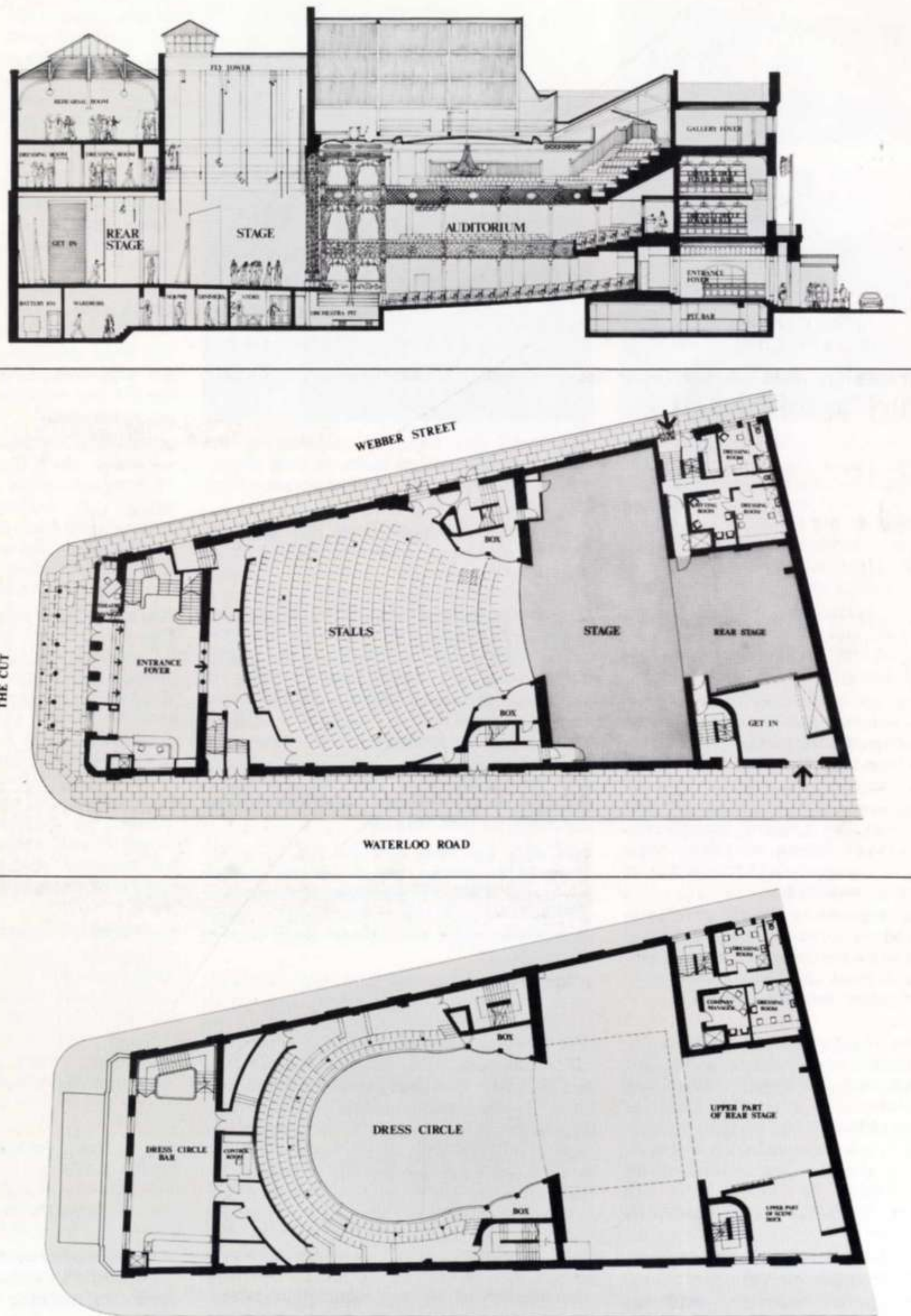
Kyle Stewart Management Ltd., part of the Kyle Stewart Group, became involved immediately following the appointment of the professional team. The company was shortlisted along with other construction firms, and each was asked to present a submission document, including a method statement which included a programme to show how they would organize the construction to achieve the opening date together with a competitive tender for management costs.

The considerations

Confronted with a building whose dominant external walls are Georgian, an auditorium shape derived from mid-Victorian times, backstage accommodation converted from the Morley College in 1890 and unacceptable foyers adapted over many years, the architects had to develop a separate strategy for each area which would work and provide a unified scheme.

Much time was spent considering alternative façades. The familiar 1928 façade was rejected as being too austere and unconnected with the side elevations. A recreation of the Victorian façade was studied but, with none of the original fabric remaining, it was difficult to come to terms with a pastiche. It was concluded that it must read as a complete and positive building on this almost island site and the proposal was to evoke a feeling for the original design and maintain the side elevations.

The foyers needed to be replanned, simplifying the circulation, abolishing the segregation of audience between pit, dress circle and gallery and enlarging the bar



Section

Ground floor

First floor

Fig. 2
The Old Vic: section and plans

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Fig. 3
Existing structural timbers forming galleries

Fig. 4
Replacement steelwork in corners of upper galleries

Fig. 5
End conditions at existing timber gallery supports

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areas. The reduction in the administration requirements meant that the mezzanine was freed for public use and gave direct access into the front of the gallery, reducing the long climb to the top of the building. The foyers were to be a transition between the Georgian exterior and an appetizer for the restored auditorium.

Toilets were numerous but inconvenient; bars were small and difficult to service; offices were crammed into a mezzanine floor between the dress circle and gallery bars.

Attracted by the traditional mid-Victorian horseshoe – shaped auditorium and influenced by the drawings of J. T. Robinson and Elija Hoole, together with the illustrations and surviving decoration, the architects favoured a restoration of the auditorium with the original proscenium arch and twinned boxes on either side, while trying to accommodate the technical requirements of musicals.

Care was to be taken to reduce the disturbance caused by external noise entering the auditorium by blocking all unnecessary openings, and forming lobbied entrances into the auditorium and onto the stage.

The budget

The problems of cost control were sharply etched right from the outset when the appointment was made in October 1982. The client had a very clear idea of a maximum budget – the architect had an equally well-defined view of the improvements and rearrangements which he considered necessary to meet the client's brief. The problem was to achieve a balance in monetary terms.

The solution was to break the project down into a great number of its constituent parts – auditorium, seating, curtains, stage foyers at various levels, dressing rooms, ancillary accommodation, external works, etc., and to put as accurate a budget figure as possible to each of those parts. In this way the relative value of each aspect of the works was weighed carefully by the client and the design team so that expenditure would be put to maximum effect throughout the project.

What finally emerged from this exercise were two schemes, each integral in its own right. There was the 'minimum' scheme where the amount of alteration and refurbishment was strictly limited to those items necessary to restore the theatre to a level at which it could be re-opened to the public but without any major improvements in facilities; this was valued at £1m., excluding fees. The second scheme represented the architect's full response to his brief and included all the improvements and restorative work that he considered were necessary. The estimated cost of this including all fees was £2m.

Inevitably the final solution lay in an intermediate scheme, which initially excluded items from the preferred scheme but allowed the client the option to add a range of specific items by defined dates during the contract.

Whilst the initial cost planning exercises were progressing, steps were being taken for the appointment of a contractor. The rapid time-scale – about 12 months from appointment of design team to completion of the project – made it impossible to contemplate the traditional method of selecting a contractor, namely production of full design information and comprehensive tenders from contractors. So the management approach was adopted whereby the contractor offers in the first place his organizational and supervisory skills, and then 'manages' the activities of subcontractors. A tender competition for the appointment of the management contractor was mounted in November 1982 and, as a result, Kyle Stewart Management Ltd. were appointed.

The contractor joined the team, and work on site commenced in January 1983.

Front of house

Extensive work has been undertaken in the foyer and the bars above and below. Before this refurbishment project began, the staircase system created a labyrinth for the audience to negotiate. The upper circle, for example, was reached up a winding staircase from the side street.

To overcome the problems of segregated access a single main staircase was built that rises from the Pit Bar in the basement through four floors, opening onto three bars and the entrances to the stalls, dress circle and gallery (now to be called the Lilian Baylis Circle).

The new staircase has an open well, protected with cast iron balusters to an 1830 design and also a continuous mahogany handrail.

To support this and other loadings, massive box-frames, fabricated from large steel beams, were installed at each floor level. These beams were man-handled into position in cramped conditions and the structure bolted together once the pieces were in position. These box-frames were designed by Ove Arup and Partners and supervised by Kyle Stewart's Temporary Works Division.

The entrance foyer was gutted and completely refurbished with fibrous plaster columns included to recreate the space and feeling of Emma Cons' 1880s coffee tavern. Two of these are original cast iron columns which were found encased in brickwork. These have been retained and decorated in fibrous plaster as well.

The foyer decorations have been kept simple with purpose-designed lighting, while the Pit Bar exhibits scenes from Victorian life in Lambeth.

Upon entering the building, the audience will have seen themselves reflected in a 1.8m square mirror etched with the original design of Cabanel's auditorium. The original print from which it is taken is in fact an etching of the auditorium reflected in a 63-piece mirror house curtain which existed for a short period in the 1880s.

The auditorium and the stage

The auditorium, which now has an increased seating capacity of 1077, is entered through new lobbies leading from the foyer to gangways down each side of the auditorium. The Lilian Baylis Circle is accessible through new vomitory entrances bringing the audience in at the front of the circle rather than at the very back of the auditorium. The vomitories were made possible by modifying the existing timber structure and forming new corridors within the triangular void below the stepped seatways and above the ceiling of the dress circle.

The stalls seating has been set out with continuous rows, without intervening gangways, and has increased the seating capacity from 458 to 575. The dress circle, with new entrances and five rows of newly stepped seating, accommodates 55 more seats. The gallery, once all benches, with narrow seatways, has been restructured with wider seatways to accommodate proper seats.

The fibrous plasterwork around the front circles and on the ceiling, has been restored to a design based upon the 1881 and 1890 illustrations from the *Graphic* and *Illustrated London News*.

The restoration of the proscenium arch and the boxes has been carried out as authentically as possible, the original proscenium arch structure having remained under the various alterations. A small piece of the original plasterwork, found halfway up the left hand side of the proscenium, was used to develop the moulds for the new pro-

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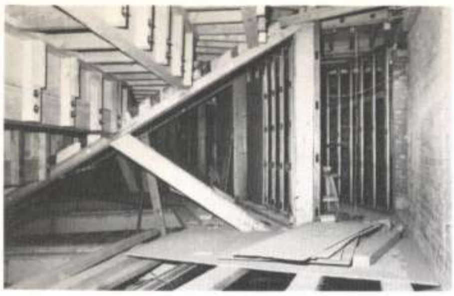

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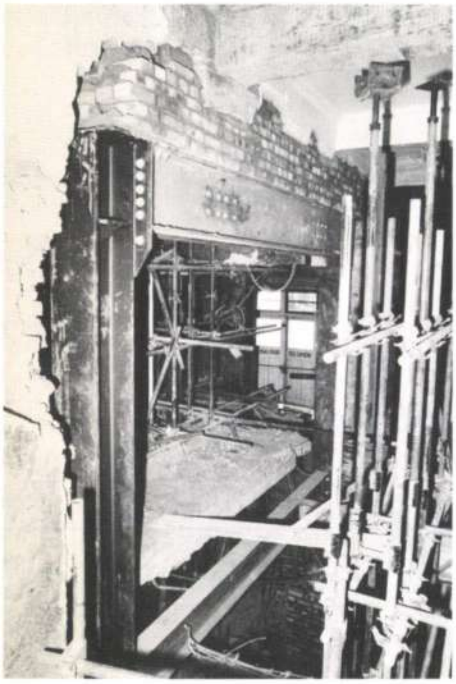

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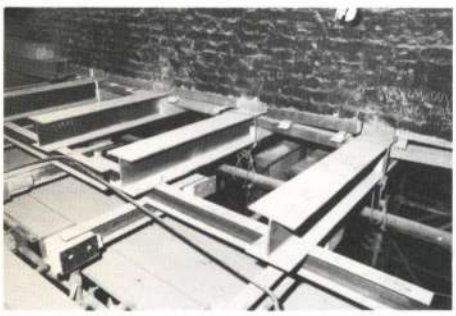

Fig. 6
Gallery timbers modified to create side vomitories

Fig. 7
Steel 'goalpost' inserted to create opening in auditorium wall

Fig. 8
Steel needles to support flytower wall before permanent structure installed

Fig. 9
Delivery of major elements for flytower 'goalpost' frame

Fig. 10
Manhandling upper beam into place

Fig. 11
The completed frame supporting the rear flytower wall

Fig. 12
Air supply to plenum above the circle of ceiling diffusers

(Fig. 3-12: Photos: Barry R. Bulley)

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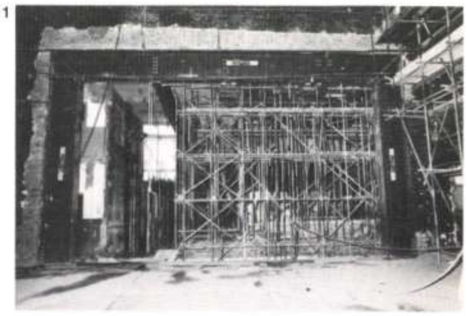

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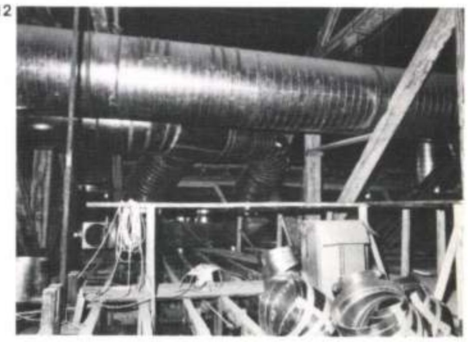

scenium plasterwork. The balcony fronts, initially changed by Matcham & Co., have been realigned and the boxes constructed had to be demountable.

