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Back cover:
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Torre de Collserola, Barcelona

Architect:
Sir Norman Foster & Partners

Chris Wise

Introduction

In February 1988 the City of Barcelona invited five architects to compete for the design of a new telecommunications tower. They wanted it to be a 'monumental technological element . . . to enhance the image of Barcelona in the context of the 1992 Olympics'. The site was magnificent, overlooking the city from a height of 440m above sea level. The tower was to be called the Torre de Collserola, after the mountain on which it stands. Ove Arup and Partners entered jointly with Foster Associates and won the competition as the only non-Spanish team; in May 1988 this team was awarded a commission for the concept and scheme design of the tower complex. This was later extended to include detailed design and tender documentation of the tower itself, with a reviewing role during the construction phases. The client, formed specifically to build the tower, was a joint venture company of RTVE-Radiotelevisión Española (the principal Spanish national television network), Telefonica (Spanish telecommunications) and CCRTV-Corporació Catalana de Ràdio i Televisió (Catalan television).

The project is part of the recent renewal of the City of Barcelona, which has seen much new infrastructure work, the construction of the 1992 Olympics' facilities, and the renovation of much of the city's historic architecture, including the work of Antoni Gaudí.

The brief

The brief called for a new telecommunications complex that would form part of the overall communications infrastructure of Spain. The project was also to be a symbol for the City of Barcelona as it entered the 21st century, and the design had to be sensitive to the natural beauty of the site, a national park planted with Mediterranean pines. The complex is divided into two parts: the tower, which houses the broadcast and relay antennae, signal processing equipment and a public viewing gallery, and the support building, which holds signal generation equipment and principal services.

The use of the tower can be summarized as follows:

- Up to a level of +85m: Nothing
- From +85m to +152m: 12 equipment platforms and antenna galleries for parabolic satellite dishes, and one viewing gallery, each of 550m^2
- From +162m to +206m: Small antenna galleries for UHF/VHF transmissions
- From +210m to +281m: Even smaller galleries for mobile telecommunications and radio telephones
- At +281m: A crane to lift antennae onto the galleries.

Implicit in the brief was the requirement that broadcast signals should have unobstructed transmission paths as far as possible. This meant that no electrically conducting elements, including, critically, structural steelwork, could occupy a position in front of an antenna.

The operational efficiency of the tower is defined in terms of the amount of time each year in which the signals can be transmitted, the aim being to minimize broadcasting 'down-time'. This means that the tower has to be structurally stiff to limit twist and tilt of the satellite dishes under wind.

In addition, the design team had to provide the tower with power and data risers to serve the antennae; a passenger lift; an equipment lift large enough to carry a 3.6m diameter satellite dish; and an escape stair. Public and operational functions were to be kept separate for security reasons.

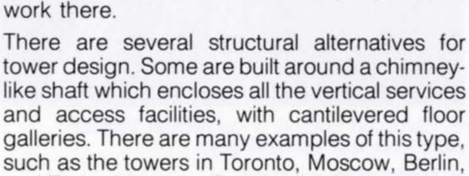
1

Design precedents

The amount of floor accommodation is much greater than in typical towers, and called for a fundamental rethink of traditional designs. This is perhaps more easily understood if the enclosed antenna galleries are envisaged as office space; if this were the case, 700 people could work there.

There are several structural alternatives for tower design. Some are built around a chimney-like shaft which encloses all the vertical services and access facilities, with cantilevered floor galleries. There are many examples of this type, such as the towers in Toronto, Moscow, Berlin, and Emley Moor (an Ove Arup & Partners' project of the early '70s). For Barcelona, a 'control' design was carried out during the competition which showed that, for this type of tower, a slip-formed concrete shaft at least 25m in diameter at its base would be needed. In this kind of structure, the lateral and vertical load systems are separated.

Towers such as the Eiffel Tower in Paris and many microwave towers worldwide use a tapering steel lattice. As an alternative, there is the guyed mast, of which many have been built to carry small antennae systems. Some of these reach a height of 600m. There are also examples of cable-stayed towers, such as the Centrepoint Tower in Sydney, which uses a network of steel cables to stabilize a comparatively slender concrete core.



3. Scale comparison.

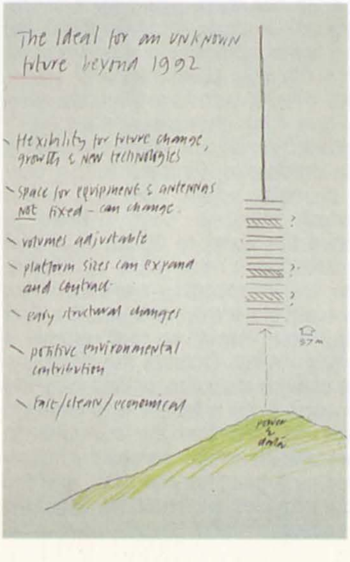
2

A new concept

For the Torre de Collserola Arups developed with the architect a structural system which integrates in the most minimal way the requirements of the brief with a skeletal system which carries both lateral and vertical loads.

Functionally, the following were needed:

- The main floor system: a simple block beginning 85m above the foundation
- Above this: a more conventional radio mast
- On top of this: a crane
- And servicing this: power and data risers, lifts and stairs.



4. Sketch by Norman Foster.

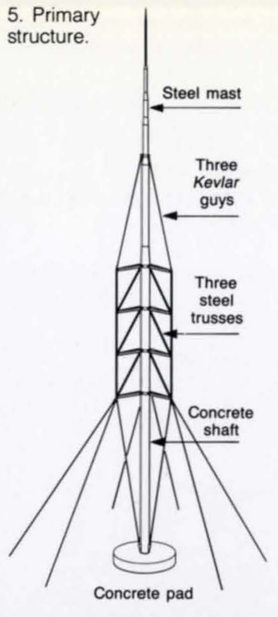
Primary structure

The primary structure is essentially a simple concept. It is made up of a circular hollow shaft, braced by three vertical steel trusses spaced equally 120° apart on plan. Within the body of the primary structure, the trusses are made from high strength steel; the lower truss diagonals are parallel strand steel guys, and the upper diagonals made from *Kevlar* fibre rope. The entire shaft and truss system is stabilized to the mountainside by six principal guys arranged in three pairs.

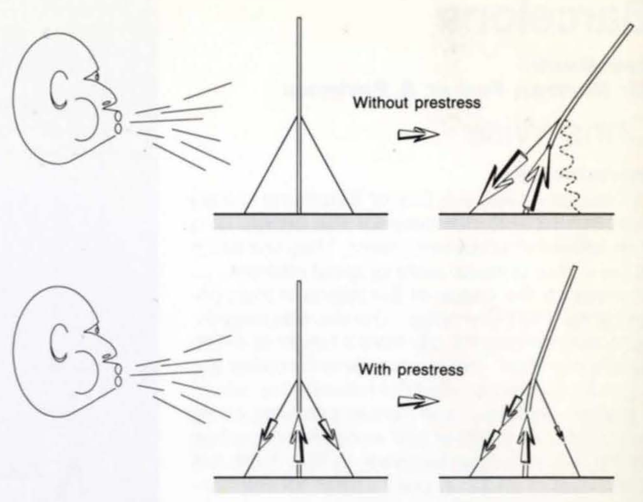
To maintain stiffness during strong winds, the primary structure is prestressed by tensioning the principal guys, which means that the downwind guys do not go slack, even under extreme winds. The primary structure is as stiff as a conventional high-rise building: it will deflect 85mm and tilt less than 1/12th° at a height of 152m, under a wind speed of 28m/sec.

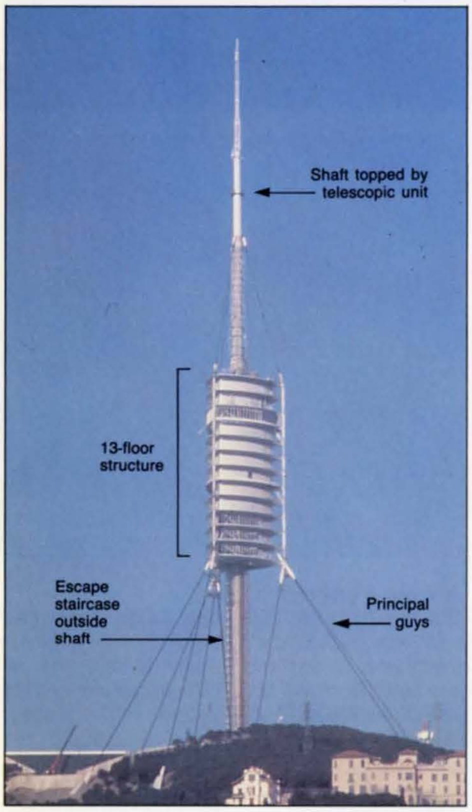
Principal connections were tested analytically and aesthetically with model and computer graphic prototypes. They are fabricated from steel plate, and are designed so that truss forces, up to 3100 tonnes in the lower diagonals, are co-incident at each node.

5. Primary structure.



6. Prestress for stiffness.

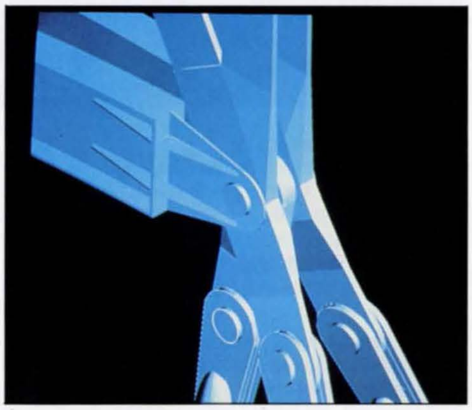




7. The tower as built showing principal elements.

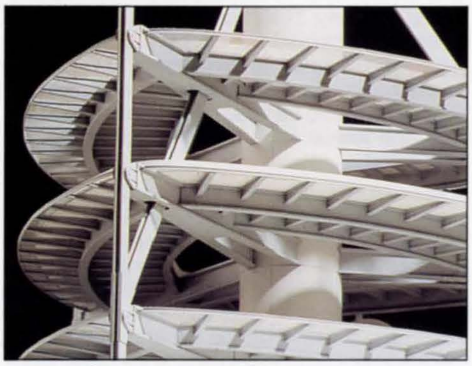
Shaft

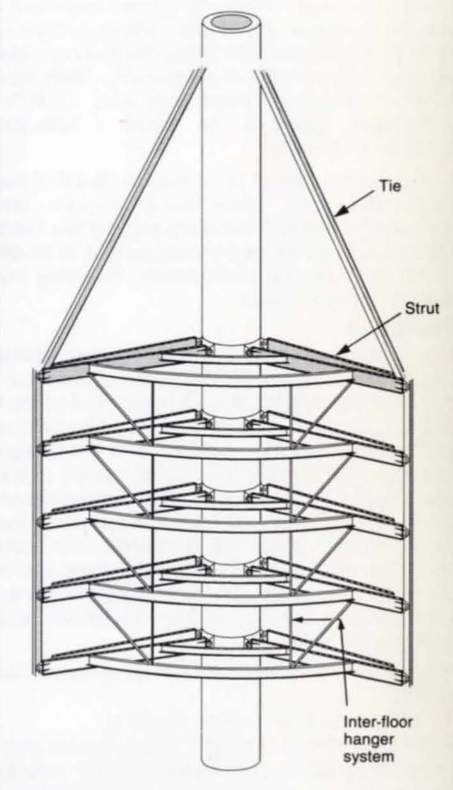
The central shaft has three uses. As a fundamental part of the structure, it carries the entire weight of the tower, plus the precompression resulting from the guy prestress, and resists torsional wind effects, with help from the principal guys. From 4.5m diameter at the base, it tapers to a point. For the first 205m the shaft is slipformed in reinforced concrete with a continuous 3m diameter hollow core and a wall thickness which reduces from 750mm to 300mm. Above this level, to 288m, is a steel mast which telescopes from 2.7m to 2.2m to 1.5m to 0.7m, and is topped by a small pointed crane. In the event of a fire in the tower, the shaft acts as a four-hour barrier so that escape is possible by two routes. Outside the shaft is a conventional escape staircase, while inside the alternative means is by a ladder and platform system which runs 288m from the foundation to the top of the tower. In normal service the hollow shaft behaves as a giant service riser, and the escape ladder provides access to wave guides and power cables.



8. Computer graphic of connection between steel truss and principal guys.

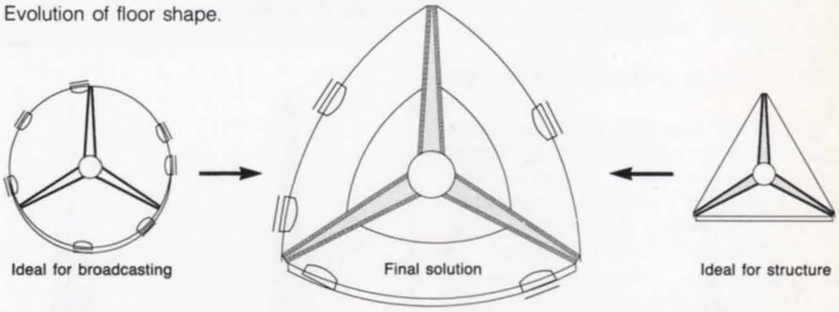
9. Model of typical floors.





11. Floor systems.

10. Evolution of floor shape.



Floors

The floor design has to balance the demands of broadcasting and structure. For broadcasting, the maximum perimeter would be obtained with circular floors, but for structural simplicity, a triangular grid spanning onto the primary truss system is the optimum choice. The interaction of the broadcasting circle with the structural triangle gives the characteristic shape of the floors.

There are 13 main floors, of composite construction with an open stainless steel grillage around the perimeter. They hang from the shaft by the three primary trusses, and are linked together by a secondary inter-floor hanger system. This distributes heavy point loads between floors, which also act as stiff rings to transfer wind loads to the primary structure. They touch the central shaft at just three points per level, with the lifts and stairs fitting between these points.

Guys

The main guys are made from bundled parallel steel strands. For the ultimate load of 1700 tonnes this requires a hexagonal guy of 320mm diameter. Because the tower is on top of an undulating mountain ridge, the main guys have different lengths, for which the design compensates by adjusting the number of strands in each guy to maintain equal stiffness.