Above the ceiling, provision has been made for the air conditioning ducts and front of house production lighting positions over the forestage. The flying facility over the forestage has been retained and removable panels included in the new ceiling to enable scenic pieces and additional lighting or sound equipment to hang in front of the proscenium arch and be used in conjunction with the projection of scenery into the area of the removable boxes.

Since the decorative box fronts can be removed, the boxes themselves dismantled and the proscenium arch masked, directors and designers have considerably more freedom to use this zone for scenery or as an acting area or install extensive lighting and sound equipment.

The background colours to the auditorium are four shades of grey and include a re-coloured hand printed wallpaper from original blocks of the period. The proscenium arch, boxes, balcony fronts and ceiling dome are in cream with details picked out in apricot, pale grey, silver and gold. The seating has been re-upholstered in deep coral. The matching curtains and pelmets are trimmed with gold in the boxes and proscenium arch. The house curtain has 63 pieces of mirror sewn on to it which, together with the silver light fittings and perforated silver shades, all give lightness to the auditorium.

The stage has been widened to the full width of the site from Waterloo Road to Webber Street, which involved the demolition of six rooms and the conversion to a double purchase counter-weight system. The stage has been returned to its original rake and relaid, the rear walls taken down and the external lightwell included in the large rear stage. By so doing, the depth of the stage has been increased by 9.5m while maintaining good sightlines up to the rear wall.

The deepening of the stage was achieved using a box frame, similar but larger than the one installed at the front of house and made from one of the largest, standard, rolled steel sections available from British Steel, which was prestressed to support the 150 tonnes upper half of the wall extending some 15m above the stage.

The front of the curved stage has been cut back and an hydraulic scissor lift has been installed, which in the down position can be used as an orchestra pit, accommodating up to 35 musicians. When at stalls level, it carries three additional rows of seats; fully raised it forms the forestage.

The stage door has been moved from the Waterloo Road to Webber Street side of the building so as to be nearer the dressing rooms. 12 dressing rooms have been refurnished and redecorated with the other rooms converted to the offices which were once accommodated at front of house. The scenery 'get in' areas have been lobbied and provided with a large, sound-reducing door.

Heating, air conditioning and ventilating services

The existing systems in the Old Vic consisted of a low pressure hot water heating installation. This system was fired by atmospheric gas boilers, located under the stage with pumped distribution into one circuit, that served all areas of the building. Heating of the areas was accomplished by cast iron radiators with piped coils in the flytower and under roof lights.

The auditorium was ventilated by a mechanical extract system, drawing air from ceiling level in front of the proscenium arch through a duct to a fan located within the flytower. Make up air was via entrance door or through grilles installed behind the radiators. Internal toilets were mechanically ventilated and all other areas were naturally ventilated.

The brief for the new services was to maximize re-use of the existing systems, to keep within very tight financial constraints and to improve the environment in the auditorium and front and rear of house.

The auditorium was required to be air conditioned, and its acoustic performance improved to achieve NR25. These two requirements presented a number of problems, particularly plant location, ductwork distribution and the location of supply air terminals within the auditorium.

Possible locations for the main air handling plant and associated refrigeration plant were limited, in that all available space at the back of house was required for theatre production. The adopted solution was to install the air handling plant on the platform used within the flytower for the old auditorium extract fan and to encase this area in blockwork to prevent noise breakout back onto the stage. The refrigeration plant was positioned on a new slab constructed above the existing lightwell, and packaged air cooled plant was chosen with suitable inlet and discharge attenuators. Planning restrictions limited the extent of this support slab and plant, which meant that the associated chilled water pumps and pressurization equipment had to be installed in a separate plant room.

The distribution ductwork from the auditorium air handling plant runs above the auditorium ceiling and feeds the circular diffusers mounted in the ceiling which were co-ordinated within the decorative plaster work. Return air is drawn under the balconies into vertical plenum ducts each side at the back of the auditorium. These are connected into a single system at high level which passes through the roof to an extract fan on the Waterloo Road elevation. The air is then discharged to atmosphere or returned to the supply air system. The proportions of return/fresh air can be controlled by a thermostat to save energy, or overridden by a manual controller depending on the occupancy levels of the auditorium.

The new internal spaces back of house are now mechanically ventilated. The existing radiator installation has been retained, and modified only where new rooms have been created.

The front of house is heated by a new radiator system, as it was not possible to retain the existing one due to the extent of architectural replanning in this area. A mechanical ventilation system was also added to supplement the natural ventilation. The mechanical plant was located at roof level front of house.

It was possible through appropriate planning measures to retain the existing boiler house although a new system was installed. The water heated by the new atmospheric gas boilers is split into two circuits, one being of constant temperature which serves the air handling plants, HWS calorifiers and new radiant panels on the stage. The other circuit is a variable temperature system connected into the existing radiator circuit back of house and a new radiator circuit front of house. The circuit to the front of house is fitted with a diverting valve to isolate this zone from the rest of the building when not in use.

The same principle has been adopted to save energy for the air handling plants in that they can be isolated by time clocks or manual override when these areas of the building are not being used.

Public health

Extensive alterations to the existing 150-year old plumbing services, and the relatively new 50-year old automatic sprinkler installation have been incorporated into the overall refurbishment programme, and will greatly improve the facilities, and safety of both public and actors.

There was a history of partial flooding to basement areas of the theatre, caused by the surcharging of local authority sewers during heavy rainstorms. As the refurbishment programme excluded works to these sewers, measures were taken to contain the existing installation, this being achieved by sealing existing basement outlets, and designing the new systems to discharge above the surcharge level.

In modifying the existing sprinkler installation to meet planning changes, the opportunity was taken to update the system, which over the years had been extended beyond current sprinkler protection standards. This work was carried out on a sectional basis, to maintain fire protection to the theatre during the construction programme.

Electrical

Prior to refurbishment much of the electrical services equipment was obsolete or had been designed to meet regulations long since superseded. Many items were considered for retention in an attempt to restrict costs, but ultimately only a few light fittings, the auditorium chandelier and the secondary maintained battery equipment were salvaged.

A new low voltage installation using moulded case circuit breaker and miniature circuit breaker equipment was planned and designed by the contractor to the 15th Edition of the IEE Regulations.

Many new installations applicable to modern theatres have been introduced, including such items as installed microphone and tie lines, fire alarms, a modern telephone system and computerized ticket sales facilities.

The external lighting has been conceived to throw a curtain of light upwards and in front of the facade, lighting the architectural features and providing a dazzling entrance to the theatre. The less intense lighting to the side elevations illuminates the repetitive arches and features within them.

Structural engineering

Modernization of the Old Vic Theatre resulted in significant structural alterations in all areas. The need for more spacious foyers, a more open and flexible side and rear stage area, and a more functional circulation plan, along with restoration of the auditorium and the addition of modern air conditioning, all created major structural modifications.

Fig. 13
Auditorium and galleries. Supply air diffusers encircling ceiling rose

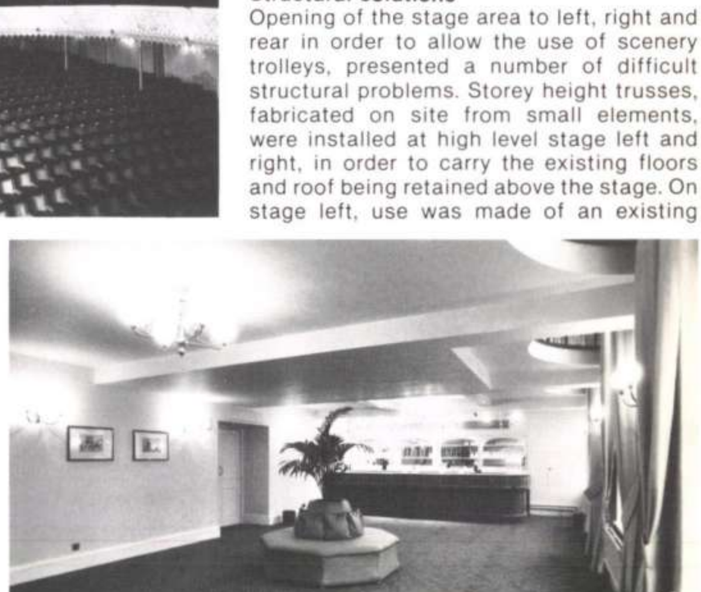

Fig. 14
Circle bar at front of house

(Photos: Ove Arup & Partners)

Removal of the existing closed staircase and its associated loadbearing walls in the foyer, and replacement with a new staircase spanning between the main walls, allowed the foyers to be opened out. It was necessary to determine whether the remaining areas of floor were spanning or supported on secondary load-bearing elements. In some areas special details were required to ensure existing floor construction was supported by new beams, in order to allow removal of interior columns and hangers. At one stage during the works the Webber Street corner of the building was an empty well from the basement to the roof.

The need for a more functional circulation between the foyer and auditorium led to a series of new openings in the dividing wall. These were quite large at ground floor and basement level, and a special two storey box frame was used to return loads to existing foundations beneath the openings. New vomitories serving the gallery at low level necessitated extensive changes and strengthenings to the existing irregular series of timber trusses. The large 300mm square timbers were over 100 years old, and detailed examination of their condition, and their connections, was carried out during the work.

Placement of air conditioning plant and ductwork along the roof adjacent to Waterloo Road, along with reconstruction of the 2m high parapet , required to conceal the plant as well as restore the exterior of the building, generated a series of difficult problems at this level. The 22m span timber roof trusses dated back to the original 1814 construction, and careful study was required before the increased loads on the roof could be sanctioned. Detailed examination revealed extensive cracking in the upper levels of the outer brick walls, possibly due to a slight overall outward lean, combined with lack of positive support at the upper level. Extensive new restraint systems were required in order to extend the 225mm parapet to a 2m free height above the roof, and contain the outward movement at lower levels. The placing of the support steelwork together with extensive ductwork distribution, into the already crowded roof space, was an extremely difficult exercise requiring full co-ordination between all disciplines.

Restoration of the stage boxes, demountable at circle level, in another area of jumbled existing structure (from foundations to roof), required close attention to construction detail.

Structural solutions

Opening of the stage area to left, right and rear in order to allow the use of scenery trolleys, presented a number of difficult structural problems. Storey height trusses, fabricated on site from small elements, were installed at high level stage left and right, in order to carry the existing floors and roof being retained above the stage. On stage left, use was made of an existing

Fig. 15
Auditorium with reinstated boxes and circle seating. (Photo: Ove Arup & Partners)

beam over two thirds of the span in order to reduce temporary works.

Transfer of loads from the trusses into the proscenium arch and backstage walls was complex due to the already high stress levels in these walls. Location of the main plantroom, with its massive sound reducing wall, above stage left, and the installation of a double purchase counterweight system above stage right, further increased the loadings. Brick and mortar tests failed to indicate potential increases in allowable stress levels, and considerable reductions in the truss loadings had to be engineered in order to keep the stress increases within nominal levels. Heavy high level walls and a double slab at third floor level had to be demolished in order to accomplish this, and a special hanger was required at stage left in order to avoid additive end shears from the wall truss and roof support girder.

The rear stage wall opening was more difficult due to the very high loads to be carried by the 11m span lintel. A large universal beam box frame was found to be the best solution and this was pre-loaded by tensioning between the upper and lower beams, in order to ensure the full transfer of the high level loads back to their original foundation beneath the new opening. This also minimized the potential for extensive cracking which could have occurred due to the anticipated 24mm combined deflection as the box beams took up their load.

Finding solutions to many of the situations described above was complicated by a number of factors, including lack of existing structural drawings, lack of opportunity to carry out extensive exploratory works prior to demolition owing to occupation of the building, and at least four previous major alterations to the building.

These factors combined in making it difficult to establish the nature of the existing structure until the demolition works were almost complete, and much of the detailing was carried out on a daily basis with the site team.