The *Kevlar 49* of which the upper guys are constructed does not conduct electricity, and being 'invisible' to broadcast signals, allows unrestricted transmission and reception. The material has excellent fatigue performance, about half the stiffness of steel, and roughly the same strength; each guy is made from a bundle of seven 50mm cables. Full-scale prototype testing of the guys and their connections was carried out by the manufacturer.

Wind engineering

Wind forces on the tower are unusually high. This is because of the exposed position of the tower in its mountainous surroundings, and also because the local topography produces an acceleration of the prevailing 'Tramontana' wind as it funnels down the valleys from the north west and rises over the ridge on which the tower has been built. The result is similar to the airflow over an aeroplane wing.

The effect was studied by wind tunnel testing carried out in two stages:

(1) A topographic wind study explored the speed-up of the wind because of the terrain, using a 1:4000 model of the surroundings 3.5m in diameter.

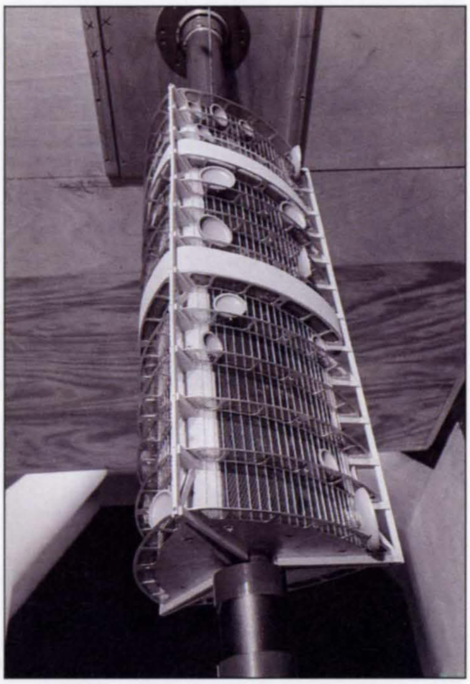
(2) An aerodynamic and aeroelastic study tested the response of the tower, using a 1:100 carbon fibre model of the main floors.

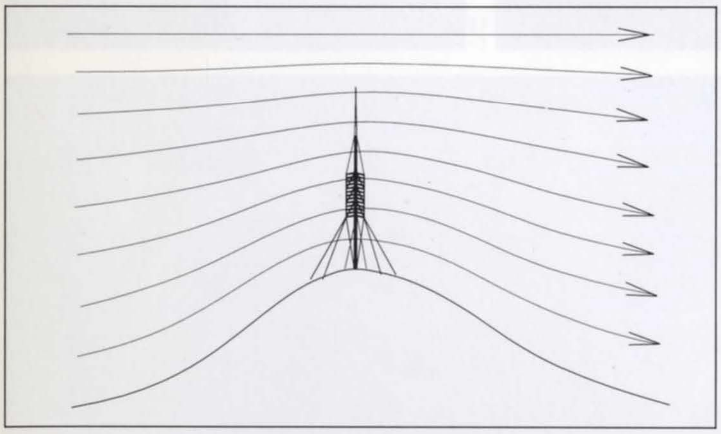
These showed that the wind accelerates across the mountain ridge in gusts up to 59.9m/sec at the height of the main floors, and 64.9m/sec at the tip of the tower. The clad and equipped floors experience maximum drag factors (C_d) of about 1.35. Measured twisting moments were comparatively small, and the tests showed that for all credible wind speeds the tower would not experience galloping instability, or vortex shedding problems.

Geotechnical engineering

The tower foundation is a simple reinforced concrete disc 20m in diameter and 5m thick. It carries the shaft working load of 10 700 tonnes onto the schist-like phyllite rock of the mountainside. Under this load, we expect a settlement of 11mm. As this shortens the main guys with the loss of 55 tonnes of pretension per guy, a small adjustment of prestress is needed during the construction process.

The rock is jointed in blocks and it proved possible to excavate without explosives, using a large excavator. The dip direction of the joints was an important consideration in the design of the anchorages for the main guys, which will carry a maximum working tension of 1260 tonnes each. After rejecting rock anchors because of their expense, the anchor blocks were each made of 800m^3 of mass concrete.





12. (left)
Wind acceleration over mountain.

13. (above)
Wind tunnel test.

15. Construction sequence.

14. The tower base, November 1990.

Awarding the contract

For projects of this type, the main element of cost is in the techniques used to erect the structure rather than in the cost of the materials themselves. After an invited international tender, the Spanish contractor Cubiertas y MZOV won the contract with a programme of 18 months.

They submitted two offers. One was a conforming tender, using a method of construction which relied on assembly of the structure, unit by unit, in its final position. They also, however, submitted an alternative which was intended to minimize crane time by building as much as possible as close as possible to the ground. Their proposal was based around the concept of constructing at ground level the 13 floor platforms as a rigid body, and then jacking up the entire assembly weighing 2700 tonnes through 85m, into its final position. Their slightly reduced offer for the tower and the support building for this alternative was accepted by the client, who acknowledged that it contained a degree of risk.

Developing the erection method

Cubiertas commissioned the noted Spanish engineer Julio Martinez Calzon to assist them in the design of the erection sequence for the project. While keeping largely to the tender design, Martinez Calzon recognized the advantage of minimizing the number of connections from the primary steel structure to the concrete shaft. To do this, he introduced an additional line of vertical structure at the inner end of the radial arms to collect together the forces from the 13 floors into four discrete levels, which coincided with the intersection of the primary structure diagonals with the shaft. The steel ring at each floor, which was part of the tender design, was replaced by a Y-shaped yoke passing through the shaft at levels 1,5,9 and 13. Wind-induced torsional effects were transmitted to these 'stability' levels by the action of the inter-floor diagonals and mullions which were modified to act over four floors as vertical trusses.

The tender documentation proposed the early installation of the steel telescopic mast inside the partly complete concrete shaft, to be jacked up the hollow core and then telescoped up into its final position from the top of the concrete. To allow this, the four sections of the mast had been designed so that they fitted snugly one inside the other, like a giant car aerial. The advantage of this was to remove the need for a very tall crane 290m tall, replacing it by a more modest 210m model. Martinez Calzon adopted this in his final construction method.

Building the tower

After excavating and concreting the foundations, Cubiertas slip-formed the central shaft to its full height of 205m, with temporary stability guys at three levels. On top of this was a steel transition ring, which doubled as a platform for the jacking operations carried out by the Swiss company VSL, and which also formed the connections for the upper Kevlar guys.

Around the base of the tower, surrounding the central shaft, the 13 floor platforms were constructed. The floors were cast on steel permanent shuttering like a normal building, albeit with 5.625m storey heights. By early June 1991, the 73m tall assembly was complete, giving a stable shell structure with a total floor area of 7150m^2, weighing 2700 tonnes. After a champagne launching ceremony, the jacks were charged and the floors jacked up by a nominal 25mm, and left hanging for a weekend to check that nothing was amiss. Then, guided by wheels, the floors were lifted from the ground to their final resting place at about 4m/hour. The final connection to the shaft was made by site welding to the Y-splices at four levels.

During these early stages, the shaft was stabilized by tiers of prestressed temporary steel guys, 90m, 160m, and 200m above the foundation. The top two tiers remained in position during the lifting of the floor assembly, to provide a degree of fixity at the top of the shaft and prevent buckling over its length of 210m. After installation of the main steel and Kevlar guys, the telescopic upper mast was jacked upward, sliding inside the concrete shaft through phosphor bronze bearings.

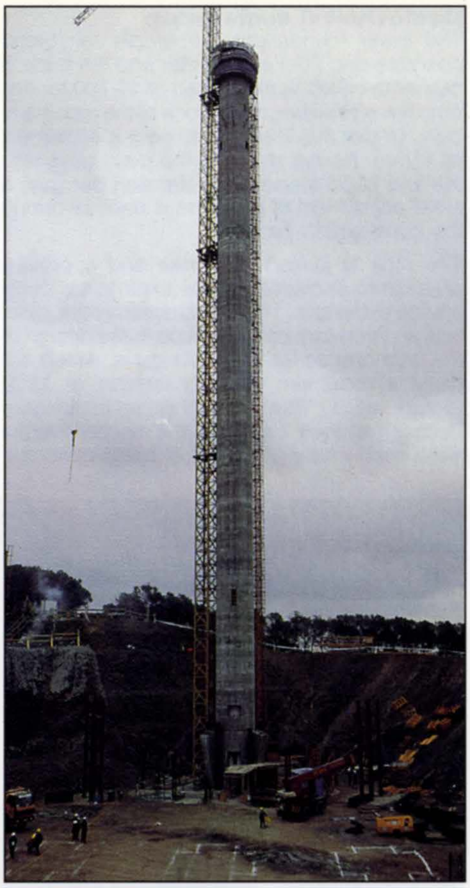
16. Tower at +90m, November 1990.

17. Assembly of floors, March 1991.

18. Guiding mechanism during floor lifting operation, June 1991.

19. Floors rising, June 1991.

20. & 21. The completed tower in February 1992.



16 ◁

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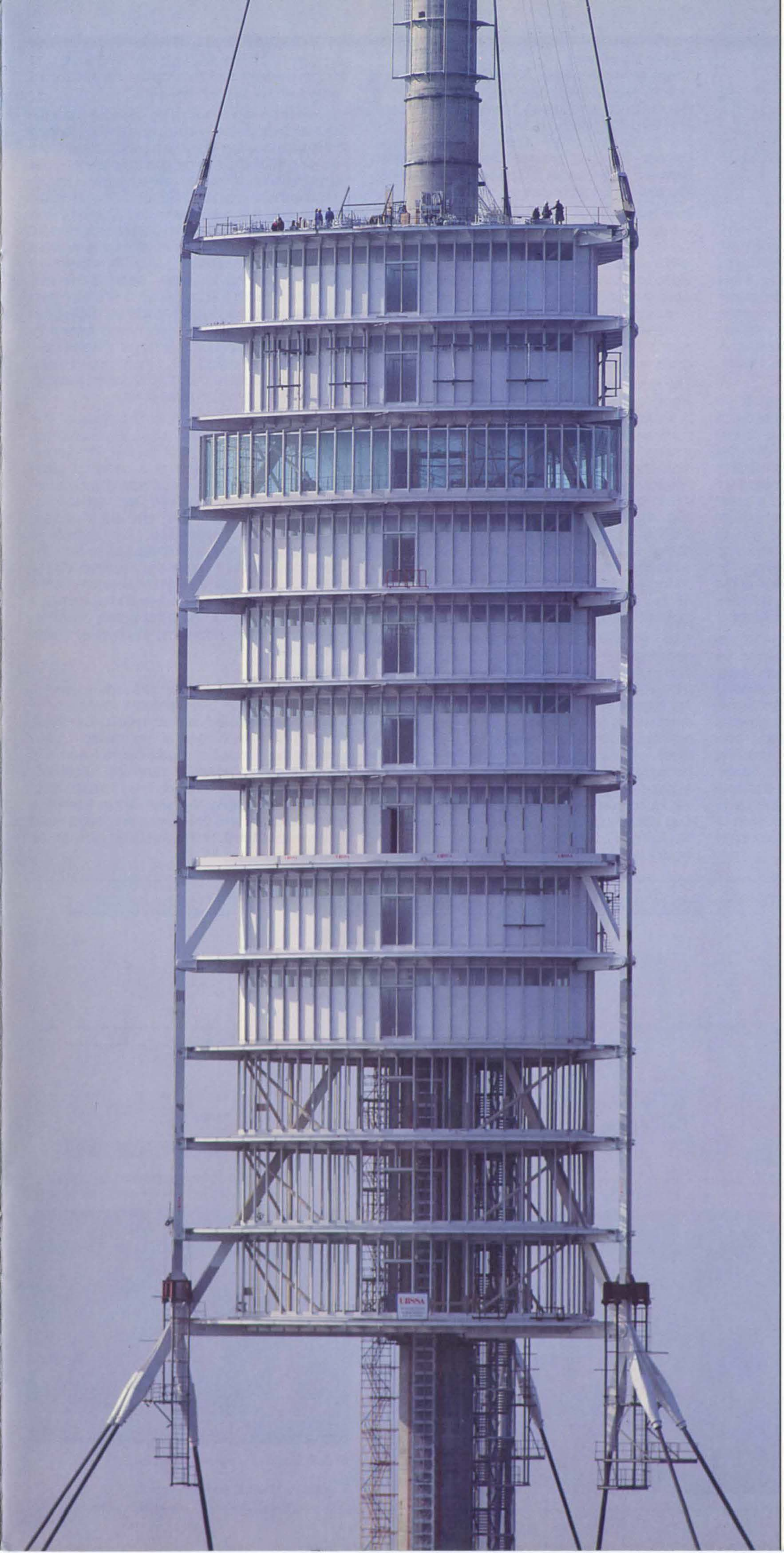


Completion

The full height of 288m was reached in November 1991, and completion of the tower, support building, and infrastructure work was scheduled for March 1992. Installation of the broadcasting antennae and signal processing equipment is expected to be sufficiently complete for transmission of the Olympic Games in July this year. Later this year, visitors to the tower will be able to ride in one of the glass lifts to enjoy a magnificent view of the City of Barcelona and the Mediterranean Sea from the newly opened public viewing gallery.

Credits

Client:
Torre de Collserola SA

Structural, geotechnical, and wind engineers:
Ove Arup and Partners, London:
Paul Cross, Tony Fitzpatrick, Alan Tweedie, Andrew Chan, Mike Willford, Chris Wise (structures); Andrew Allsop (wind); Sergio Solera, Nick O'Riordan (geotechnics)

Architect:
Foster Associates

Associated structural, service, and economic consultants:
CAST Engineering, Barcelona

Topographical wind tunnel testing:
Oxford University

Structural wind tunnel testing:
B.M.T. Fluid Mechanics Ltd.

Main contractor:
Cubiertas y MZOV

Structural steelwork:
URSSA, Vittoria, Spain

Steel guys:
Freyssinet, Spain

Kevlar guys:
Verto Phillystran, Holland

Photos:
1, 20, 21: Ben Johnson;
4, 7-10:
© Sir Norman Foster & Partners;
13: BMT Fluid Mechanics Ltd.;
14, 16-19: Chris Wise

Illustrations:
Chris Wise

Centro de Arte Reina Sofia, Madrid

John Thornton

Introduction

The Centro de Arte Reina Sofia was originally built as a hospital in the 18th century by Carlos III to care for the wounded of his army. It lies at the lower end of the Paseo del Prado, about 600m from the Prado itself. The Villahermosa Palace, currently being converted into a gallery for the Thyssen collection (another Ove Arup & Partners project), also stands on the Paseo, making this a major cultural centre.

The architects for the conversion, Vásquez de Castro and Íñiguez de Onzoño, chose to place glass towers around the outside as a formal contrast with the massive gray walls. With the contractor, Huarte, they approached Ian Ritchie who, as part of RFR, had been responsible for the glass walls at La Villette. Huarte had a much greater involvement in the project than is usual with UK contractors, and Arups' role was to supply sufficient drawings and calculations to enable them to provide working drawings for the primary structure. The detailed design of the façade was Pilkington's responsibility, but they subcontracted this to Ian Ritchie and Arups.

As the programme was short the design for the locally fabricated primary structure had to be finalized quickly. The principles, member sizes, and co-ordination were agreed in a series of one-day site meetings between the architects, Huarte, and Arups. There was an obvious conflict between a contractor's natural preference for the simplest solution and the architects' wish for something special. Arups' position was strengthened by the fact that one of Huarte's directors had been instrumental in the appointment, but there was no question of any design being imposed on their chief engineer — he had to be convinced.

The structures

There are three towers, 36m high. Two identical visitors' towers are on the main façade, flanking the entrance and facing out onto the Square. The third, for goods, is around the corner. The former each contain three glass-sided wall climber lifts and provide vertical circulation between floors, whilst the goods tower has two lifts and an escape stair.

The basic tower structure is a welded steel vierendeel girder which forms a wall separating the lifts from the landings and the building. The girder cantilevers from the ground floor and provides horizontal stability parallel to the building, while the landings tie the tower to it in the other direction. The girder with the lift guide frames is the vertical structure supporting the lift motor rooms, the structure above the roof carrying the glass and the cleaning crane.

The most important part of the design was the glass, a clear skin around a simple steel frame but as far from it as possible to emphasize the contrast. The structure carrying the glass is external, breaking up and adding interest to the skin. The glass is suspended from cable-stayed brackets at roof level using a tie-down system which picks up each panel at a single point (Fig. **1**). Wind forces are carried back to the internal frame by articulated brackets at each corner of a panel, allowing the glass to move vertically relative to the frame as temperatures change and the frame deflects under wind load. All the connections to the glass use the Pilkington *Planar* system.

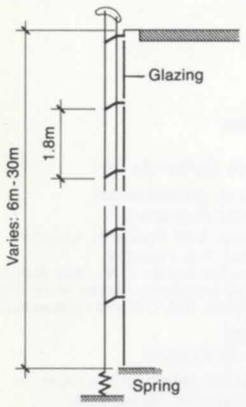
From the technical point of view the most interesting part of the design is the glass suspension system, which has to cope with differential temperature movements between those parts of the façade in sun and those in shadow, since there was a limit to what could be accepted in the silicone joints between the vertical strings of glass. A simple tie-down system magnifies temperature movements because the rods expand in opposite directions (Fig. **2**). Anchoring the rods at both ends and prestressing them was considered, so that they would never go slack (Fig. **3**). By this means the only movement would be that due to differential temperature along a rod. However, there was excessive load on the primary structure when the rods contracted under low temperature.

Movements were reduced by anchoring the tie-down at the top and prestressing it with a spring at the bottom (Fig. **4**), causing the temperature movements in the two rods to take place in the same direction. A further refinement was to use a different stainless steel (S316) for the tie-down rod than for the suspension rod (Duplex). The latter's greater thermal expansion coefficient meant that the temperature movements were partially self-compensating (Fig. **5**). Movement of the glass could have been eliminated altogether but as the proportions of the system increased the loads in the rods by more than was felt reasonable, the movements were only reduced to an acceptable amount. Duplex steel is also stronger than S316, which helped maintain a satisfactory relationship between the suspension and tie-down diameters.

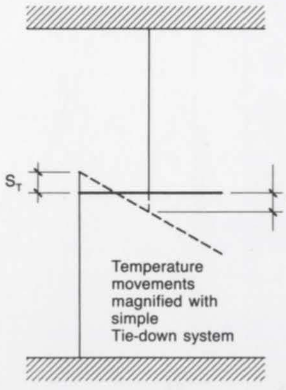
The suspension systems at the tops of the towers, the strains in the rods, and the spring stiffnesses were designed to limit differential movements in the event of a panel of glass breaking. The system was designed to allow for adjustment to compensate for deflections, strain, and tolerance. The rods are in storey-height lengths connected by cylindrical couplers which are also threaded externally. These pass through internally threaded blocks which receive the pivot pins for the support arms as they connect to the tie-down and suspension rods. By this means the pivot points could be adjusted in level before the support arm was assembled.

Erection

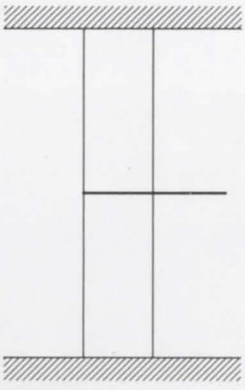
Arups designed an erection procedure using a set of jacks which compensated loads as the glass was assembled, and eliminated the effects of strain and deflections of the towers. Unfortunately the contractor chose not to follow this nor to apply trial loads to calibrate the deflections of the primary structure. The resultant initial difficulties in getting the wall within tolerance were overcome and the towers were completed in November 1990. They have been nicknamed 'Sofidou'.



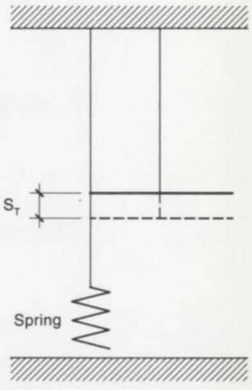
1. Tie-down system for glazing.



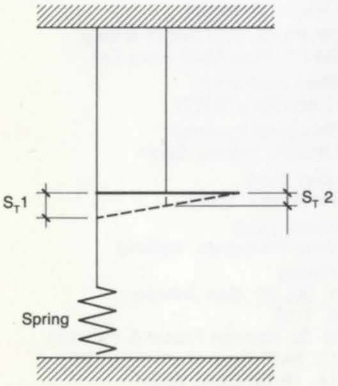
2. Simple system.



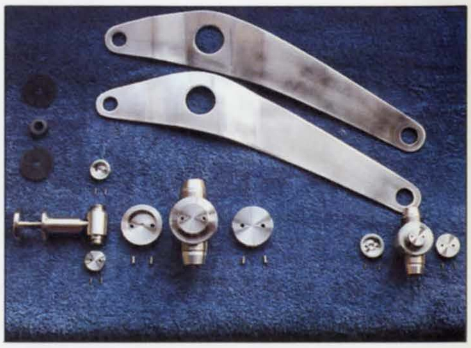
3. Both hangers prestressed.



4. Tie-down prestressed by spring.



5. Added refinement: two steels.



6. (left) Detail of suspension system.

7. (above) Bracket components.

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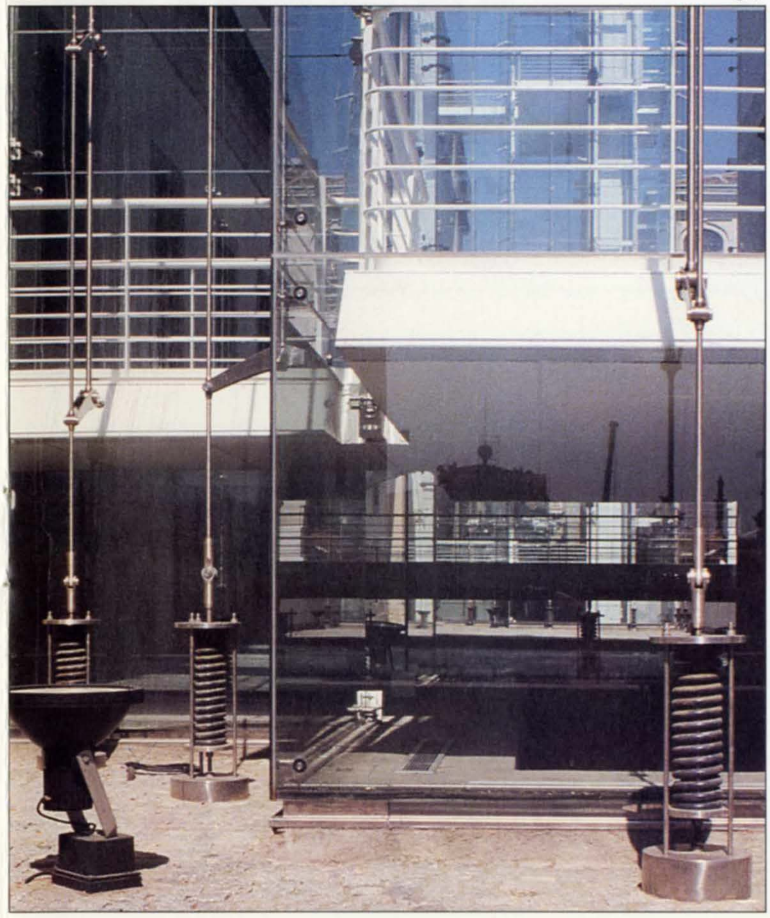
9 ▽



Credits

Client:
Ministry of Culture

Architect:
Antonio Vaźquez de Castro
y José Luiz Iñiquez de Onzoña,
with Ian Ritchie Architects

Structural engineers:
Ove Arup & Partners: John Thornton, Bruce Gibbons

Contractor:
Huarte

Glazing sub-contractor:
Pilkington

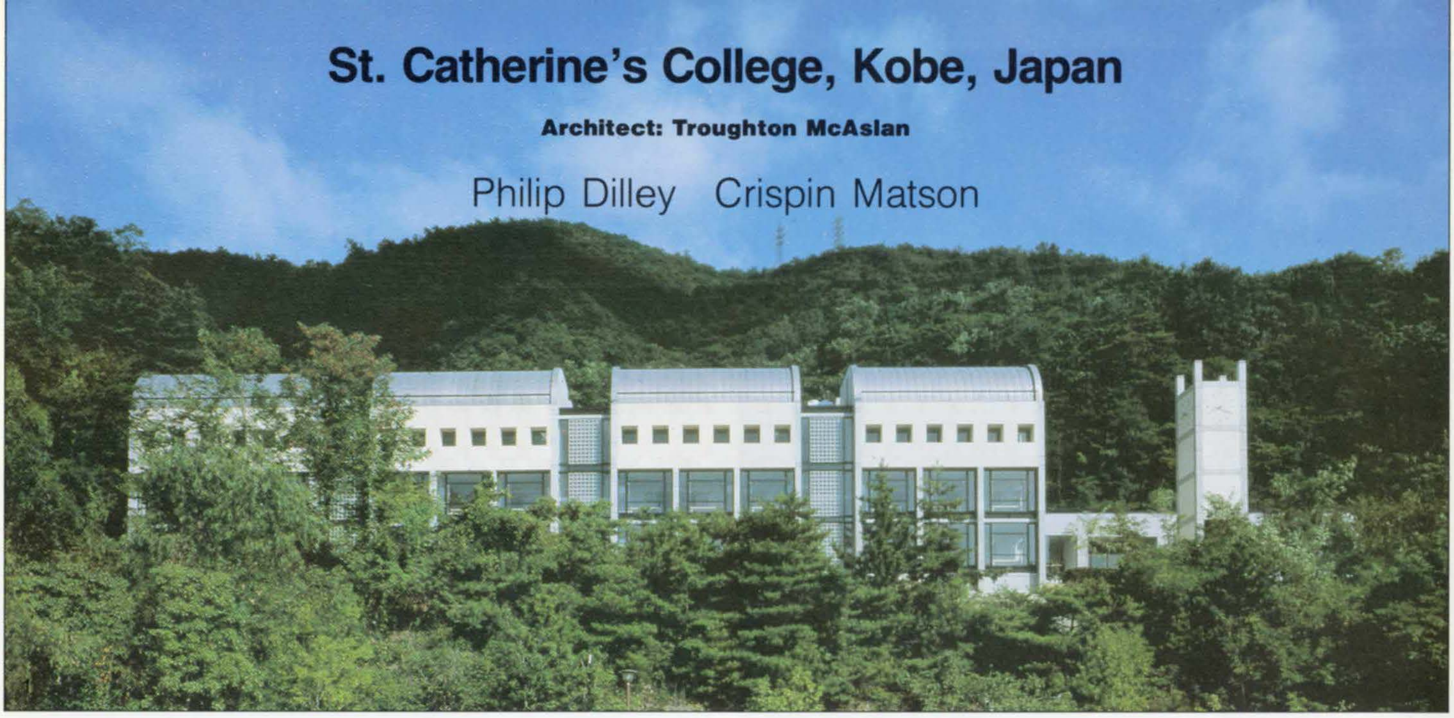
Photos:
6, 8, 9: © Jocelyne van den Bossche;
7: Simon Connolly; 10: Bruce Gibbons

10 ▷

St. Catherine's College, Kobe, Japan

Architect: Troughton McAslan

Philip Dilley   Crispin Matson



Introduction

In the summer of 1990 Arups in Japan learned of an opportunity to assist Kobe Steel in developing proposals for a branch school of an Oxford college to be built in Kobe, Japan.

Kobe Steel is a large Japanese firm whose core business is steel manufacturing. In recent years it has employed in various departments a number of overseas graduates, the majority being from St. Catherine's College in Oxford. This relationship between the British College and the Japanese company led to the idea of founding a branch school of St. Catherine's in Japan.