A selective chronology

1817	Waterloo Bridge opened
1818	Theatre opens as *The Royal Coburg*. Architect: Rudolf Cabanel. Seating approximately 4,000.
1833	Theatre re-decorated and re-named *The Victoria*. Soon becomes known as The Old Vic, noted for extravagant melodrama.
1869	Auditorium completely re-built, with two tiers. Architect: J. T. Robinson. Seating reduced to 2,800.
1870	Theatre sinks to lowest level of melodrama, with audiences even rougher than the shows. Frequent accidents, disreputable audience, danger of footpads to gentry crossing Waterloo Bridge.
1880	Leased to Emma Cons, social reformer: re-opens as *The Royal Victoria Coffee Music-Hall*, run on temperance lines, giving lectures and concerts.
1898	Emma Cons' niece, Lilian Baylis, joins and assists with management: 'New, moving pictures' are introduced.
1912	Emma Cons dies. Lilian Baylis takes over.
1914	The Old Vic Shakespeare Company formed under direction of Ben Greet.
1925-1926	Rebuilding and alteration Architect: Frank Matcham).
1931	Sadler's Wells opened by The Old Vic under Lilian Baylis' management.
1931-1936	Shakespeare, opera and ballet all alternate between The Old Vic and Sadler's Wells.
1937	Lilian Baylis dies. Tyrone Guthrie appointed administrator.
1941	Theatre hit by bombs.
1950	Renovations and re-opening. New proscenium designed and built for Michel Saint-Denis.
1963	The Old Vic Company is disbanded. The National Theatre takes a lease. Laurence Olivier appointed director. Extensive alterations, including removal of boxes and building new proscenium arches by Sean Kenny.
1976	National Theatre moves to new home on South Bank.
1981	Arts Council withdraws subsidy without warning, and the resident company, Prospect Productions, goes into liquidation.
1982	Without subsidy, Governors obliged to sell the freehold after 94 years. The Old Vic returns to private ownership when they sell it to the highest bidder, Ed Mirvish of Toronto, who announces a plan to restore its interior to the design of Robinson of 1871.
1983	After £2m. facelift, The Old Vic reopened on 31 October.

In the 165 years of its existence, The Old Vic has been a producing drama theatre for 60 years (one-third of its life so far) and its occupants have been subsidized by public funds for 35 years (one-fifth of its life).

Credits

Client:
The Old Vic

Architect:
Renton Howard Wood Levin Partnership

Quantity surveyor:
Gardiner & Theobald

Main contractor:
Kyle Stewart Management Contracts Ltd.

World headquarters for General Accident Fire & Life Assurance Corporation Limited

Architect: James Parr & Partners

Jim Hampson

Some of the finest examples of architecture during the last 30 years have been office blocks. We are proud to have been involved in this prestigious project which has been recently completed in Perth, Scotland. The building incorporates flexibility in use and preserves the client's corporate identity and prestige whilst creating an extremely pleasant environment in which to work.

General Accident was founded in 1885 by some Perth businessmen and is now one of the largest UK-based insurance companies with branches and representatives in more than 50 countries. The company has remained loyal to its origins by retaining its worldwide headquarters in Perth.

Ove Arup & Partners were originally invited to join the design team as mechanical and electrical engineers and after discussions in which we explained the benefits of building engineering, we were offered and accepted an appointment for the design and supervision of all engineering elements of the project.

The design approach was based on ultimate flexibility for the long-term future, deep planning of office areas and a desire to blend in with the landscape over the extensive site, thus preserving the existing skyline. The design which emerged was a low-rise building with large areas on each floor providing accommodation for 1200 staff over an area of 25,000 m^2. In addition there is a 22-bedroom hostel – this is positioned adjacent to two ponds with an interconnecting weir in the north-east corner of the site away from the main building and well placed in relation to public transport into Perth. The hostel is intended to accommodate people on training courses.

There is also a sports building which comprises a 25m swimming pool, a sports hall and squash courts together with facilities for a wide variety of social and sporting activities. This building is adjacent to and serves a bowling green, tennis courts and a playing field. The sports facility is located on the flat area in the south-east corner, blending in well with Buckie Braes and the adjoining golf course. There is surface parking for 500 cars located on the upper levels of the site and providing separation between the office building and the adjacent motorway, thus reducing potential roadway noise. The car park location leads users to the highest part of the site and keeps the main views from the building free from interruption by vehicles.

The site chosen is approximately 18ha of the former hill farm of Pitheavlis – bounded by Necessity Brae to the north and west, the new M90 motorway to the south, and the wooded Buckie Braes Glen to the east. Rural in character, the site is part of the southern boundary slopes of the city of Perth and provides a magnificent view northwards across the city. The site slopes fairly steeply to the north and is underlain by a layer of boulder clay over rock. The main building is terraced into the slope of the hill, sited along the contours in an area where there is a suggestion of a plateau which has minimized excavation. The north edge has been brought close to a pronounced drop which enhances the view from the building and its appearance from the city of Perth. The main aspect is north which takes advantage of the panoramic vista as well as alleviating the problems of solar heating gain. (The heating gains are minimized further since there are relatively few south facing windows, and where these occur solar glass has been installed.)

The foundations, cut into the rock at the back of the terrace, are on mass concrete in the central area and are piled through compacted fill at the outer edge of the terrace. Within the building the need for retaining walls has been largely eliminated. All slabs next to earth are of watertight construction in order to keep out the groundwater which seeps through the rock in many places.

The form of the main building is a product of a 10m square grid which has been adopted to reduce the building to a human scale, providing an economic plan form and allowing maximum flexibility in shaping the plans and sections to the contours as well as providing facility for future expansion. The grid allows courtyards to be introduced which relieve the deeper plan areas. The result is a series of floor plan shapes set into corners of the site. The roof terraces provide important foreground interest and merge with the natural landscape as well as fulfilling a secondary role as fire escape routes from all levels of the building.

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Fig. 1
Main Building

Fig. 2
The original accommodation
(Photo: T. Berthon, copyright: GAFLAC)

Fig. 3
New accommodation

(Photos: Ove Arup & Partners, except where otherwise stated)

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The superstructure is entirely of reinforced concrete with exposed aggregate columns on a square 10m grid. The precast concrete columns were joined by means of holes in the base of the column into which the lapping reinforcement from the column below could fit. The annular space was then subsequently grouted under pressure. The columns support a coffered slab which spans in two directions into the columns. This system has no downstand beams which allows free passage of the many services in any direction.

The building is clad in chipped rib precast panels with matching sills and copes. All exposed concrete, i.e. columns, precast cladding and some external retaining walls immediately adjacent to the building, has been made from a uniform quality of concrete consisting of white cement, quartz and sandstone gravel aggregate and sand. Gravel and sand were obtained from the same quarry. The external retaining walls which are used to shape the landscaping close to the building are formed of *Kriblock* units – also in matching concrete.

The main concourse is entered directly from the car park and this will be the hub of movement within the building, accommodating control point, cloakrooms, banks, and leading directly to the staff and management restaurants and recreation areas. Part of the entrance hall is a double volume providing an internal gallery at the executive level above. There is also general office space on this level which is directly accessible from the hall. The Executive Suite, including individual offices, board room and executive dining facilities, is

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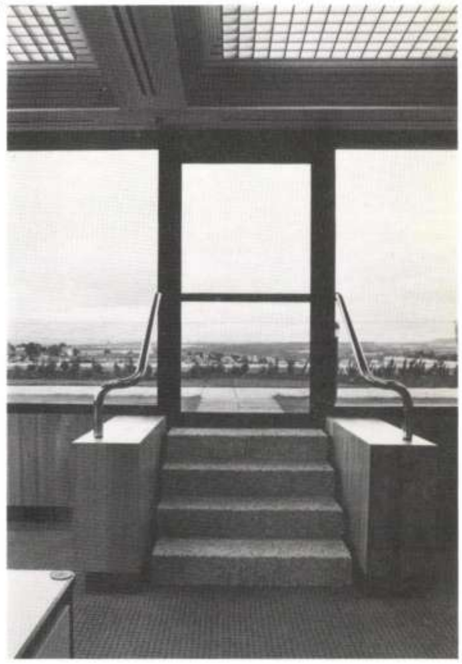

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Fig. 4
Staircase to executive level (n.b. the wall tapestry is hung over ribbed concrete)

Fig. 5
Artwork ceramics

Fig. 6
The hostel

Fig. 7
Auxiliary fire escape; the landscaping is level with the sills

6

located on the floor above the entrance level to offer the advantage of both privacy and view.

Escalators were chosen as providing the most efficient link between floors in this relatively low building and also to provide the interest of movement.

The floor immediately below concourse level contains mainly open office accommodation with a proportion of conference and meeting rooms centrally positioned with archival storage, lecture and studio facilities.

A feature of the open plan office area is its coffered ceiling.

Lighting is provided by utilizing small diameter, high efficiency fluorescent tubes integrated with the coffer.

The main office areas are protected by a sprinkler system and the more sensitive computer area by a Halon gas system.

A very high standard of finish is used throughout the building, ranging from the Bottocino marble of the entrance hall to elm panelled walls, timber coffered ceilings and specially designed top quality carpet in all office areas. The furniture is selected to blend with the overall interior design but additionally a special system of 'top-servicing' has been developed by which power, telephone and VDU services are delivered to desk level via a vertical pole from ceiling level. This system has the advantage of freeing the floor areas of socket outlets and trailing cables, and encourages greater flexibility in use.

The Data Processing Department has been placed on the lowest floor to allow for the specialized under-floor servicing requirements of the Computer Suite and the possibility of future expansion. A basement area has been located below the data processing floor in a natural depression in the site and allows vehicular access to a loading bay for servicing plant areas and paper handling facilities. The service area offers additional security protection to the Computer Suite, since this is effectively cut off from ground level by the underlying loading bay areas.

The main central plantroom, which is 2,080 m^2, is accommodated at the lowest level and houses heavy items of equipment allowing access to be shared with the bulk paper handling area. This plantroom accommodates equipment including boilers, refrigeration machines, transformers, standby generation equipment, hot water storage and high and low voltage switchrooms. The air handling plantroom is located at the topmost south end of the site running horizontally for the full length of the building to provide ease of distribution of air ducts within the ceiling void areas. This arrangement allows good economical distribution of services and has been evolved to accommodate future extension and with ease of maintenance in mind.

Due to the level of the site relative to the water reservoir mains, water is supplied only to the lower level of the building and booster pumps are employed to distribute the water to the other parts of the site. Emphasis has been placed on achieving a low energy concept. A separate refrigeration machine has been selected for the Computer Suite to allow restart in the event of

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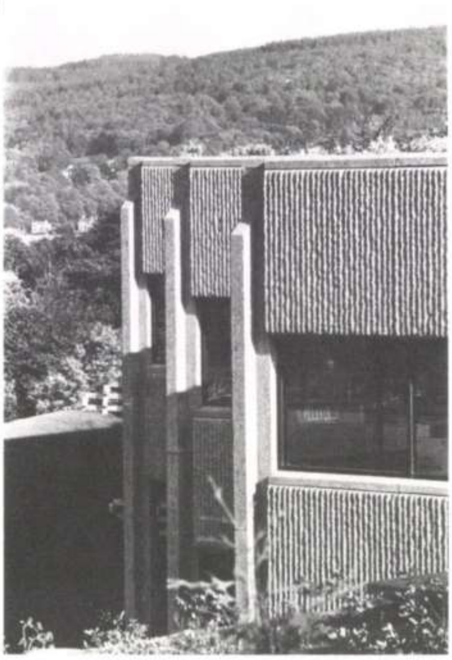

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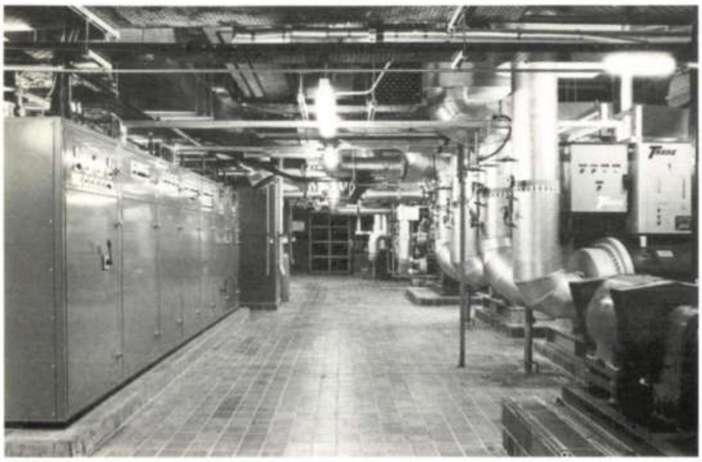

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Fig. 8
View from a bedroom

Fig. 9
Precast cladding

Fig. 10
Granite sculpture by Ronald Rae

Fig. 11
Boiler plant

Fig. 12
Refrigeration equipment

Fig. 13
Air handling plantroom

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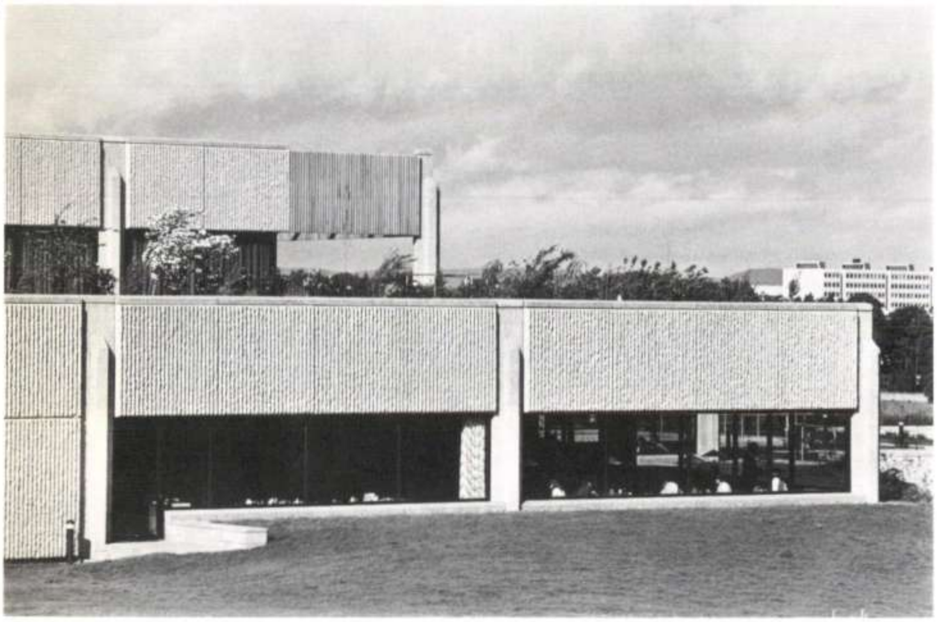

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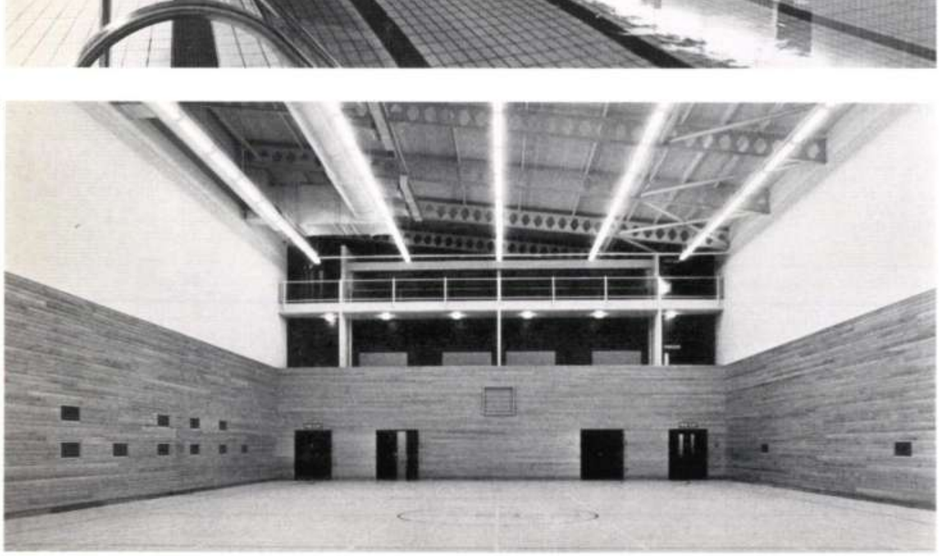


Fig. 14
Dining room interior

Fig. 15
Exterior of dining room

Fig. 16
Swimming pool

Fig. 17
The games hall

an electric supply failure via the standby generation plant. This refrigeration machine operates on a 24-hour per day basis and heat is recovered for the purpose of pre-heating the swimming pool tank and the domestic hot water services. Two further centrifugal refrigeration machines provide chilled water for all air-conditioning requirements and also for the cooling of the main frame computer cores. The total refrigeration load is 4,600kw. The top-up heat for domestic hot water and other items for the building is provided by three low temperature gas-fired boilers incorporating a total boiler power of 6,600kw. The open areas of the building are air-conditioned by variable air volume systems, the computer areas by individual units supplied with chilled water from the central plant which serve floor distribution outlets. Air-conditioning to the executive areas of the building is supplied by dual duct systems. The services include 16 miles of pipework, 480 tonnes of ductwork and some 82 miles of electrical cable.

All services operate at optimum levels of performance by the employment of a central automated building management system with intelligent outstations. This facility includes light switching, data logging, storage and alarms for connected plant and energy monitoring. It also has a major role in the building security and fire alarm systems. Combustion gas detectors are installed throughout, with heat detectors in plant areas.

The car park is recognized as a major landscape exercise where the aim has been to break up the area using site levels, ground mounding and planting. The roof gardens and courtyards are used to bring a variety of small-scale planting close to the occupants and planting themes can be adopted in different areas. Indigenous trees and planting are used along with water to provide an apparently natural landscape which could also become a wild-life habitat. The ponds have been sited in relation to the hostel to give it a special amenity separate from the main building.

A number of major art commissions including sculpture, tapestry, batik, ceramic wall and landscape paintings were incorporated to enhance further the high quality spaces in and around the main building, integrating art and architecture in a way that is rare in modern times.

Credits

Client:
General Accident Fire & Life Assurance Co. Ltd.

Architect:
James Parr & Partners

Quantity surveyor:
W. J. R. Christie & Partners

Main contractor:
Sir Robert McAlpine & Sons Ltd.

An integrated design approach to the modern low energy swimming pool

Des Gurney
Paul Stevenson

This paper was given at THE ARUP PARTNERSHIPS Seminar on innovation in practice held in London in November 1983. Further papers from this seminar will appear in future issues of The Arup Journal.

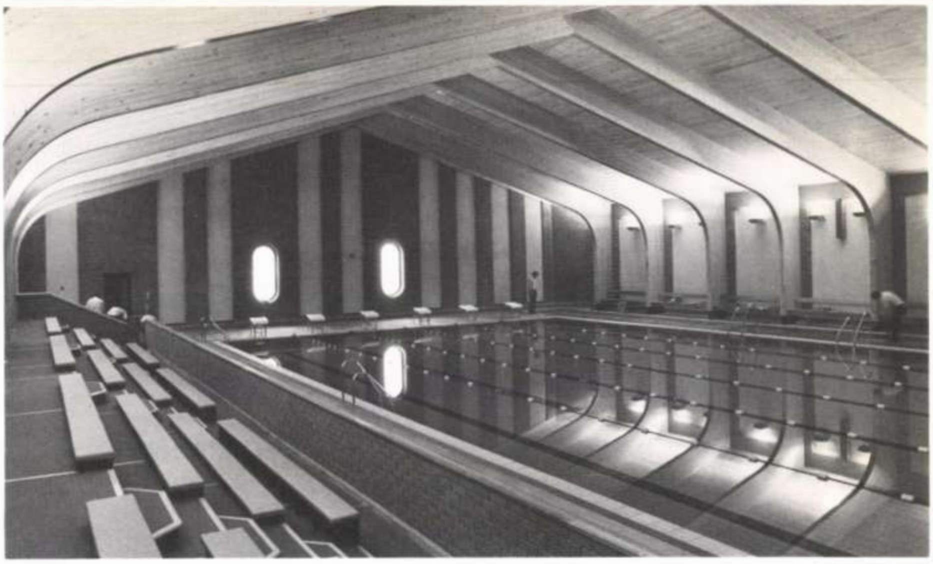


Fig. 1
Wellington Swimming Pool for Wrekin District Council (Photo: Ove Arup & Partners)

Introduction

Accepting the long Arup track-record in the mainly structural design of swimming pools, and Walton Pool which was designed by Arup Associates about 1964, we first became involved in problems which merged the environmental and constructional aspects of pool design when Manchester office was invited to advise on the failure of a pool structure in 1975. As these investigations proceeded, we became aware that the problem was more complicated and more widespread than had been envisaged at the start. This has led us to an approach to swimming pool design which is quite fundamental and an example of the integrated working method which Arups coined as the Building Engineering Approach to Design.

In recent years, and certainly since the development of the Energy Crisis, rising energy and other costs have had such an adverse effect on the profitability of swimming pools in the UK that many local authorities have been forced seriously to consider their closure. The combination of modern energy technology and an integrated design approach has shown that a new breed of pools can be designed to be more profitable and also more attractive to users than heretofore.

We in Arups have been in the forefront of these developments, a number of which have been innovative and not without attendant risks; some known and quantifiable, others yet to be evaluated, no doubt a few yet to be uncovered.

Integrated design of swimming pools

Our firm has been fortunate in receiving a number of commissions which have provided the opportunity for us to give considerable thought to the design of swimming pools, both in development of existing ideas as well as in new techniques. In our experience careful attention to integration and detail of design is a vital constituent of success. In undertaking mechanical and electrical as well as structural/civil engineering commissions, we are able to provide a multi-disciplinary service backed by specialists in the appropriate fields of research and advanced technology, for example in heat recovery and studies in building physics.

We have found that the following energy-related aspects merit particular consideration:

(1) Modern high efficiency lighting systems
(2) Energy conservation and heat recovery measures
(3) Fuel selection, fuel efficiency and tariff assessment aimed at optimum cost-in-use
(4) The optimizing of building fabric thermal properties and a proper match and operation of the building services installations with minimum cost-in-use as the aim.

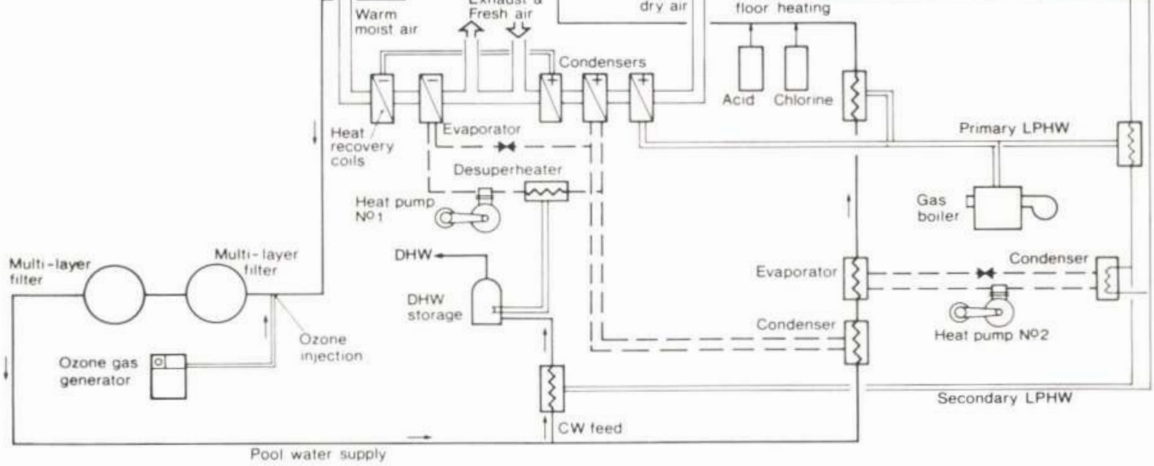


Fig. 2
Wellington Pool heat pump system schematic. Filtration and ozonization plant

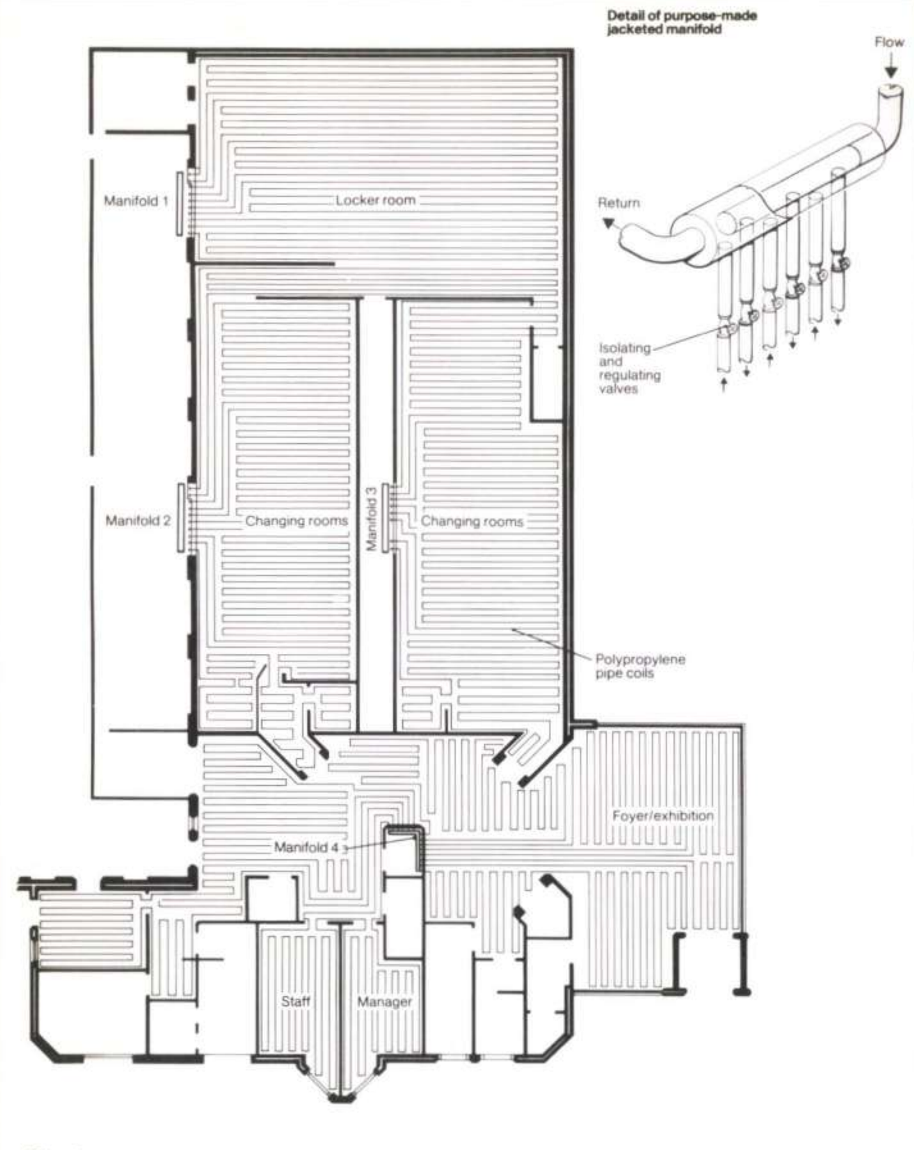


Fig. 3
Wellington Pool: layout of underfloor heating for areas adjacent to pool hall

One aspect which we feel may be of particular interest is the innovative work to develop a ventilation system associated with heat pump recovery and ozone water treatment. This is aimed at eliminating problems due to the humidity, and has improved both the environmental conditions and the quality of the pool water while providing considerable energy economy.