Kobe provided a site and agreed to fund and build the new College, which was to offer courses in European studies to be undertaken by Japanese post-graduate students. The courses were to be run by tutors from the parent body, and in the long summer vacation undergraduate students from there and elsewhere would have the opportunity to use the new College for short courses in Japanese studies.

The client was keen to appoint English designers and approached the British Consulate to ask their advice. Arups is one of very few British design organizations with a good reputation in Japan and Kobe were recommended to approach the firm. An appointment was secured to act as prime agent and the architect Troughton McAslan was subsequently engaged as sub-consultant.

The brief was to provide a college for 50 students and their associated tutors, consisting of student and tutor accommodation, classrooms, dining room and kitchen, library, administration offices, computer room and a lecture theatre. The construction budget was set at 1.4bn yen — about £6M.

The time-scale was extremely short. There was little over two months to produce a 'basic design' — the Japanese design stage which represents an advanced scheme where everything is fixed. The project was then handed over to Takenaka, one of the big six Japanese contractors who have large and powerful in-house design offices. Takenaka were responsible for the detailed design, obtaining approvals, and construction of the buildings. The college was to be designed and built in 15 months.

Site

The site provided by Kobe Steel is situated on the wooded slopes of Mount Rokko above Kobe with views out to the sea. The city is in Kansai, the region dominated by Osaka, Japan's second largest city. For this densely populated and heavily built-up country, the site is spectacular.

There were several existing structures there, including a 25-year-old reinforced concrete research building. It was quickly decided to retain part of this, refurbish it and use it as a classroom block. The others were to be demolished to make room for the new buildings.

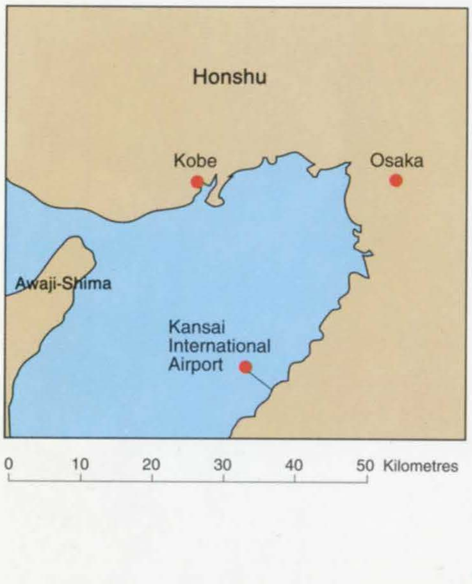
Soil conditions

Mount Rokko is granite; the site had been quarried from its side, so beneath the 300mm or so of top-soil was solid granite fractured only by the original blasting operations. Takenaka had constructed the existing buildings 25 years ago and their records were sufficiently convincing for Arups to agree to leave any site investigation to be carried out during the construction itself. As it turned out, the biggest ground problem was excavating trenches for the drains.

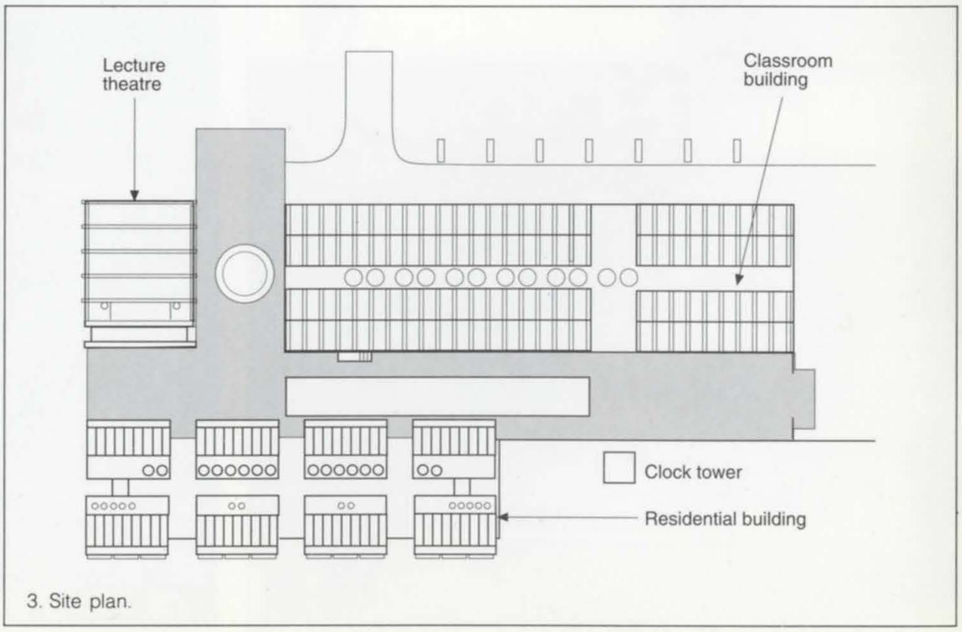
Design development

Although Kobe Steel was the client, they were keen to involve the future users — staff from St. Catherine's College. The design team therefore had the interesting and stimulating experience of working with a client which brought together two very different cultural backgrounds, and with highly contrasted ideas about what constituted an Oxford campus.

The initial design proposals by Troughton McAslan had a number of Modernistic elements. Although they had not spelt it out, the Japanese clearly had in mind a building with a traditional 'Oxford' appearance. It did appear at one stage that a stalemate had been reached, but as prime agents Arups became actively involved in the architectural concept and encouraged various compromise proposals which were developed by the architects and accepted. Following completion, the client is now delighted with the buildings, and the image they create.



2. Location plan.



3. Site plan.

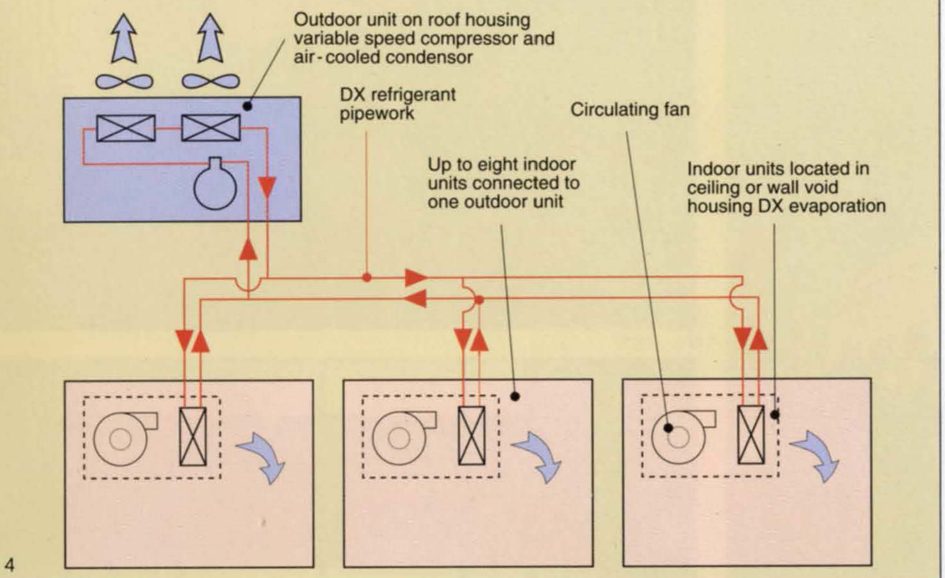
VRV system

The VRV system consists of a condensing 'outdoor' unit housing an inverter-controlled, variable speed scroll compressor and an air-cooled condenser connected by DX refrigerant pipework to up to eight 'indoor' cooling/heating units which house the DX evaporator, expansion valve, circulating fan, and controller.

This principle advantage of this over previous DX split unit air-conditioning systems lies in the use of the variable speed compressor. This varies the amount of refrigerant circulated in the system according to the number of indoor units in operation. In this way up to eight indoor units can be connected to one outdoor unit (c/f one outdoor to one indoor with the normal DX split system).

These units are also heat pumps and can therefore be used for heating.

This system was developed in Japan by Daikin, but is now also available in the UK. The same company has also recently developed a three-pipe system, which allows simultaneous heating and cooling by different indoor units connected to the same outdoor unit.



4

The architect's design for the new College draws on the traditional organizational principles of an Oxford college, and in particular the original St. Catherine's, designed by the Dane Arne Jacobsen in the early 1960s (a building for which Ove Arup & Partners had been structural engineers).

The College consists of three separate buildings arranged around a quadrangle: the refurbished two-storey classroom block, a new lecture theatre for 100 people, and four storeys of residences containing 48 study bedrooms and eight tutor's apartments. The otherwise open quadrangle is closed by a clock tower.

Structure

The existing building which was to be converted into classrooms had housed some substantial electro-magnetic equipment, and had consequently been designed for a substantial live loading of 10 kN/m^2. On the other hand Japan has one of the most severe earthquake regimes in the world and the governing criterion for such buildings is lateral strength. In this case the building had a large number of concrete shear walls in both directions, some of which had suffered diagonal cracking caused by earthquakes. Some of these walls had to be removed in order to create the new spaces, and much of the structural effort on this building involved the insertion of new shear walls at strategic locations to strengthen the building and replace the walls which were to be removed.

The analytical work was carried out with assistance from Arups' office in Japan.

Of the other, new, buildings, the residential block was also designed in reinforced concrete, which is both cheaper and quicker than steel for low-rise buildings in Japan. In this case the design was kept very simple, again by the use of cross walls readily accommodated due to the cellular nature of the building. The lecture theatre is also a reinforced concrete frame whereas the clock tower is in steel, this being selected for ease of erection. Many of the internal concrete surfaces are exposed and have a fair-faced finish which, like the original St. Catherine's College, is of a very high quality. Externally, the surfaces are either fair-faced concrete, render (in the case of the refurbished building), and in certain limited areas, of stone.

Services

The summer temperature in Kobe is 34°C with 54% humidity, and this dictated from an early stage that all three buildings should be air-conditioned. Various alternatives were presented to the client and it was agreed that a Variable Refrigerant Volume (VRV) system was to be used for all the buildings (see Fig. 4). This type of air-conditioning system is cost-effective, very popular in Japan, and — important for the client — easy to maintain as there is no water involved.

Room cassette heat pump units are provided in each classroom and residential room, with specially modified concealed units located in the entrance hall. Larger units are provided in the lecture theatre. The outdoor units associated with the room units are on the respective roofs.

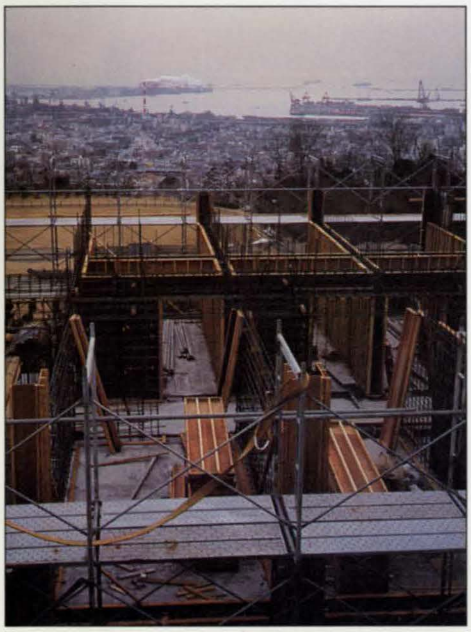
Extract ventilation is provided to the toilets and the kitchen. The extracts from the shower rooms in the residential building are connected to a variable speed extract fan which matches the extract air volume to the number of shower rooms being used at any one time.

In Japan, compact modular prefabricated bathroom/shower rooms are very popular and used extensively. The sophistication of some of the sanitary manufactures is quite astounding, but the units used on this project were relatively simple, consisting of toilets, hand basin and a small bath/shower.

Construction

Once the basic design proposals were complete and presented to Kobe Steel, Arups assisted in the negotiation with Takenaka who were contracted to provide the building on time, at a fixed lump sum cost. Despite having no authority in relation to any design changes by Takenaka, the design team were consulted about any variations to their original proposals, and the contractor was very keen that any alterations were agreed. Just as Jacobsen had designed all of the fittings for the original St. Catherine's College, John McAslan was retained to assist selection and in some cases design the furniture and fittings for the new College.

The buildings were completed to a high standard, and received their first students on time in September 1991.



5. (left) The residential block under construction.

6. (above) The classroom building in course of refurbishment.