Other features of particular interest are the integrated design of scum channel, deck-level and free-form pools, with wet and dry ducts and specially designed air recirculation systems arranged to optimize heat recovery.

Objectives
Our objective is to provide our clients with a professional service to ensure a well co-ordinated engineering design. It is apparent to us that there is a need for additional, detailed co-ordination of the structure and engineering services on swimming pools.

The principal objectives in the design of the modern pool can be summarized as follows:

(a) Improved environmental conditions, particularly in air quality, water quality, air and water temperature
(b) Reduced energy consumption and costs
(c) Reduced levels of manning and building maintenance
(d) Greater acceptability in use for all ages and conditions of swimmer
(e) Increased life span of the building and services.

Meeting the objectives
Energy conservation in swimming pools
Instead of the conventional system of discharging return warm moist air to outdoors a considerable amount of heat can be recovered by using a specially designed heat pump system. In removing this heat the air is dehumidified and it is now possible to recirculate the ventilation air through an air-conditioning plant, thus resulting in substantial energy savings.

By careful design of the air movement using 'wet and dry ducts' and integration of this system into the planning for the pool and changing rooms, the heat recovery can be optimized so that even more heat is extracted from the air entering the 'wet ducts'.

The output of the heat pump is arranged to provide the majority of the total heating requirement of the complex, to heat the incoming fresh air to offset fabric losses and to heat pool and domestic hot water. This is adequate for a high proportion of the normal annual operating periods of the pool, and we have found that the back-up gas or oil-fired boiler system operates only during the coldest periods of the year. The boiler system is usually sized to provide initial heating or full standby should failure of the heat pump occur. It is our normal practice to recommend that the heat pump should be of substantial and reliable UK manufacture, since it is such a critical element in the design. Detailed consideration is required to establish the long-term efficiency and life of the equipment.

By integration of the design activity, it is possible to influence the selection of the structure and fabric of the building. This aids the energy conscious design, by providing thermal mass which retains building heat and stable temperatures, thus minimizing the operation of the standby boiler system during the coldest periods of the year.

Improved environmental conditions
Traditionally swimming pool internal conditions have been controlled only on dry bulb temperature and pool water temperature with the introduction of large quantities of fresh air. The humidity within the space was related to the amount of evaporation from the pool surface and the quantity and condition of outside air being introduced.

So, during the winter months the outside air, at comparatively low temperature and high humidity, would be passed over a heater battery to raise its dry bulb temperature to above the internal design condition, with the effect of lowering the relative humidity of the supply air. During the summer months with higher outside air temperatures and lower humidities, the air would be heated only slightly, to suit the design conditions of the pool supply air.

As a result, varying relative humidity levels can occur and, since these are all at an elevated internal air temperature, there is no real control to prevent surface and interstitial condensation. The only way to protect the fabric and structure is to introduce large quantities of fresh air.

In existing traditional pools the air distribution systems tended to be at high level, of a high velocity, and not very efficent. This resulted in disturbing the high moisture content layer over the pool and an increase in evaporation and humidity levels. The large spatial volumes normally found in the old pools contributed much to whatever success was achieved.

The modern philosophy for the supply and extract of pool air is to create a stream of warm dry air to sweep the structure and to exhaust as close to the source of evaporation as possible. A system of wet and dry ducts is the most advantageous and cost effective for this approach, the wet duct acting also as a collector for the overspill water from the pool, and as a balance tank.

Although limited heat recovery can be achieved using traditional sodium hypochlorite water treatments at levels of 2.5ppm, we have found that the use of ozone water purification with a minimum of residual chlorine (0.5ppm) provides the opportunity to maximize heat recovery potential by allowing increased air recirculation to be used.

One of the other outstanding features resulting from the use of ozone is the lack of the familiar swimming pool smell and of the widespread problems of eye irritation and related symptoms. The reason for this is the reduction in the water, by the ozone, of the organic compounds which when combined with normal levels of chlorine, give rise to these problems which are so often experienced in modern swimming pools. An added bonus with ozone is a noticeable improvement in the visual quality and taste of the water.

If the water quality is more pleasant and due economy results in more amenable air and water temperatures, with the lack of condensation on exposed surfaces, the total environment of the pool area is improved, as is that of the associated facilities.

Fabric and equipment maintenance
A major cause of high maintenance costs in swimming pools has resulted from attack

on both fabric and equipment by condensation carrying with it residual chlorine, so the condensed moisture is highly acidic.

The removal of excess moisture in the air immediately above the pool provides a source of recovered heat and also reduces humidity levels. This reduces the effect on the structure and fabric of surface and interstitial condensation and if, in addition, ozone is used for pool water purification, savings in maintenance costs are achieved over the traditional designs of pools.

Although the systems are designed to reduce fabric/structural deterioration, it still remains important that the external fabric build-up is designed to minimize condensation should an item of plant break down.

Attendant advantages

By the integrated design approach, it is possible to plan the pool so that there are a substantial number of spin-off advantages, for example:

(a) Ancillary equipment distribution piping and controls can be located in the 'dry duct' which can be designed also to collect, for easy removal, rubbish otherwise dropped into any convenient spot in the spectator areas.

(b) Because the heat pump provides optimum economy when delivering recovered heat at around 40 – 45°C, and these temperatures are ideal for showers and general domestic hot water, mixing controls for showers and taps are thus not required.

(c) The large mass of pool water, at about 27°C, is suitable as a convenient 'heat sink' for any recoverable heat and a large quantity of heat can be absorbed. This can be particularly beneficial if night time heating is available at a preferential rate, when substantial savings are possible, while control of water temperature is very easy and consistent.

The air distribution concept usually employed removes all mechanical equipment, fans and ducts from above the pool, to easily accessible positions around the pool, under the floor and/or in an adjacent plant room.

The availability of cheaply recovered excess heat from the heat pump creates the opportunity to provide winter underfloor warming for the areas outside the pool hall itself, so that an even temperature is achieved and floors in changing-rooms otherwise wet, remain generally dry, mildly warm and very comfortable (see Fig. 3).

There are a number of other features achievable within the integrated concept, which make it possible to reduce the need for specific and/or perpetual attendance. These include ease of external servicing for changing areas, a 'unisex' but still private changing and locker room facility, automatic controls on temperature, humidity and pool water treatment, reduced need for maintenance of equipment and fabric, leading to the possiblity of an external maintenance agreement so that full-time engineering presence is not required.

Flexibility in use

We have found that the generally improved environment, even temperatures achieved at low cost, lack of draughts, visual and chemical quality of water, all tend to make these modern pools attractive, particularly for the very young, the elderly and the incapacitated for whom the therapeutic value is considerable.

Ease of use (timed shower switches, for example), automatic operation, easy access and low maintenance requirements, add to flexibility and the attractiveness, and longer period of use benefits the revenue income.

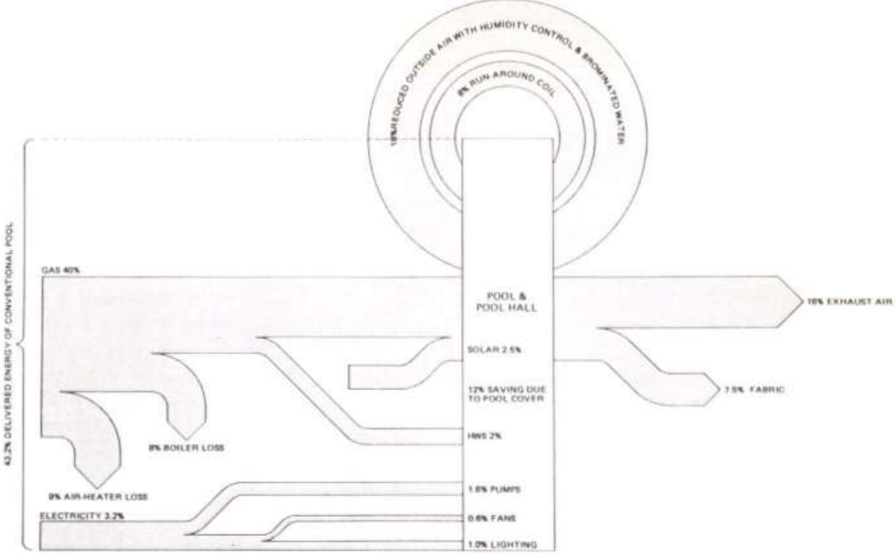


Fig. 4
Eton College Swimming Pool:
'Sankey' diagram of annually delivered energy required by the site

Cost benefit

Financial investment

The fundamental basis of all energy conservation and energy efficient design is that any additional financial investment on such measures is paid for either out of savings achieved or by increased revenue.

Capital costs

In general terms, the cost of a typical modern county pool with heat recovery will fall into the range of £500 – £850 per m^2 gross area, at 1983 prices.

Equipment costs are typically between 25% and 35% of 'total cost'. The wide range is due to equipment selection (e.g. proven machines) extent of facilities (e.g. sauna), spatial provision, and also geographical location.

The lower end of this range will include only conventional services, minimal provision for heat recovery, with chlorine-based pool water treatment. Our designs have shown, however, that a fully integrated design can result in lower capital costs, i.e. the cost of a wet and dry duct system is less than a good ducted ventilation system. Therefore, even pools at the lower end of the cost range can still include many of the features available from a fully integrated design. The upper figure covers most of the aspects discussed in this paper. There may be regional and contractual variations, and these figures must be taken as indicative costs only.

Payback

Typical costed examples, compared with a conventional pool, provide an indication of the improvement which may be achieved by the integrated design approach and investment in modern heat recovery systems, as shown in Table 1.

Table 1

Pool comparisons

(a) A conventionally serviced 25m × six lane school-sized pool, with chlorine-based water treatment

(b) Simple cross-flow exhaust air heat recovery system, chlorine-based water treatment: 25m × eight lane municipal pool

(c) Full heat pump recovery system with ozone water treatment: 25m × six lane municipal pool

Costed examples	(a)	(b)	(c)
Additional capital cost for recovering system	nil	£10,000	£90,000
Annual savings in energy costs	—	£4,000	£20,000
Equivalent simple payback	—	2½	4½
Building gross area	1070m^2	1600m^2	1576m^2
Total cost	£0.55m.	£1.1m.	£1.375m.
Total cost/gross m^2	£520/m^2	£680/m^2	£870/m^2

It will be seen from the table that payback for a swimming pool heat recovery system lies typically in the two to five year range. Of course, the greater the investment the greater the size of the cost savings, especially when the seemingly inevitable rise in fuel costs is taken into account over the lifetime of the pool. We believe that many of the older and larger local authority pools are losing in the order of £50,000 annually, primarily due to rising costs of fuel for heating, maintenance and attending wages. It therefore follows that to save £4,000 p.a. when the total annual losses are 10 times greater, is not a good way in which to achieve profitability. A better option, always provided that the capital is available, may be to invest more over a longer period in order to achieve a better balance between revenue and expenditure.

For the private pool owner the financial equation may be different, but the balance between initial capital expenditure and operational running costs is usually just as critical.

Risks

In the breaking of new ground, especially where the technology is still developing, we are all aware that we may be on a knife-edge between success and disaster. Nowhere is this more true than where building services are involved, and especially when these services are an integral part of the principle features of the project.

In the design of a swimming pool the internal environmental conditions, by their very nature, impose an unnatural impact on the fabric and structure of the building. The performance of the building services, especially in the modern design concept which we have described here, is inseparably linked to the internal and external environmental conditions. If the building services design performs correctly, both economic and fabric life will be good. If this design is bad, all will be lost because of the interlinking of equipment and fabric. Poor advice, whether formal or casual, may have far-reaching results.

At the Seminar, we concentrated on our examination of these risks, outlining those which we have experienced and our knowledge of them to date and indicating areas where our knowledge may still be less than we would like. Areas which we covered included the following:

(a) Design complexity
Both in concept and in equipment utilization (integration, machinery, controls)

(b) Achievement of financial targets
We must assess capital and operating costs relative to hoped-for energy savings, financial payback and the client's cost for borrowing money.

(c) Relationships with other disciplines
In respect of advice (formal and casual): the architect on the design of the fabric, the QS in relation to costs, the client (usually Local Authority officers and members) in relation to his and our intended modes of use, and the client's accountants on their methods and understanding of the value of the proposed investment.