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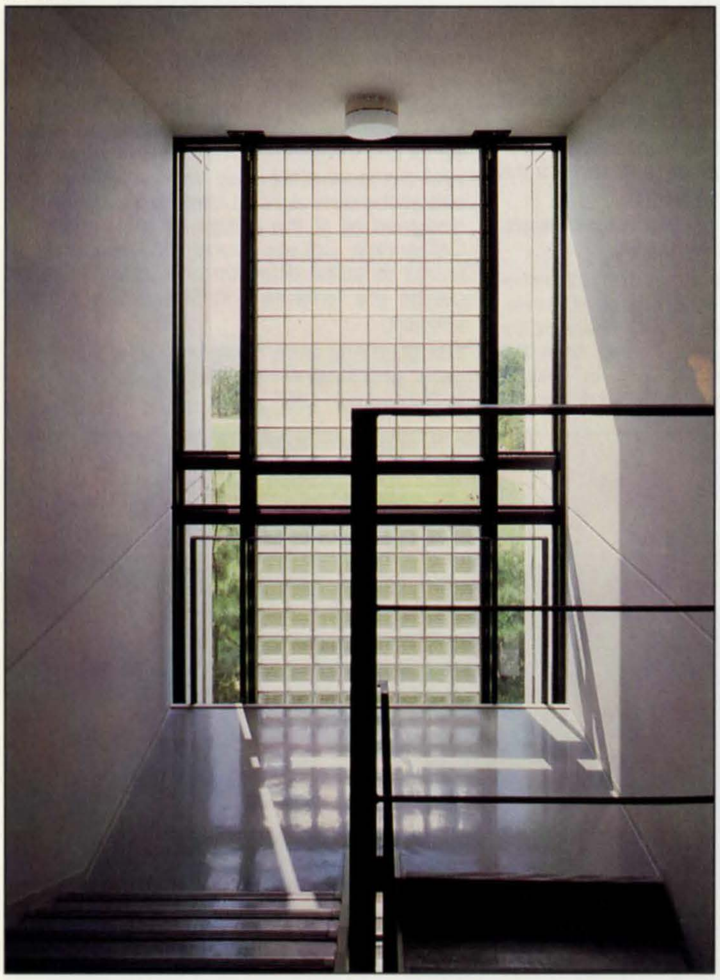
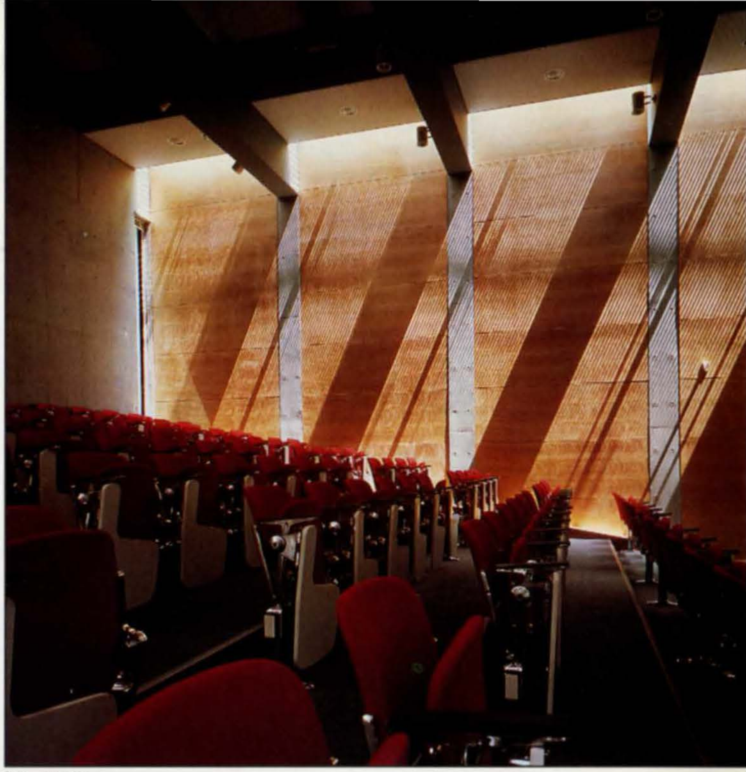
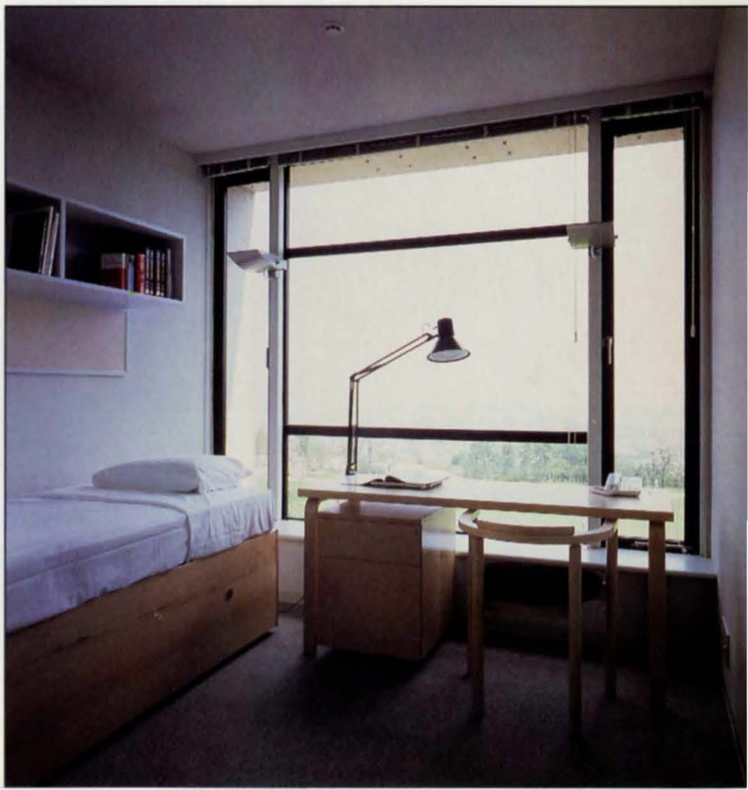


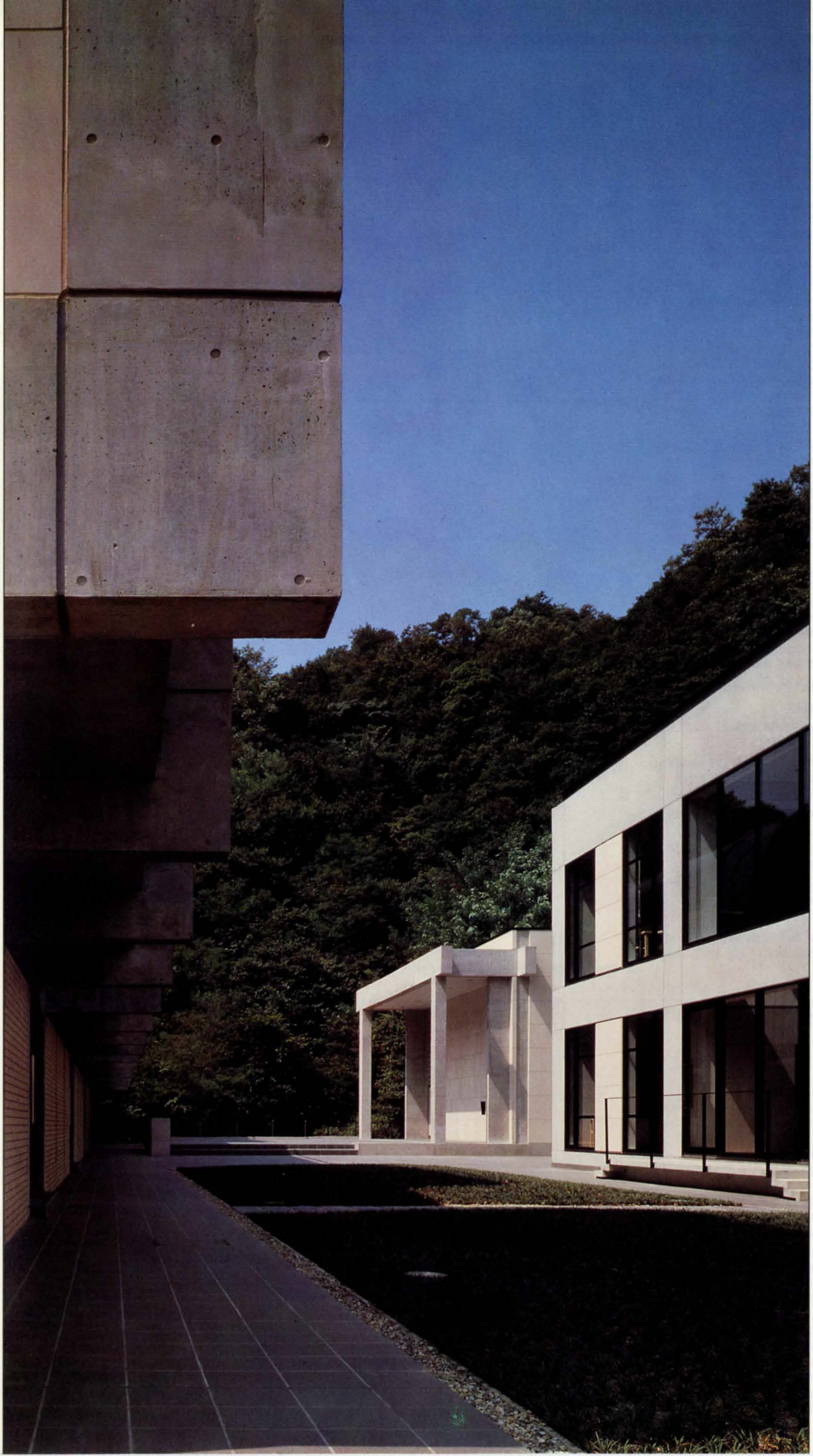


9△ 10▽

11▽

12





St. Catherine's College, Kobe

7. Residential buildings.

8. Internal staircase of residential building.

9. The lecture theatre.

10. View from classroom block entrance.

11. Typical study bedroom in residential building.

12. The quadrangle, with lecture theatre and classroom block on the right.

Credits
Client:
Kobe Steel
Architect:
Troughton McAslan
Structural and services engineers:
Ove Arup & Partners
Philip Dilley, William Lai (structure)
John Batchelor (structure – Arup Japan)
Crispin Matson, Giovanni Festa (mechanical services)
Nick Dibben (electrical services)
Malcolm Wright (Arup Acoustics)
Detailed design and construction:
Takenaka Corporation
Cost advisors:
Davis Langdon & Everest
Construction advisor:
Bovis Construction Ltd.
Photos:
1, 7-12: Hiroyuki Hirai
5, 6: Philip Dilley

The Trocadero

Introduction

Brian Whaley

What is now known as the Trocadero in London's Piccadilly Circus has been a prominent West End landmark for over 200 years. The first building of note there was a tennis court (1744), which continued in use until the 1840s variously as a circus, a theatre and exhibition building. It was reopened as the Argyll Rooms for public entertainment in 1851 and again in 1882 as the Trocadero Palace music hall.

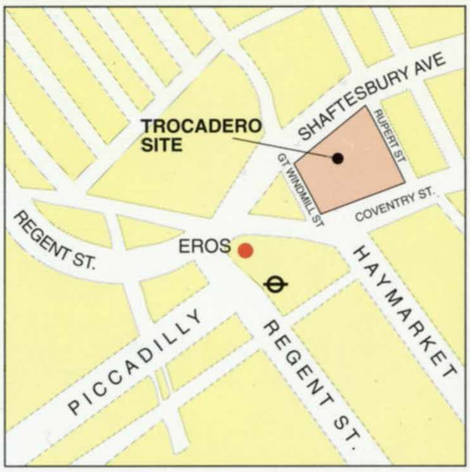
In 1872, an oyster warehouse, which later became known as Scotts Corner Restaurant, opened on Great Windmill Street. Lyons built one of their famed Corner Houses at the junction of Rupert and Coventry Street in 1907 on the site of the former Challis Hotel. This was extended in 1921 when a much larger glazed terracotta building was constructed on Coventry Street.

During the early 1980s Electricity Supply Nominees developed the Trocadero site into an entertainment centre containing a mix of retail, leisure and restaurant uses appropriate to its prominent location. Ove Arup & Partners were structural and services consultants for the development. It never, however, reached its full potential and in 1986, ESN sold the Trocadero and adjacent island site to Brent Walker, who subsequently sold a 50% share to Power Corporation of Dublin and formed a joint venture company, Walker Power, to expand the site and increase its rental income. Ove Arup & Partners were appointed as consultants for the redevelopment a second time within the decade.

Walker Power proposed the following:

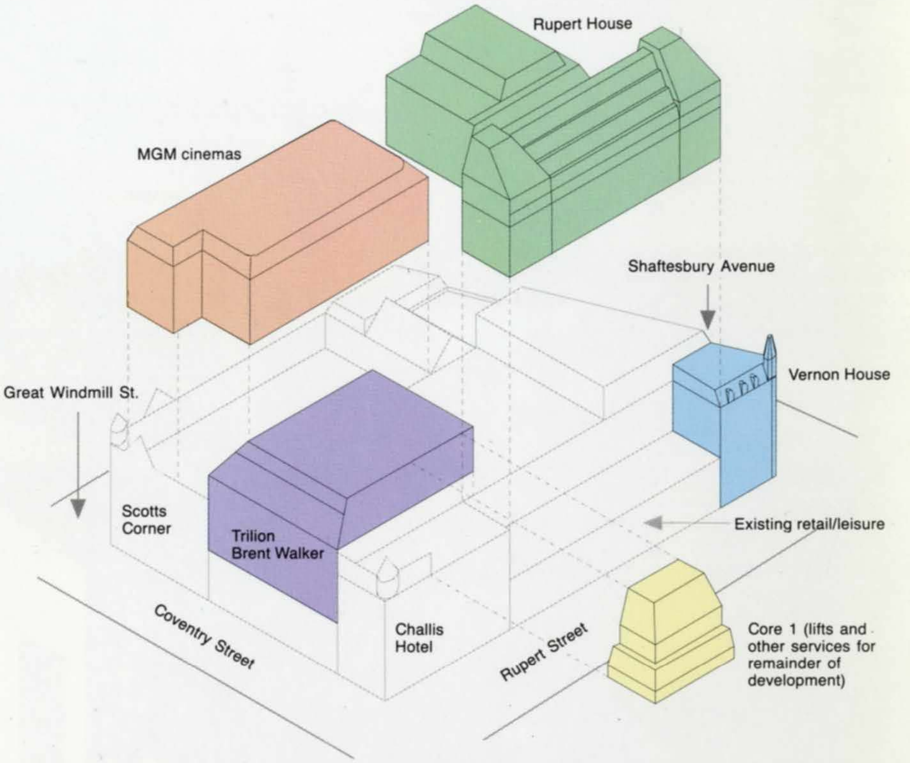
- A multi-screen cineplex
- An 'air rights' office development over the central atrium (Rupert House)
- A series of mezzanines within the existing building to increase net lettable floor area
- Completion of the basement link with the adjacent London Pavilion site and Piccadilly Underground station
- Refurbishment of a small office building on a corner of the site (Vernon House)
- Conversion of the upper floors of the former Lyons Corner House into a television studio for Trilion plc and offices for Brent Walker.

It was envisaged that all works should be undertaken whilst the existing shopping centre remained operational.