(d) Our dependence on others
The brief; ability of other disciplines to appreciate our intentions: can we trust manufacturers to meet their stated product performance? Our designs must be such that users will operate them correctly.

(e) Health and safety
In order to save energy, we must alter the traditional operating modes, recirculating air instead of using the fresh air only approach. This may concentrate chemicals evaporated from the water (notably chlorine used in water purification), with an adverse effect on the health of swimmers. An alternative is to alter the water purification chemicals and plant, but then we must be satisfied that the new methods work: they are likely to be more expensive in capital cost and maybe in chemicals too. This affects the overall financial viability. New medical evidence is being published which has a substantial impact on this subject, and we must continue to design while these discussions and the technical medical arguments flow first one way, then the other.

Conclusion

We believe that there are lessons to learn from the swimming pool examinations which can be applied in other types of building, particularly in those closely allied to pools such as leisure centres and skating rinks. Some of these lessons may be more widely applicable. This aspect we hope, will develop from the presentation of our paper at the Seminar.

Fig. 5
Walton-on-Thames Swimming Pool, designed by Arup Associates (Photo: Arup Associates)

Wylam footbridge

Peter Ross

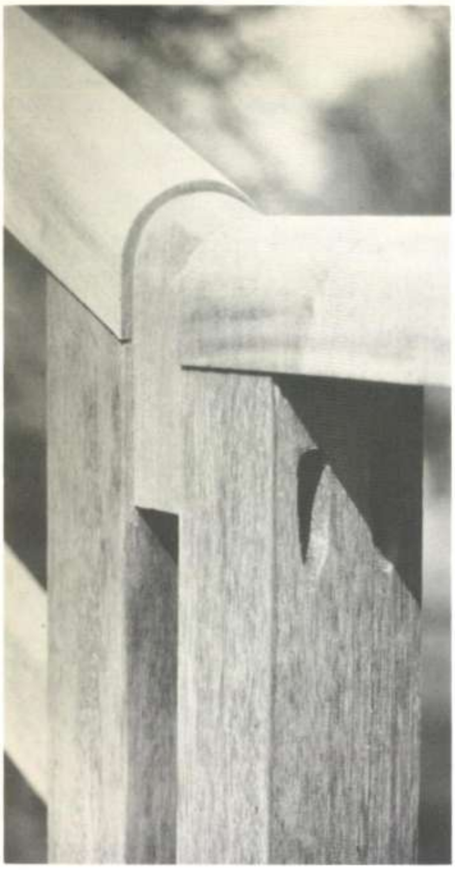
The bridge is used primarily by visitors to the Wylam Hospital, and links a footpath through the grounds to the local railway station, across a small dell. The commission originated from a need to replace the existing bridge, a rather impromptu affair of softwood, which was becoming unsound. The health authority, as the client, required a structure which would have a life of 30 years with minimum maintenance, and since the existing structure seemed proof of the lack of durability of timber, they suggested concrete. The site, however, is only really accessible by foot, and favours the use of a relatively light constructional material. Furthermore, timber would be more sympathetic to the surrounding woodland, and could be durable, if correctly detailed.

A scheme was developed using a gentle ramp and three short flights of stairs. The structure was deliberately designed to avoid 'liveliness' and to give a feeling of confidence. All the timber is dressed, to make the form very precise. We tried where possible to allow shop prefabrication, and so the stringers and handrails were designed so that they could be made as a unit.

Fig. 1
The approach to Wylam footbridge showing the abutments in hand-made brick

Fig. 2
Wylam footbridge: the three short flights of stairs down to the bridge

(Photos: Ian Champion)



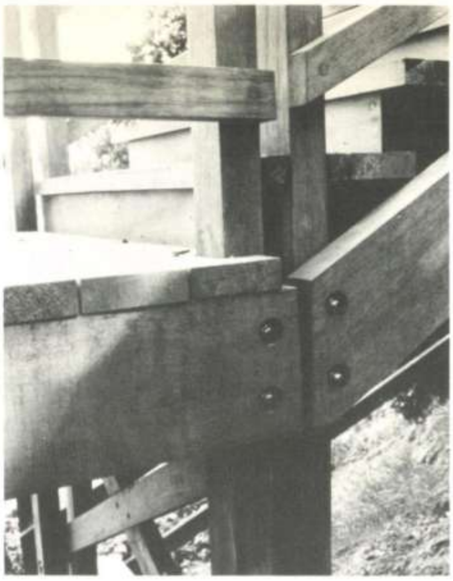
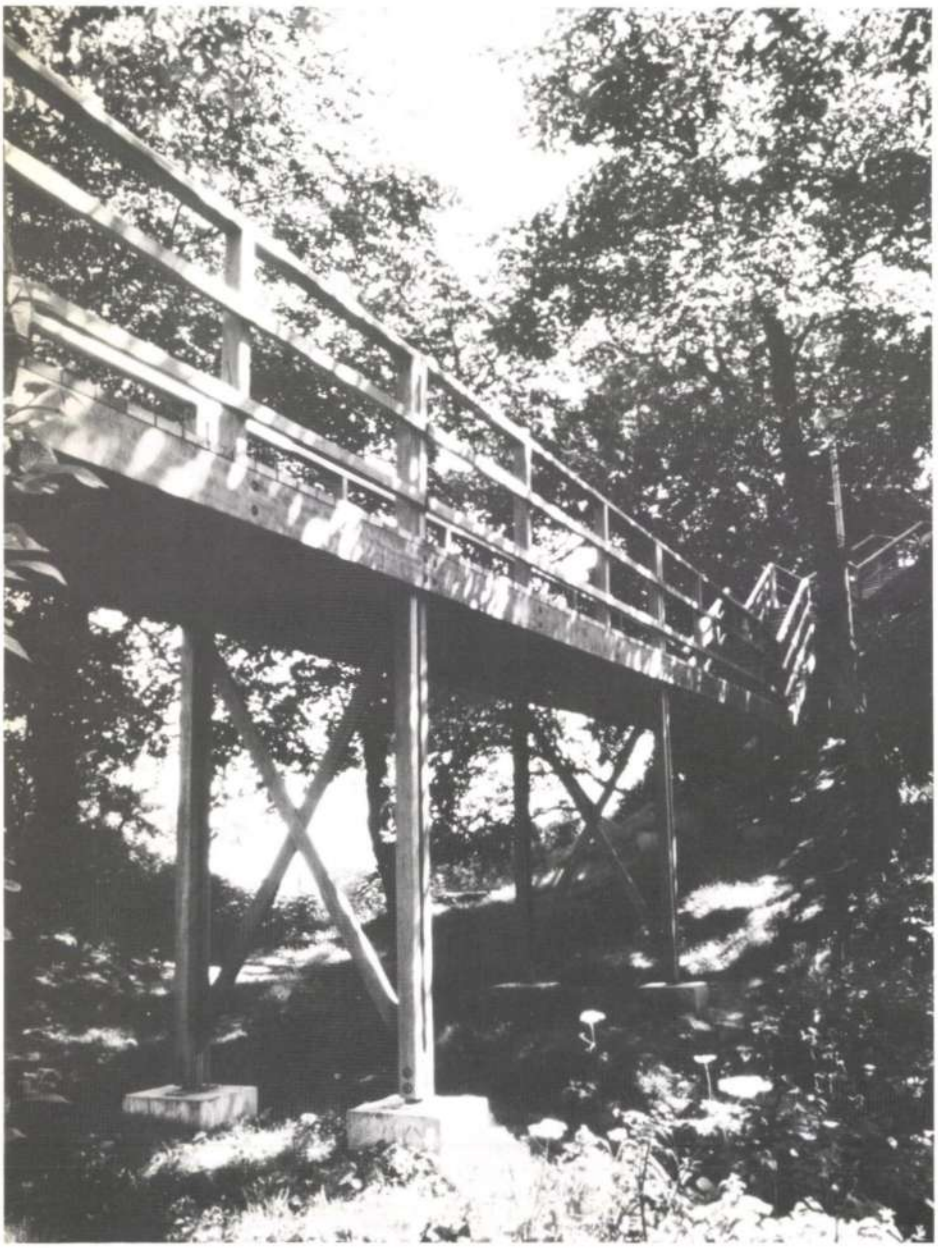


Fig. 3-4
Wylam footbridge:
details of twinned uprights
and handrail junctions

Fig. 5
Wylam footbridge:
View from the woodland floor



This idea generated the twinned uprights which also allowed the handrail junctions to be orderly.

The choice of material lay between the soft and hard woods. The softwoods are undoubtedly cheaper, but preservatives would be necessary. Eventually we decided that the advantages of hardwood in appearance, durability and wear would make it a 'better buy' provided that we kept to the cheaper end of the range. Keruing was an obvious choice, being available in large sections, of good natural appearance and very hard and resinous. It can be machined very precisely, and the only disadvantage, a small amount of grain rise, meant that it would not be suitable for the handrail, where we substituted Utile. Although Utile is more expensive, the quantity needed is small, and the interlocked grain assists in maintaining a good line.

In order to be consistent with the philosophy of using durable materials without an applied finish, all the bolts are of stainless steel. Aluminium non-slip nosings are rebated into the front edges of the treads and deck planks, which are both fastened down with brass screws. It is, of course, most important to keep timber from contact with the ground, and so the uprights rest on small concrete bases and stub columns, while the abutments are built in a hand-made brick.

In conclusion, we should mention that the specification for the work suggested that perfection was just about acceptable, and that was just about what we got. The quality of the contractor's work has been remarked on by several judges, both for the Civic Trust, who awarded it a Commendation in 1982, and for the Carpenters Award who gave it a Special Award in 1983.

Credits:

Client:
Newcastle Health Authority

Consulting architects:
Waring & Netts

Contractor:
Stephen Easten Ltd.

Royal Concert Hall, Nottingham

Architects:
Renton Howard Wood Levin Partnership

Nigel Clift
Dane Green
Alistair Guthrie
Neil Noble

Architects' brief

The idea of a concert hall building has been talked about in Nottingham for the last 50 years. In June 1975 RHWL were selected as architects to carry out a feasibility study, and at the same time concern was expressed about the existing facilities at the Theatre Royal. The Arts Council proposed that the city council should provide additional dressing room accommodation. The feasibility study expressed the view that unless refurbishment at the theatre was carried out in the short term the building would be beyond redemption. The report was accepted and RHWL were asked to prepare a scheme for the refurbishment of the theatre, new dressing rooms, a 400 seat multi-purpose hall and a 2,000 seat concert hall.

Following the municipal election, however, the scheme was reconsidered, and it was decided that only the theatre refurbishment and the new dressing room accommodation should proceed.

The Theatre Royal has been very successful since it reopened in February 1978, but the deferred part of the scheme was not given the go-ahead until 1979. The experience gained by the client on the Theatre Royal, where Ove Arup & Partners were the structural engineers, convinced him that he should appoint a multi-discipline consultant to design and co-ordinate both the structure and the services. Ove Arup & Partners were appointed and we began preliminary work with RHWL and Theatre Projects Consultants Ltd., in October 1979. The engineering design was integrated as the building evolved and the complexity of the final design, particularly in the roof space, amply justified the necessity of drawings co-ordinating the structure, ductwork theatre equipment and other services.