1. Trocadero site.

2. The cineplex complex beyond the Scotts Corner building.



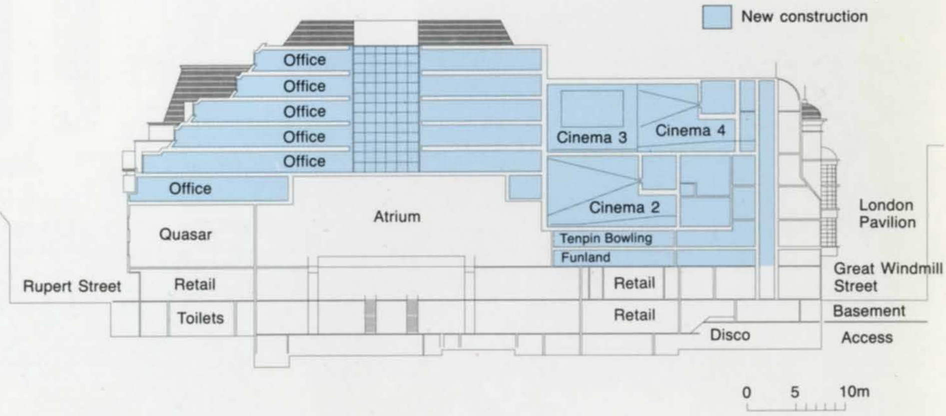
3. Main elements of the redevelopment.

MGM Cinemas

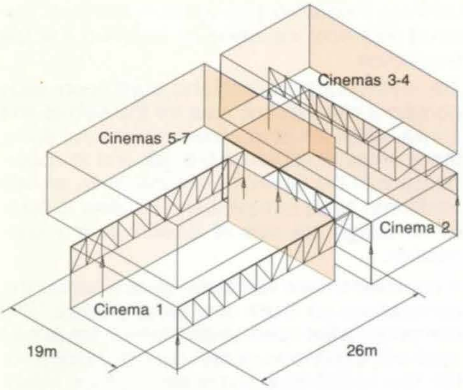
Brian Whaley
Dylan Evans
Fred Brenchley

The cinema scheme comprises a seven-screen multiplex arranged on two levels at second and fourth floor, seating c.1800 people. Five auditoria are located on the upper level and two on the lower. The main entrance foyer opens onto the atrium at first floor level, with a second entrance located at the corner of Shaftesbury Avenue and Great Windmill Street. All levels are interconnected by escalators.

The design brief was set by the original cinema tenant Cineplex Odeon and their technical consultants Kofman Engineering of Toronto. The original specification required extremely high standards of acoustic isolation, with all cinema floors and walls being resiliently supported. However, it was subsequently modified during construction, as the tenant changed through merger first to Cannon and then MGM. Some three months before handover, the scheme was revised from a four to a seven-screen complex.



4. East-west section.



5. Block plan of cinemas.

The brief was further complicated by the fact that the floors below were tenanted throughout construction, the landlord requiring that all new elements of vertical structure be located within landlord's areas and not pass through existing tenancies. Despite this, however, the final layout proved to be a relatively efficient use of space.

Structure

The building beneath the cinemas is part of the early 1980s development, a structural steel framework supporting precast and composite concrete floors. Lateral stability is by in situ stair cores, and the entire structure supported on piled foundations. This development had been curtailed at a late stage, the additional storey which its structure had been designed to support remaining unbuilt.

The first level of cinemas were built relatively easily by employing this additional load capacity within the existing structure. The upper level however, some 12m above the first, posed a much more difficult problem. The client's limitation on vertical structure meant that the entire cineplex superstructure had to be supported on seven primary columns arranged on the line of the 'party' walls between cinemas, and subjected to axial loads of up to 15 000kN. Steel transfer girders up to 5m deep and 500mm wide were also accommodated within the width of these walls, and support steel composite floor beams up to 900mm in depth and spanning up to 19.5m.

The acoustic specification required the party floors between cinemas to have a mass equivalent to a 300mm solid concrete floor. This was achieved by increasing the topping thickness of the composite floor to 170mm and constructing a second floating floor of 130mm thickness on resilient pads on top of it. The floating floor was complicated by the tenant's requirement for it to be doubly curved to give optimum site lines from any point in the seven auditoria.

The original stair cores were extended in situ for lateral stability and the existing foundations checked. A cautious approach adopted in the original design proved useful here.

New piled foundations were constructed in the basement beneath the retail tenancies, which fortunately remained unlet during the contract period. The 600mm diameter piles were installed using a shortened tripod rig.

Acoustic design

Being close to Piccadilly and Shaftesbury Avenue meant that much traffic noise was to be expected. This was particularly significant at the upper storeys of the building where parts of the walls and roof of some cinemas were directly exposed. Levels in excess of 73dB(A) were established, resulting in very stringent sound reduction ratings for the walls and roof. Sound reduction between cinemas (horizontally or vertically) varied slightly, depending upon the type of sound track amplification equipment being adopted, but was generally even more rigorous. Maximum background noise in the cinemas due to M&E services or occupational activity in other parts of the complex were not to exceed the stringent criterion of NC25.

6. Original (a) and revised (b) plans for upper level of cinemas.

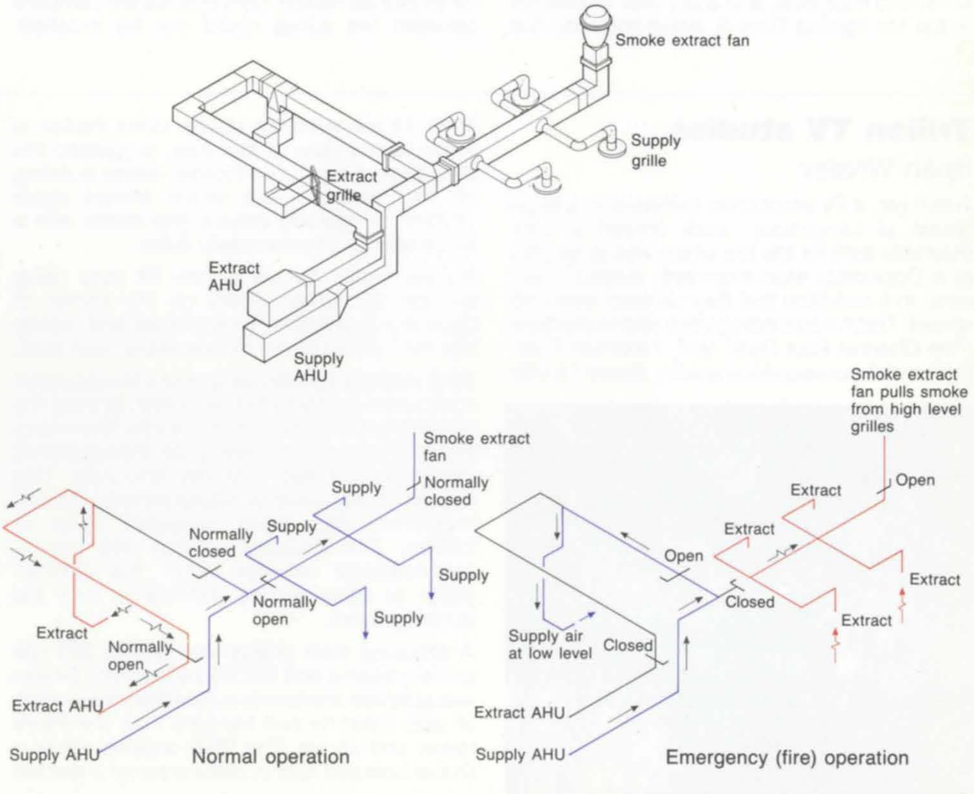
7. Steelwork transfer girders for cineplex.

Lightweight construction methods were preferred for the new external walls, roof, and internal walls between cinemas — an approach not always compatible with high levels of sound reduction. Consequently, complex multi-layer barriers were evaluated based upon plasterboard-faced stud frames with large air spaces between. The previous experience of British Gypsum was very helpful as they had developed special stud wall constructions specifically for the subdivision of multiplex cinemas.

However, flanking sound transmission via common floor/ceiling slabs can often limit the achievement of high room-to-room sound reduction. With the additional restriction on the thickness of concrete slabs that would be possible, the potential vertical sound reduction between cinemas appeared insufficient to meet the tenant's requirements. A floating concrete slab construction was proposed with the partition walls built off it. Each cinema on the upper level would therefore become a box-within-a-box construction, with minimum sound transmission both between them and from outside being ensured.

Building services

The cinemas form part of a building designed to Section 20 of the Building Regulations, and are therefore regulated by this as well as the Cinemas and Places of Public Entertainment Acts. The need to extend from the existing landlord's services and to relocate existing tenant's plant which would clash with the new installation also complicated the design. To satisfy the Section 20 Regulations each cinema is independently air-conditioned by a dedicated constant volume air-handling plant and supply and extract ductwork system. Inside the cinemas, air is supplied at high level by ceiling-mounted diffusers, with return air extracted at low level through grilles in the wing walls towards the front.



8. Air handling for cineplex.

9. Interior of cinema.

In order to comply with the stringent noise criteria of NC25, sound attenuators were installed on all ducts entering or leaving the cinemas and on all secondary branches wherever duct noise regeneration could occur.

In the foyer and concession areas, heating and comfort cooling is provided by a conventional ceiling fan coil unit installation. A supply of fresh air is ducted to each fan coil unit from a control plant.

Chilled water for comfort cooling is supplied from a new tenant's air-cooled packaged chiller installed at roof level, and low temperature hot water for space heating by the existing landlord's central boiler plant in the sub-basement.

A building management system has been installed to monitor and control the plant operation throughout the new complex.

Fire services
Fire protection is extensive and includes blanket sprinkling throughout, hose reel protection to each cinema, each foyer, and the new offices at second floor level, and a dry riser installation in the fire fighting Core 5, extending from the ground floor to fifth floor level. Further protection is afforded by a system of portable fire extinguishers and fire blankets, strategically placed throughout the complex.

To satisfy Westminster City Council's requirements for six air changes/hour smoke ventilation from each cinema, smoke ventilation systems have been installed.

Because of the limitations on space for plant and ductwork, the standard ventilation plant serving each cinema has been utilized for smoke ventilation. In the event of fire, a failsafe system of fire-rated dampers is designed to connect the cinema supply ductwork to a fire-rated smoke extract fan, and the return air ductwork to the supply air fan on the cinema air-handling unit.

If fire starts in a cinema the supply fan provides 'make up air' at low level through the wing walls, whilst the smoke extract fan takes the smoke at high level through the ceiling-mounted diffusers and discharges it to atmosphere.

Since air-conditioning ductwork is being used for smoke ventilation, conventional fire dampers between fire zones could not be installed. Careful consideration was therefore given to fire zoning between the cinemas and other areas and it became necessary to clad the ductwork between the various fire zones in two-hour fire-rated rockwool insulation to maintain the fire separation.

The foyers at first, second and fourth floors each contain a concessions area for the sale of soft drinks, popcorn and other snacks. As such, these areas constitute a fire risk and in accordance with the Council's requirements, smoke ventilation systems have been installed to cater for a design fire size of 2.5MW in any concession.

A common smoke ventilation system serves the concessions on fourth and second floors. This comprises a fire-rated smoke extract fan at roof level with a common extract duct dropping from fifth floor to high level on the second floor. Make-up air for the system is supplied at second floor level. A smoke curtain has been installed around the escalator void between the second and third floors to prevent smoke created by fire at second floor level rising to the upper levels of the complex.

If a fire is detected, a motorized damper in a branch duct on the level in which the fire has occurred automatically opens the smoke extract duct to that level, and the supply and extract fans operate to extract the smoke.

Firemen's switches have been provided in the main fire fighting core for the manual operation of all smoke ventilation and core pressurization plant. A dedicated 11 kV emergency generator has been installed to serve the plant, smoke extraction systems and emergency lighting.

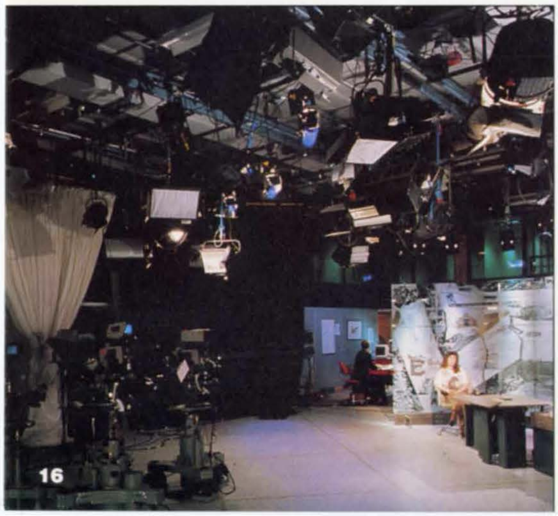
Core pressurization
In addition to the smoke ventilation and fire protection systems mentioned, all escape cores inside Trocadero are independently pressurized in the event of fire to $+50 N/m^2$ above the main accommodation spaces. This will ensure that any smoke emanating from the fire moves in a direction away from the main escape routes and the cores are therefore maintained smoke-free for escape purposes.

Those cores serving other tenancies were maintained 'live' throughout the duration of the contract using the existing core pressurization plants. New plant was designed to serve the extended cores and connected to the existing system during changeover periods agreed with the District Surveyor and Fire Officer.

Trilion TV studios

Brian Whaley

Trilion plc, a TV production company in a large studio at Limehouse, were offered a considerable sum for the site which was to be part of a Docklands redevelopment; subject, however, to a condition that they vacated within 16 weeks. Trilion had binding contracts to produce 'The Channel Four Daily' and 'American Football' and in consequence quickly needed a fully fitted-out live television studio. Brent Walker, a Trilion shareholder at that time, suggested the third floor of the Lyons Corner House building on the Trocadero site, which offered about $1670 m^2$ of relatively column-free space with a headroom of approximately 5.5m.



10. Trilion studio in operation.

Access would be via a new lift core rising through the Challis Hotel on the corner of Coventry Street and Rupert Street and linking into the Lyons Corner House above roof level.

Trilion required additional space and suggested a mezzanine around the perimeter, leaving the full height at the centre for the studio. Recording and dubbing suites were to be manufactured off-site and slotted into the structure. This resulted in the overall structural thickness for the mezzanine slab being squeezed down to 200mm. The structural solution also had to accommodate services within this 200mm depth to allow service distribution over the dubbing suites.

A structural steel grillage comprising 203 UB primary beams and 102 RSJ secondary beams was adopted, the former supported via a system of stub columns and hangers from the floors below and above. The RSJs support either a timber boarded floor in office areas or a welded composite steel plate and floating screed in recording areas. The webs of the UBs were predrilled for horizontal service distribution. Considerable attention was given to the effects of dynamic loads, and additional supports were introduced to increase the natural frequency of the floor plate. Construction began within a week of the client's instructions to proceed and was completed within three working weeks, with much of the detailed design being undertaken by the resident engineer.