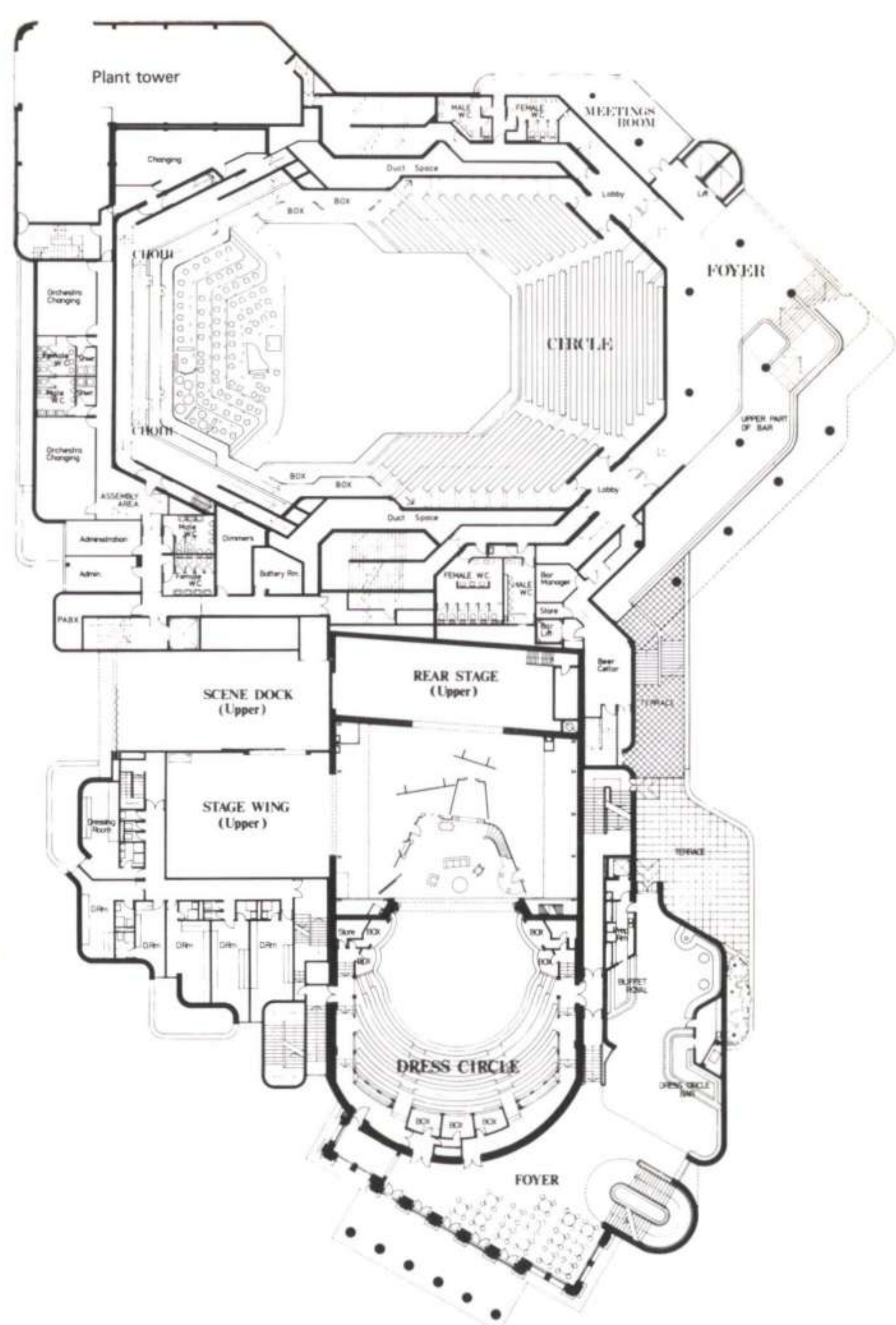


Fig. 1
Plan of the Royal Centre, Nottingham:
Royal Concert Hall at the top; Theatre Royal below
(Reproduced by courtesy of Renton Howard Wood Levin Partnership)

Fig. 2
View of auditorium looking towards the stage from the second tier, showing seven of the acoustic barriers in position behind the canopy.

(Photos: Figs. 8 and 11, Dane Green; Figs. 2-7, Harry Sowden)

The design and construct programme was extremely short for a project of this nature, with work beginning on site in April 1980 and a completion date of November 1982.

A revised brief was given simply stipulating 2,500 seats in an end stage hall. The final brief evolved in the months that followed. The hall had to be suitable for a variety of uses in order to maximize box office revenue.

Despite its title of Royal Concert Hall the building has been designed to be custom made for a considerable range of events with minimum compromise, including trade shows, cinema, conferences and international darts.

As a concert hall it is suitable for the full spectrum of musical events including orchestral and popular music. The interior geometry and finishes affecting the hall's natural acoustics evolved through constant discussion between RHWL, TPC's New York-based acoustician and ourselves.

Acoustic flexibility for such a wide range of events can be provided by a series of 15 air-sealed banners which can be lowered automatically to mask the major reflecting ceiling surfaces and a 30 tonne canopy above the stage area (see Fig. 2). The canopy can be driven electrically from between 4 to 14m above the stage and tilted to a maximum of 10° inclination. Where shows such as rock bands require electronic assistance, a series of installed loudspeakers are available. These are mounted in a sound bridge which can be driven electrically through an access panel in the canopy to its working position (see Fig. 4). Other speakers are located at each level either side of the auditorium. The sound installation is controlled by a Rank Strand desk with 12 channels in four groups and has associated plug connections giving access to 122 microphone lines and 50 tie lines for touring companies.

Foundations

As the concert hall is founded on sandstone which is known to contain caves and voids, the site was extensively probed to a depth of 5m on a 2.75m grid across the entire site. These probes indicated there were no voids under any of the proposed foundations, therefore strip and pad foundations were used.

Superstructure

Due to the complexity of form of the tiers of seating, the split level configuration of foyers, and the acoustical requirements for dense construction, reinforced concrete was chosen as the primary medium for construction of the concert hall.

Fig. 3
The auditorium viewed from the choir stalls behind the stage looking towards the seating tiers. A row of supply air outlets and house lights can be seen in the acoustic ceiling, and various glazed production lighting slots. The canopy is in its raised position (note the two glazed panels for house and production lighting).

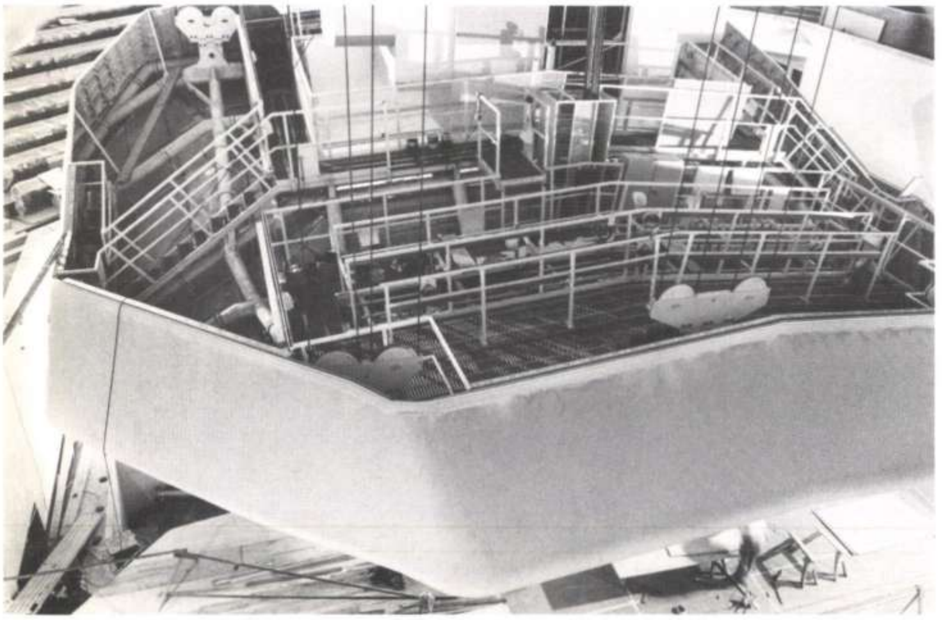


Fig. 4
View from above the canopy showing the tubular steel superstructure and lighting gantries. At the centre top of the picture can be seen the sound bridge and the hatch that allows it to travel through the canopy.

The six layers of foyers wrapping round below the auditorium seating tiers were analyzed as flat plates. This was necessary because of the cantilever nature of many of the levels, the lack of vertical support walls, the number of columns acceptable and the floor to floor height of 3m giving a maximum structural depth of 450mm. In addition, the main interlinking staircase consists of large cranked cantilever structures which were designed using finite element analyses. From these analyses an assessment of deflection was obtained. This was necessary as the structure also supports the curtain wall glazing (see Figs. 6 and 7).

The two large raking cantilevers (see Fig. 9), forming the first and second tiers, are tied back into the foyer structure, further complicating the plate analysis of the foyer slab. The cantilevers were analyzed using finite elements and a dynamic analysis was also undertaken to check the natural frequencies of the structure to ensure that they do not correspond to forcing frequencies likely to be generated by hand clapping and foot stamping during concerts.

The lightweight roof of the auditorium is supported on 3m deep steel trusses spanning 32m from wall to wall (the first truss was in position on 17 July 1982, see Fig. 8). The trusses are supported on a concrete corbel running the full length of the auditorium, also used to stiffen the wall and to carry the horizontal wind loads. The six main trusses are spaced at 8.1m centres over the auditorium seating and 5.4m centres over the platform to carry the additional theatre equipment which imposes a live load (see Figs. 4 and 5), in particular the 30 tonne acoustic canopy, eight equipment hoists and the sound bridge. The trusses are supported by bearings on the corbels which allowed horizontal deflection to take place during the construction of the roof and ceiling. They were then fixed by pouring thrust blocks at the supports to limit any further deflection due to the live load from the theatre equipment.

Acoustic ceiling

The ceiling geometry was developed between Theatre Projects Consultants Ltd's acoustician, Russ Johnson, and RHWL using light model techniques to design a ceiling consisting of a series of reflecting planes. In order to reflect low frequency sound these planes had to be constructed of a dense material, and 100mm of concrete was chosen. (see Fig. 9).

Co-ordinates of the ceiling planes were taken from the model and a computer program was used to check and adjust the complex geometry. The ceiling presented two further problems; how to construct these massive, steeply inclined and angled planes, and how to support the loads they impose on the main roof structure.

Steel frames were constructed to form the individual ceiling planes. These were then suspended, on hangers, from the roof steelwork spanning between the main trusses. Each of the 800 hangers supporting the planes was scheduled for length and location according to the geometry of the planes. A system of permanent reinforcement/formwork was fixed to the frames and where holes were required for ventilation outlets, lighting, etc., these were preformed. The 100mm of concrete was sprayed on to the panels from above and the underside of the ceiling was plastered from scaffolding below.

Considerable effort was required during the design period to co-ordinate the location of hangers and steel frames, both to perform their supporting function and to avoid the large ventilation ducts, theatre equipment, etc. (see ceiling void plan Fig. 10).

Air-conditioning

A major part of the mechanical services budget was expended on the auditorium air-conditioning system. This was determined early in the design by the high auditorium heat gain and the preferred noise criterion of 15.

To meet the noise criteria, the air-conditioning system was designed utilizing low velocity, lined circular ductwork. Each group of supply and extract terminations is fed via a separate ductwork system from the main air handling unit, with the ductwork designed to be self-balancing, incorporating no dampers. All auditorium air termination devices have been specially designed to provide the required air distribution with minimum velocity generated noise.

The resultant large duct runs were integrated with the ceiling support systems, (see Fig. 10) theatre equipment, lighting platforms and access gantries. The air is introduced to the auditorium through several rows of outlets in the acoustic ceiling which were co-ordinated with the theatre equipment, house lights and slots for production lighting. Air is also supplied under the first and second seating tiers. Return air is taken from the auditorium ceiling above the acoustic canopy, at the rear of the top seating tier and through grilles at the sides of the auditorium (see Fig. 9). This downward system of air distribution was dictated by cost and need to achieve a room space of *PNC15*.

Energy conservation

The air-conditioning system was designed to maintain the auditorium at 22°C ± 2°C with no humidity control. It is estimated that the humidity will remain in the 50% ± 15% range, with the cooling coil being controlled in four sections allowing the 'off' sections to bypass the mixed return and fresh air. The air handling plant for the auditorium is equipped with a facility to use automatically up to 100% outdoor air when it is economic to do so. To make the most of this facility and to ensure comfortable air movement in the auditorium, air will normally be supplied at 15°C. At times of heavy electrical loading, e.g. pop concerts or television broadcasts, the management have the capacity to provide supply air at 12°C. Energy is conserved by recirculating up to 50% of return air under full house conditions; a larger maximum percentage can be selected by the management if there is a small audience.

Acoustic considerations for plant

To meet the noise criteria for the auditorium it was decided at an early stage to isolate the main mechanical and electrical plant in a separate structure from the rest of the building. A plant tower was designed to house two package chillers at basement level, a boiler room and substation at ground level, an air handling unit at 1st floor level and roof mounted cooling towers (see top left corner of Fig. 1). In addition the fans, chillers and pipework are supported on spring isolators and the pumps on sprung inertia bases. Special precautions have been taken with sealing joints through which pipes and ducts pass from the plant areas.

The main auditorium fan handles 31.5m^3/s and the return air fan handles 90% of this volume. The fans are equipped with auto-changeover standby motors and are located together with cooling and heating coils, attenuators and mixing sections in a 23m long 4m high 4m wide L-shaped air handling unit. The installed fridge capacity is 880kW from two packaged chillers with screw compressors and excess heat is discharged from two twin speed forced draught towers.

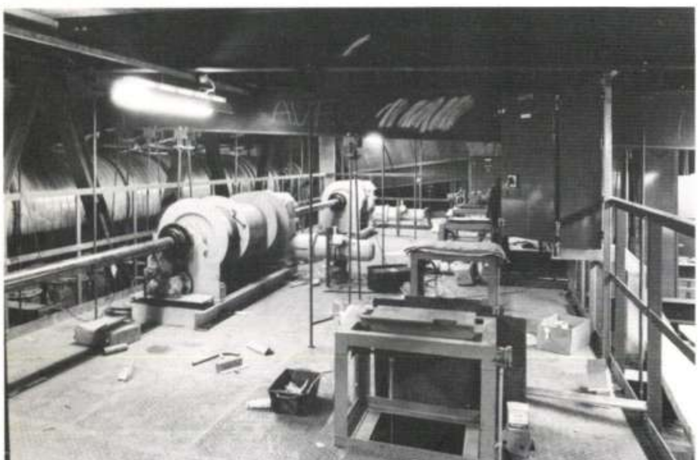


Fig. 5
Gantry for acoustic canopy and point hoist winding gear in the auditorium ceiling void. Note the size of one of the main extract ducts behind the steel roof truss to the left of the picture, and some of the ceiling hangers through the gantry.

Fig. 6
Internal view of foyer stairway showing perimeter convector heating.

Heating
Heating is provided for the whole complex by a low pressure hot water system using three atmospheric gas fired boilers with a total capacity of 1467kW.

It was originally intended to heat and naturally ventilate the backstage and foyer areas but, as the design developed, more areas required forced ventilation, resulting in a number of small air handling plant rooms around the building. All areas are zoned to permit maximum flexibility of use, and heat is emitted into the space using individually controlled radiators or, in the case of the foyer, from natural convectors which form part of the handrail detail (see Fig. 6), and are fed from a variable temperature circuit.

Computer analysis
The foyers presented a particular problem with the build up of heat during short periods of maximum occupancy, such as concert intervals. The problem was analyzed by computer to predict the effect of opening the doors at the bottom level, opening some of the window area and extracting air at the top of the foyer staircase, and the air flow from each determined. The areas immediately in front of the bars are mechanically ventilated.

Electrical installation
The electrical supply for the new plant tower sub-station was extended from the existing Theatre Royal 11kV switch-gear. Provision had been made during the first contract to supply a second transformer for the concert hall. The cable is routed in a separate duct within a pit and duct system below the stage to a new 1MW transformer.

The LV switchgear in the adjacent room to the transformer provides radial sub-mains supplies to panels and switchboards via the same pit and duct system to the various loads. A 500A interlocked feeder interconnects the LV switchgear of the concert hall and the theatre to provide some degree of security of supply in the absence of any installed standby generators.

Main services
The main services are: dimmer switch board 500A, front of house switchboard 315A, rear of house switchboard 200A, two chillers at 250A, AHU plant control panel 250A, and two auxiliary stage power switchboards at 400A and 200A.

The auxiliary switchboards are equipped with earth leakage monitoring and tripping circuitry and provide facilities for temporary installations. These are required for travelling musicians and additional lighting for TV broadcasts. The supply is available from either *BS4343* outlets or from a special bus-bar connection chamber.

Nottingham's sandstone rock provided certain difficulties in earthing the sub-station and providing lightning protection to the building. This problem was recognized early in the design when a 7000Ω/cm resistivity reading was obtained from a rock shelf in the theatre's boiler room. Some 26 structural rock probes were selected and backfilled with carbon to provide suitable electrode locations for both the system earth and the lightning protection, with very good results.

Lighting
Theatre Projects Consultants in conjunction with RHWL produced a lighting design concept for all of the main public spaces. This included selection of luminaires and their control. Ove Arup and Partners were required to check the concept technically and include it within the overall design for the electrical installation.

The house lighting comprises 284kW of installed load, 110kW of which is on the canopy. These circuits are controlled by 70 dimmer channels all with full memory, so that it is possible to programme the lighting to suit the requirements of individual events. The house light luminaires fitted within the acoustic ceiling had to be specially manufactured to fit the 100mm thickness of the ceiling. They include a 10mm thick piece of glass, to provide an acoustic seal, and to reduce heat gain to the auditorium.

The production lighting is controlled by 120 dimmer channels with full memory facilities. 40 of these are located on the acoustic canopy and most of the remainder are wired to a number of lighting bridges behind glazed panels in the acoustic ceiling (see Fig. 2).

The six levels of foyer lighting are controlled by contactors to provide staged switching for cleaners, daytime performance and night time performance.

The secondary maintained or emergency lighting is supplied from a 7.5kW 110V battery bank with three hours capacity, supplying both tungsten and 8W miniature fluorescent luminaires.

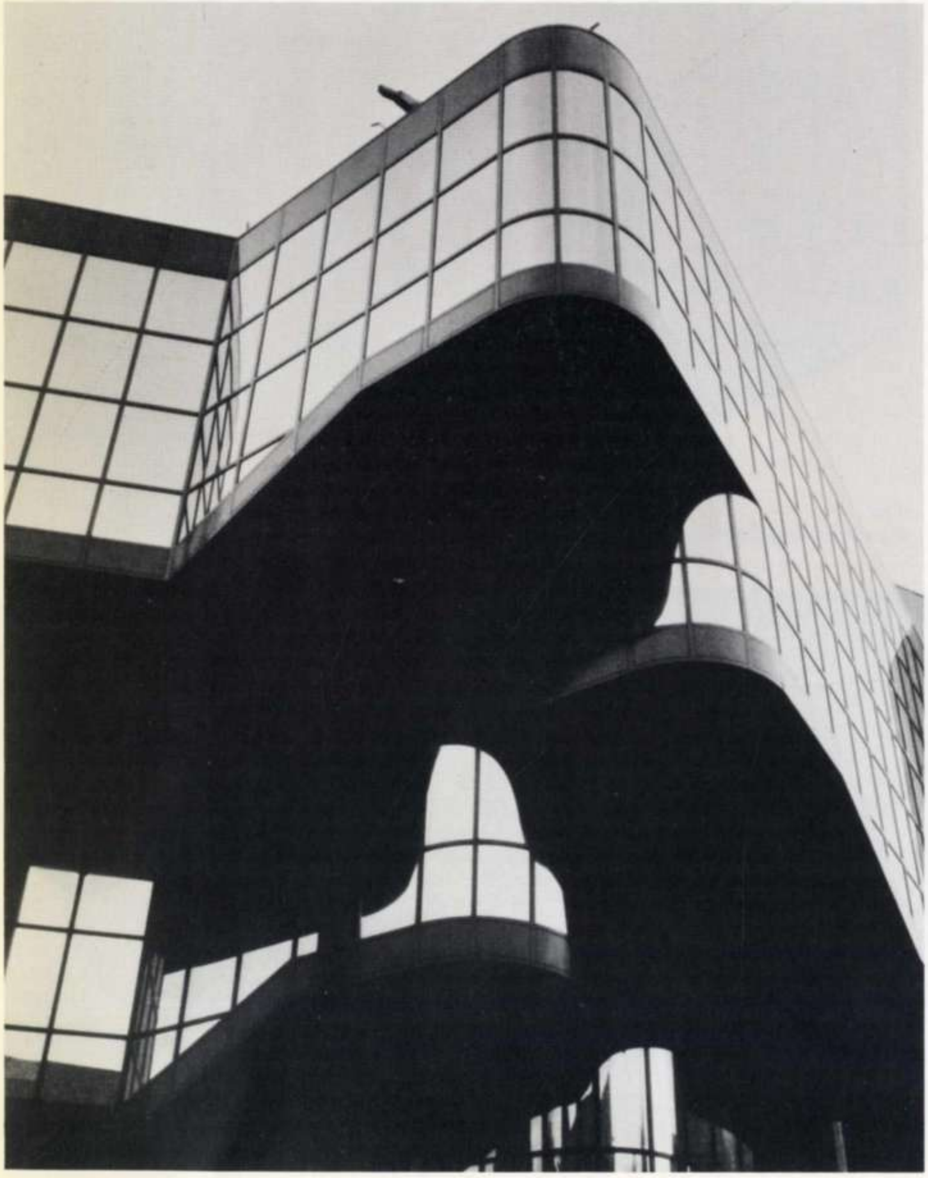


Fig. 7
External view of foyer cranked cantilever stairway and curtain walling.

Fig. 8
The first roof truss in position viewed from the top of the second tier looking towards the stage. (Fig. 2 was taken from the same viewpoint after completion.)

Public health

Sanitation: The foyer bars and toilets are located at alternate levels remote from the main drainage routes and dictated the use of a fully vented system.

Insulated cast iron was used for all major sanitation and rainwater pipework for acoustic reasons.

Water services: A sectional cold water storage tank is positioned, externally, at high level with gravity services throughout. All external pipework is insulated and trace heated, and an immersion heater within the storage tank maintains water above freezing point.

Two hot water systems have been installed, one with the calorifier storing water at 40°C. to serve spray taps in the toilets, and the second with a calorifier storing water at 60°C. to serve changing rooms, kitchens, bars and cleaners stores.

Fire protection

The existing theatre sprinkler installation was extended to cover the bars and meeting rooms at the front of house and the stage wings and dressing room areas at the rear of the house. The existing pump was equipped with a secondary electrical supply from the new sub-station.

The fire alarm installation is a two stage, multi-zoned type with an automatic link to the fire brigade. The system has visual alarm indication in staffed public areas and bells at the rear of house. The non-sprinklered areas such as the foyers and the auditorium ceiling void are protected by smoke detectors.

Light sculpture

In March 1982 Ron Haselden was commissioned to design a neon light sculpture. His work utilized about 316m of dimmerable neon tubing in four colours, supplied by 42 circuits selected at random from a specially built control panel. The sculpture is supported by a stainless tubular steel structure designed by our Lightweight Structures Division. The work was illuminated for the first time on 27 November 1982 by Elton John when he plunged a detonator painted in the colours of Watford football club.

It gave great satisfaction to see the building full of people.

They danced in the stalls as our ear drums pounded to Elton's 'Saturday Night's all right for fighting,' 'Rocket man','Crocodile rock' and many others.

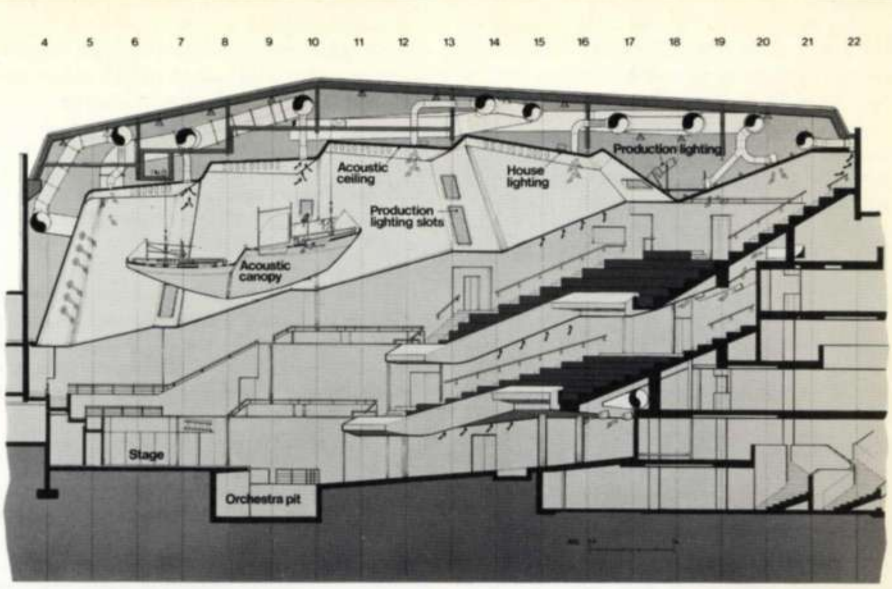


Fig. 9
Section through the length of the auditorium and foyers wrapping around below the seating tiers.

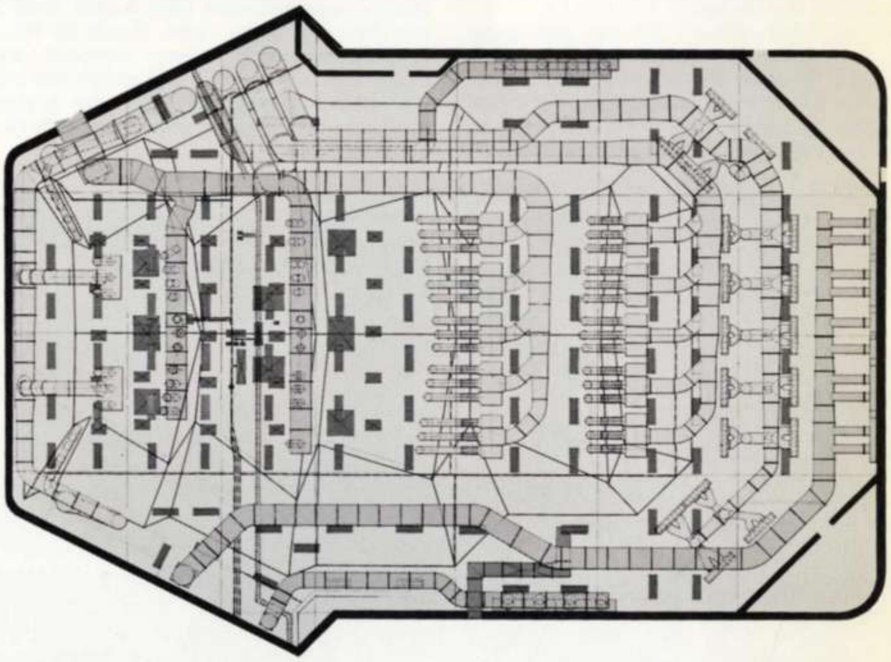


Fig. 10
Plan of ceiling void services.

Fig. 11
Royal Concert Hall, Nottingham:
Elton John gives the opening concert.

Credits

Client:
Nottingham City Council

Architect:
Renton Howard Wood Levin Partnership

Quantity surveyor:
Gleeds, Nottingham

Theatrical consultants:
Theatre Projects

Ove Arup & Partners Design team:

Director:
Nigel Thompson

Project manager:
David Atling

Structural engineer:
Neil Noble

HVAC engineer:
Alistair Guthrie

Electrical engineer:
Dane Green

Public health engineer:
Nigel Clift

Printed in England by Reedprint Limited, Windsor, Berkshire