Whilst the studio fit-out was taking place, the landlord had contracted to complete the new lift core within a similar period. The basement beneath the lift core had already been let and the client was unable to negotiate the lease to extend the lift pits down to basement level.

Since most of the ground floor was also tenanted, a transfer structure was constructed at first floor to suspend the lift pits and support the lift core which would eventually extend to five storeys to serve upper levels of the Lyons Corner House. The lift cores were prefabricated in steel and installed during two weekend possessions.

The contract was completed on time, allowing television programmes to be transmitted on schedule. The total contract figure of approximately £4.5M was expended within the 14-week construction programme.

Rupert House

David Hay

11. General view, showing Rupert House in foreground and Vernon House on left.

Rupert House is a speculative six-storey office development built over the original atrium to the shopping centre. The offices rise from the third to the eighth floor, the Rupert Street façade raking back in a series of mansards. The offices are served via a new liftcore rising through the Challis Hotel building and the extension of the existing staircase.

Structural design

The original building was constructed in the early '80s, the superstructure comprising a steel framed/in situ concrete composite construction on a 12m × 9m grid. The substructure up to podium level is of reinforced in situ concrete. The foundations are typically 600mm diameter bored cast in situ piles and lateral stability is achieved via plate action of the floors and cross-bracing in the staircores.

The original structure was designed to support live loads of 10kNm^2 and extend an additional one or two storeys above the third floor level. These design loads have not been achieved and this, coupled with the inbuilt spare capacity, enabled the new structure to be built with very little modification to the existing.

The atrium roof was a space frame, spanning 30m onto two parallel rows of concrete-encased steel columns at each side. These columns could not support five additional floors of offices plus a plantroom without the addition of two centrally placed columns and two edge columns. The distribution and extent of loads to the foundations from these required additional works — new piles and pile caps on either side of existing ones. Load transfer was achieved by post-tensioning the pile caps using four 50mm diameter stainless steel Macalloy bars in conjunction with 32mm diameter high tensile dowel bars. Several existing reinforced concrete columns from the pile caps to the podium underside were strengthened in situ, using Universal Column sections and RSC sections packed tightly to the soffit, grouted under their baseplates, and mechanically anchored to the columns to ensure load transfer. Construction of the offices over the atrium depended on extending the new perimeter supporting columns off the same columns which carried the existing spaceframe. An extensive programme of local strengthening of this was carried out; each support in turn was removed and the new columns erected to the sixth floor level. The new central columns, typically 17.5m long, were dropped into position through the atrium roof to complete the new supporting grid.

The steelwork grid for both the fifth and sixth floors was constructed and the sixth floor concreted to form a weathertight lid over the atrium. A temporary working platform at third floor level, covering the whole atrium, was constructed from the fifth floor steelwork through the atrium roof before the roof was dismantled and the fourth floor lowered into position. The remaining floors were constructed in the traditional manner.

In addition the shopping centre opens from 10am to midnight and Westminster Environmental Health Department prohibited work before 7am. The atrium works could only, therefore, be carried out between 7 and 10am each day. The building has 610 deep composite beams spanning up to 13.5m. The client's requirements for maximum numbers of floors within the allowable building envelope resulted in minimum false ceiling zones, typically 100mm beneath the deepest beams. To accommodate air-conditioning distribution ductwork, services holes up to 300mm in diameter were formed through the beam webs. The location of the holes was co-ordinated with the mechanical and electrical services design at an early stage and approximately 500 such openings were detailed. In the end, virtually all service openings were used and only 20 more had to be added in situ.

Building services

The services design, and particularly the air-conditioning system, was heavily influenced by the limited ceiling zones and lack of fireman's lift services to the eighth floor plant area, which prohibited the use of a central boiler and chiller plant. The overall ceiling depth of 720mm included 610mm deep downstand beams which effectively ruled out the use of an all-air system.

A variable refrigerant volume (VRV) system metered on a floor-by-floor basis was proposed. This is a reverse cycle heat pump system allowing up to 100m of refrigerant pipework and a 50m level difference between the external heat exchanger and the ceiling-mounted units. Since the compressors are mounted externally, the heat pumps are relatively quiet and during insite tests achieved low noise ratings of NR35-38.

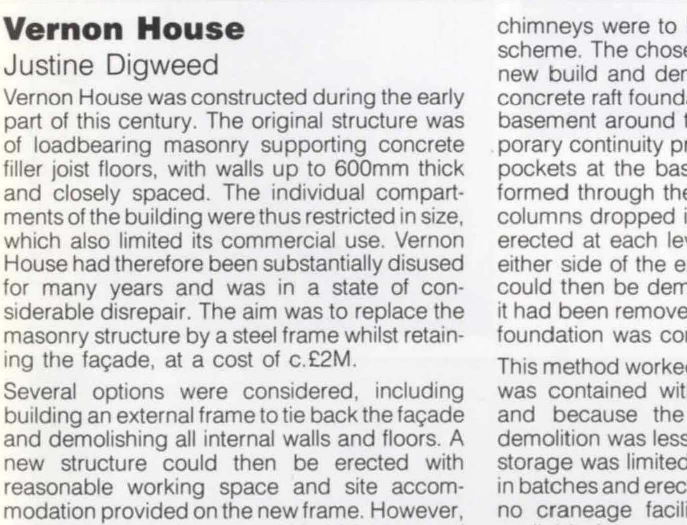
Vernon House

Justine Digweed

Vernon House was constructed during the early part of this century. The original structure was of loadbearing masonry supporting concrete filler joist floors, with walls up to 600mm thick and closely spaced. The individual compartments of the building were thus restricted in size, which also limited its commercial use. Vernon House had therefore been substantially disused for many years and was in a state of considerable disrepair. The aim was to replace the masonry structure by a steel frame whilst retaining the façade, at a cost of c.£2M.

Several options were considered, including building an external frame to tie back the façade and demolishing all internal walls and floors. A new structure could then be erected with reasonable working space and site accommodation provided on the new frame. However, planning permission was withheld because of the disruption to pedestrian traffic from the external frame. Also, English Heritage stipulated that as much as possible of the existing internal structure should be retained. As a result the filler joist floors, two of the internal walls and the chimneys were to be incorporated in the new scheme. The chosen option was a sequenced new build and demolition programme. First a concrete raft foundation was constructed in the basement around the existing walls, with temporary continuity provided by stitching through pockets at the base of the walls. Holes were formed through the filler joist floors, new steel columns dropped into place, and steel beams erected at each level to support the floors on either side of the existing walls. The brickwork could then be demolished in sequence. Once it had been removed to basement level, the raft foundation was completed.

This method worked best because construction was contained within the building's confines and because the sequential nature of the demolition was less disruptive to the public. As storage was limited, steel was delivered to site in batches and erected immediately. There were no craneage facilities as the only locations available for cranes on the existing Trocadero roof were such that Vernon House was not within reach. Hence, long span beams were spliced as the steel was manoeuvred into position from a storage location on an adjacent existing roof, via a sophisticated system of motorized tirfors. Demolished material was removed immediately to avoid overloading the existing floors. The principle of the design was intrinsically simple but the construction was complicated by the working conditions, including the presence of an existing tenant during construction. It was, therefore, an extremely interesting part of the Trocadero development. Vernon House, once disused and neglected, is now restored and back in use.



12. (left): Vernon House first floor plans:
(a) existing,
(b) redeveloped.

13. (right): Restored Vernon House facade.

Other Trocadero works

Brent Walker House
New atrium and tenant fit out of 2000m^2 of the original Lyons Corner House building

42 Rupert Street
Restaurant conversion on four levels behind a listed façade

External façades
Replacement of 1980s curtain walling with natural stone façade

Football Hall of Fame
Smoke extract system, relocation of landlord's plantrooms, remodelling of escape cores and tenant fitout

Funland
New mezzanine and smoke extract system for 2000 m^2 video amusement arcade

Fusion
New mezzanine floor and tenant fitout for retail and restaurant use

Quasar
Smoke extract system and tenant fitout for high-tech games area

Core pressurization
Extension of existing staircores and provision of new core pressurization plant

Energy study
An assessment of the energy consumption of the development and an extension of the landlord's M&E services

Traffic study
A comprehensive assessment of the servicing requirements of the development, taking into account substantially increased floor areas

Credits
Client:
Walker Power Corporation
Planning consultant:
Sir Basil Spence Partnership
Structural and service engineers:
Ove Arup and Partners
Brian Whaley, Justine Digweed, David Hay (structural)
Bryan Williams, Steve Devine (electrical)
Dylan Evans (mechanical)
Fred Brenchley (Arup Acoustics)
On site:
Derek Lincoln (structural RE)
Andy Smith, Richard Smith (mechanical REs)
Quantity surveyor:
Walfords
Rupert House, MGM Cinemas
Architect:
Robinson Keefe & Devane
Main contractor:
G&T Cramptons
Vernon House, Trilion
Architect:
Patrick Garnett Associates
Services engineer:
MDD Partnership
Main contractor:
John Sisk
Photos:
2, 9, 13: Peter Mackinven
7, 11: Brian Whaley
10: Walker Power

'Air rights' surgery

Roger Hyde

Pleasant Place Surgery, Hersham, Surrey, is a family practice serving the local community. The doctors needed to double the accommodation of their existing single-storey, flat-roofed premises, built in 1970. This was in conventional cavity wall construction and effectively filled the site, so the extension had to go above. Speed was important. The extension had to be completed in six months over the winter of 1990/91 and, crucially, the surgery was to remain open during rebuilding.

The existing structure had very little spare capacity so the new construction had to be lightweight. The design team — ex-Arup Associates architects Adam Caruso and Peter St. John, and Ove Arup & Partners — wanted the advantages of dry construction and the possibility of workshop preassembly for building elements, so timber was chosen for both cladding and structure. The latter sits on a structural steel 'raft' which distributes loads, via precast padstones, to selected areas of the existing perimeter wall capable of carrying additional load. The new floor is independent of the existing flat roof, thus ensuring watertightness during construction as well as complete acoustic separation.

The simple rectangular volume of the addition is formed by a post and beam assembly. 100 × 100mm timber posts at 1.8m centres carry a composite timber edge beam that in turn supports trussed rafters at 600mm centres. Plywood infills resist lateral loads. The ends of the rafters are left exposed and form a deep overhang that contributes to the weathering and solar protection of the building. The posts and edge beams are expressed within the building, forming thresholds at the window openings and a continuous lighting shelf that runs at the head of the perimeter walls. All timber is stress-graded Douglas Fir.

The framing of the external wall was made off-site. In order to simplify the detailing of the large openings all glazing is fixed, with fresh air provided through pivoted plywood vents. Windows are double-glazed and solid areas are highly insulated within the structural zone of the wall, with plywood and brick panels working as a rainscreen. External plywood is cladding grade Douglas Fir, treated with an opaque stain.

The relative ease of forming large openings in a timber structure allows the new rooms of the surgery to be flooded with natural light. The timber exterior means the addition is read as a discrete structure that nonetheless sits comfortably with the natural materials of the original building. Despite the tight programme, the extension was finished on time.

Credits
Architects:
Caruso St John Architects
Structural and services engineers:
Ove Arup & Partners:
Roger Hyde, Sarah Taylor, Roger Findlay (structural), Simon Hancock (services)
Contractors:
Codac Ltd.
Photos:
Russel McDowell

1. The new timber frame under construction.

2. Detail of east façade, showing the addition 'stepping over' the original building.

3. The surgery from the west with the addition complete.

Queen Mary and Westfield College

Roger Olsen
Mohsen Zikri

Site development

The expansion of Queen Mary and Westfield College in Mile End Road, East London, has been under way since 1984, and is believed to be the largest university development in Western Europe. Ove Arup & Partners have been structural, mechanical and electrical engineers for the library, residences, informatics teaching and medical buildings, and have designed the site infrastructure. Fig. 1 shows the other buildings under construction or being planned. All this has depended on the acquisition of land to the east of the existing campus, including a British Rail goods yard and a former Jewish burial ground (dating from 1733) from which some 9000 remains were exhumed and reburied. The development was financed to a total of £50M mainly by the University Grants Committee, whose guidelines meant that the budget for each building was very tight. The architects and Arups were presented with the challenge of designing complex, high quality, highly serviced buildings to strict cost limits.

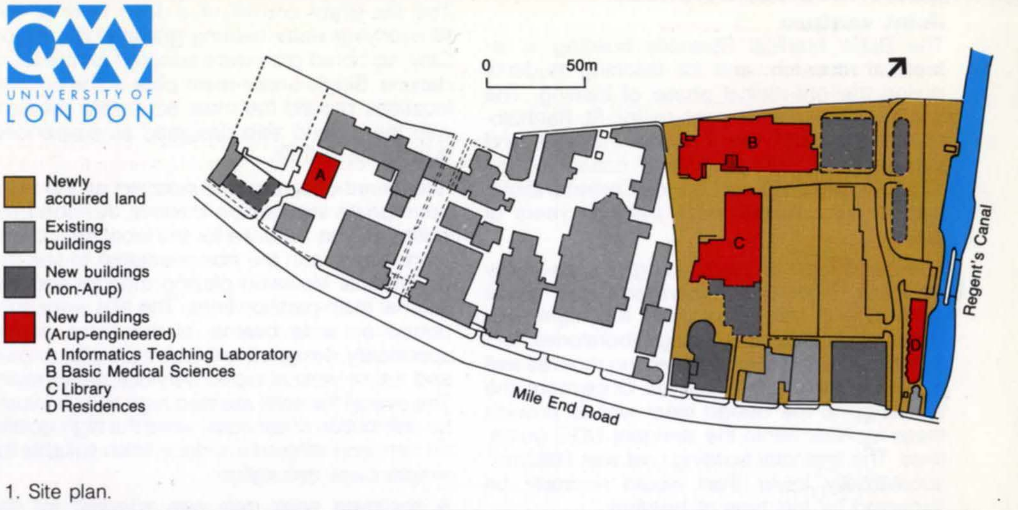
Infrastructure

The infrastructure for the East Site development comprises new access roads, car parks and landscaping. Each of the future building locations has been provided with utilities including gas, electricity, telephones, data cabling, water supply and drainage.

Library (Phase I)

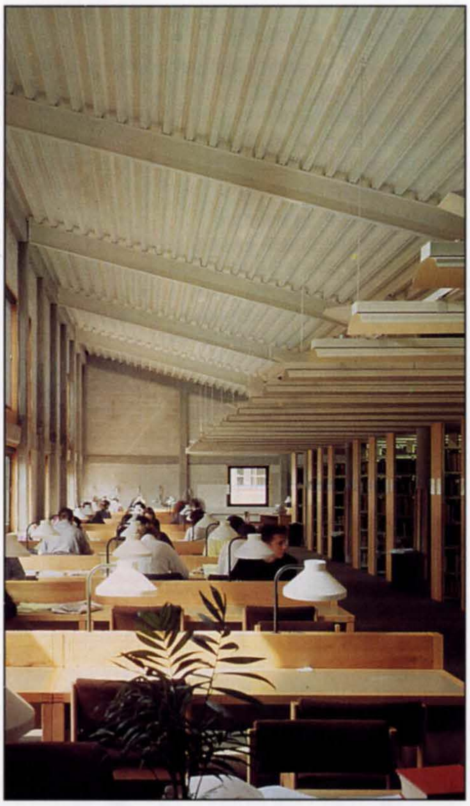
The structure of this building is of in situ reinforced concrete, with a Class I unpainted finish, exposed internally to absorb heat gains and reduce temperature swings. The majority of occupants work at desks and carrels placed at the perimeter of the building, with the advantages of daylighting and a pleasant location, though these areas are also lit by uplighters and task lights. The bookstacks are located in the centre of the building, and Arups designed a special reflector for the fluorescent lamps between the stacks.

The Library is mechanically ventilated with provision for future cooling. The exposed ring ductwork system is unique in having no diffusers or dampers, the flat oval duct being connected to a continuous 'top hat' section above with holes in the sides throwing air across the building. Phase I of the Library was completed in July 1987, and opened by HM The Queen.



1. Site plan.

2. Library interior.



3. (below): Informatics Teaching Laboratory.

4. (below): Residences and canal.

Informatics Teaching Laboratory

This building is part of the College's Computer Science Department. The limited budget and time span had to accommodate design for a high density of heat-generating computer equipment; the overall cost of £625/m^2 (gross) proved exceptionally low, 10%-60% less than comparable buildings. The structure was again in situ reinforced concrete, exposed internally to good aesthetic effect as well as acting as a climate moderator by absorbing the heat gains from the computer equipment. The substantial raised floor is used for data cabling and as a plenum for air supplied by six 'computer room' type units; these use outside air for free cooling, as cooling plant had to be omitted due to costs constraints. Pipework and spare plant space was included to allow the addition of chillers at a later date with no disruption. This part of the QMC project was finished in October 1989. In 1991 it won an RIBA Regional Award.

Residences (Phase A)

The residences are divided into six individual 'houses', each with its own staircase. The structure consists of in situ reinforced concrete floors on load-bearing walls with steel framing used for roofing and balconies. The sloping canalside site led to the incorporation of an undercroft running the length of the building, which is used as a plantroom and service distribution zone. Each study bedroom has a bathroom and there is a shared kitchen on each floor. The building is heated using pre-insulated pipes buried in the floor screeds serving radiators with thermostatic radiator valves. This project was finished in March 1990, and in 1991 it received a Civic Trust Commendation.

Basic Medical Sciences

Joint venture

The Basic Medical Sciences building is for medical research, and for teaching students during the pre-clinical phase of training. The building was a joint venture for St Bartholomew's Hospital, the London Hospital and Queen Mary College (known collectively as CELC — City and East London Confederation), and is the culmination of over 20 years of planning.

The basic form of the building is a six-storey structure, with laboratory/classroom areas either side of central corridors. It is highly serviced, and contains teaching laboratories, lecture theatres and a large dissection room as well as numerous research facilities. Once more, the challenge to the design team was to provide these facilities within the stringent UGC guidelines. The final total building cost was £652/m^2, substantially lower than would normally be expected for this type of building.

Strategy

The engineering strategy to meet this challenge was based on a multi-disciplinary approach, to achieve a cost-effective and flexible solution:

- The structure and building services were integrated. Pre-formed holes in the concrete slab were strategically located to accommodate future building services.
- The mechanical and electrical services were pared to the minimum both to meet the immediate requirements and allow future expansion, economically and with minimum disruption.
- Building services were carefully detailed and integrated with the building, in order to omit false ceilings from most areas.
- The concrete was specified to achieve a good quality self-finish for exposed ceilings and columns.

Structural engineering

The site strata consist of a deep layer of soft fill overlying water-bearing gravel and London Clay, so bored piles were adopted for the foundations. Single under-ream piles at the column locations proved the most economic solution, with the ground slab designed as suspended due to the soft fill.

Reinforced concrete was selected as the most appropriate and flexible material. A ribbed flat soffit slab was adopted for the laboratory/classroom areas, with the ribs orientated to suit the longitudinal elevation glazing module and the internal main partition lines. The ribs were supported on wide beams, of the same depth, specifically designed with soft zones for known and future vertical piped services penetration. The overall flat soffit assisted high level horizontal distribution of services, while the high quality rib formwork offered a surface finish suitable for simple paint decoration.

A shallower solid slab was adopted for the corridor areas to increase available headroom for the main horizontal services distribution. The slabs received a power-floated surface finish for direct application of the floor covering, as there was no need to provide a screed to contain electrical conduit distribution.

Stability was provided by the combined frame action of the stair walls, columns and floor slabs, which proved more economic than stiffening the walls to provide stability on their own. Steel frames support the pitched roofscape, enclosing the plantrooms.

Mechanical services

Air-conditioning was limited to those very few areas which needed it as a vital part of their function; natural ventilation was extensively used, achieving large reductions in capital and running costs. External louvres act as sunshades on the south façade to reduce solar gains. High standards of thermal insulation were adopted and a computerized Building Management System incorporated to monitor and control the energy use of the building's complex pattern of occupancy. The amount of fresh air provided in densely-occupied spaces such as lecture theatres was optimized by measuring the carbon dioxide in the exhaust air and then varying the fresh air to suit the number of occupants. The fume cupboard extract system was designed to minimize external pollution; wind tunnel tests confirmed that dispersal of fumes from the chimneys would be satisfactory.

Services such as piped gases have ring main distribution systems to facilitate the addition of extra outlets, the pipe racks (or clusters) in the laboratories having 25%-75% extra spaces to accommodate future pipes. Distribution routes for services are within the areas they serve, to facilitate future modifications with minimal disruption and cost.

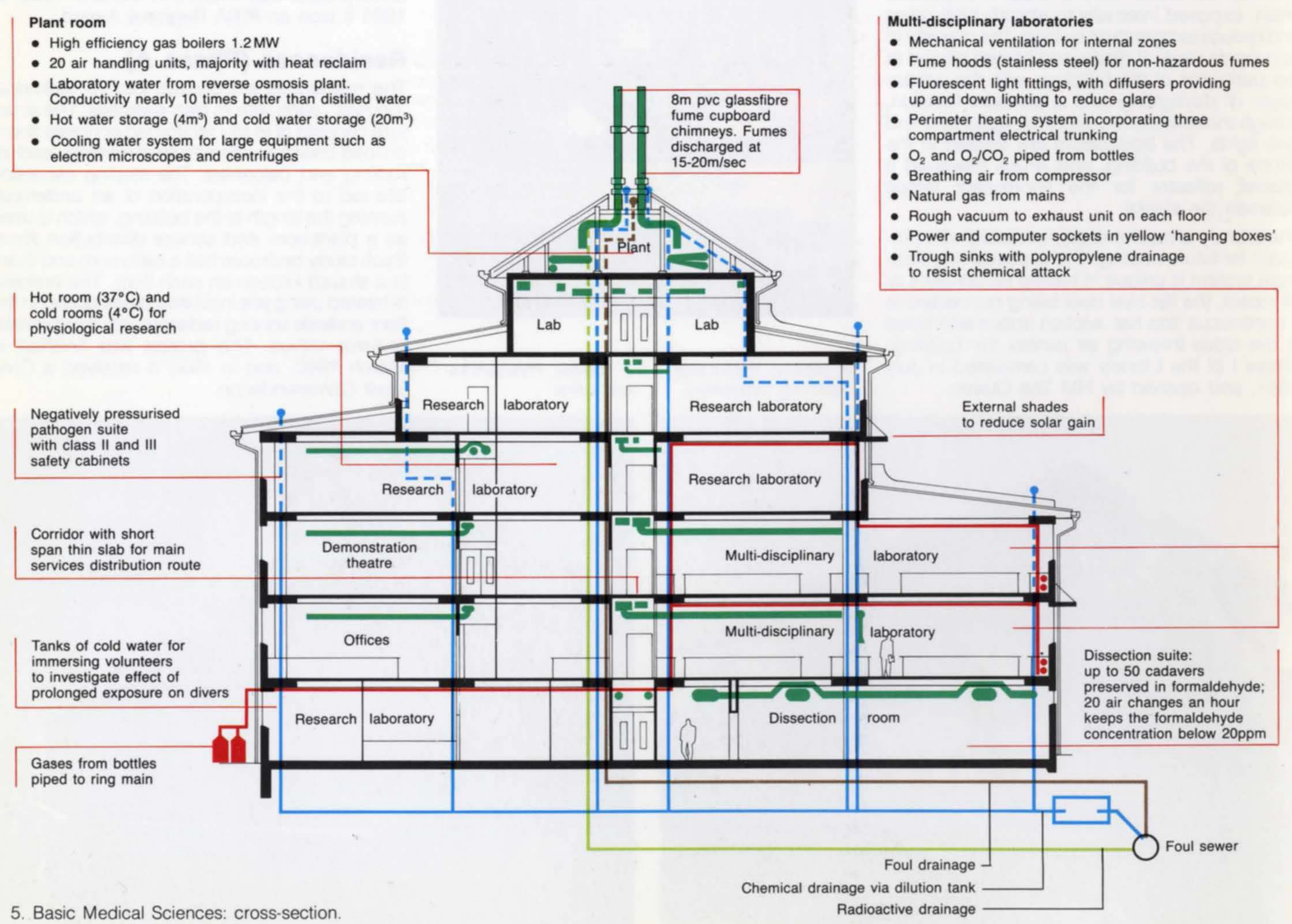
Electrical services

The main electrical plantrooms include an LEB substation and a 1000kVA power supply; a 45kw standby generator is also provided for essential services such as deep freezes and lecture theatre lighting. Electrical services are distributed upwards via four electrical risers linked to primary distribution routes in each corridor.

Electrical screening, consisting of steel mesh covering the floors, walls and ceiling bonded together electrically, was incorporated in some research laboratories to eliminate interference to sensitive equipment.

A passenger and a goods lift are provided, hydraulically-powered to eliminate the electrical interference caused by the large motors of conventional lifts. The passenger lift is designed to accommodate a stretcher patient brought in from the adjacent hospital for examination.

A computerized access and locking system has been included, to allow 24-hour access by means of 'proximity card readers', and automatic electronic locking.



Plant room
- High efficiency gas boilers 1.2 MW
- 20 air handling units, majority with heat reclaim
- Laboratory water from reverse osmosis plant. Conductivity nearly 10 times better than distilled water
- Hot water storage (4m^3) and cold water storage (20m^3)
- Cooling water system for large equipment such as electron microscopes and centrifuges

Hot room (37°C) and cold rooms (4°C) for physiological research

Negatively pressurised pathogen suite with class II and III safety cabinets

Corridor with short span thin slab for main services distribution route

Tanks of cold water for immersing volunteers to investigate effect of prolonged exposure on divers

Gases from bottles piped to ring main

8m pvc glassfibre fume cupboard chimneys. Fumes discharged at 15-20m/sec

Multi-disciplinary laboratories
- Mechanical ventilation for internal zones
- Fume hoods (stainless steel) for non-hazardous fumes
- Fluorescent light fittings, with diffusers providing up and down lighting to reduce glare
- Perimeter heating system incorporating three compartment electrical trunking
- O_2 and O_2/CO_2 piped from bottles
- Breathing air from compressor
- Natural gas from mains
- Rough vacuum to exhaust unit on each floor
- Power and computer sockets in yellow 'hanging boxes'
- Trough sinks with polypropylene drainage to resist chemical attack

External shades to reduce solar gain

Dissection suite: up to 50 cadavers preserved in formaldehyde; 20 air changes an hour keeps the formaldehyde concentration below 20ppm

Foul sewer

Foul drainage

Chemical drainage via dilution tank

Radioactive drainage

5. Basic Medical Sciences: cross-section.


△ 6. The Basic Medical Sciences building.


△ 7. Research laboratory.


△ 8. Dissection suite.


△ 9. Multi-disciplinary teaching laboratory.


△ 10. Wind tunnel tests for fume dispersal.


△ 11. Clinical lecture theatre: note exposed structure and services.

Public health services

The laboratory drainage is run in polypropylene pipework to resist chemical attack. The systems are automatically flushed with clean water three times each day, and run via a dilution tank to the foul sewer. The research department has a license to discharge small amounts of low grade radioactive waste drainage running in a dedicated stack directly to the foul sewer.

Energy and green issues

Green issues were addressed by energy conscious design, and by minimizing the environmental impact of the building. In nearly all cases the air handling plant has heat reclaim or carbon dioxide detectors to optimize the energy used for fresh air. Natural ventilation has been used wherever possible, with exposed structure and external solar shading to limit heat gains. The building is highly insulated with double glazing in all areas; clear glass has been extensively used. Arups calculated the optimum areas of glazing to give good daylighting while limiting heat losses. The fume cupboard chimneys and the chemical drainage system have been designed to ensure that materials discharged have minimal impact on the environment. The chillers use the refrigerant R22 which has an extremely low Ozone Depletion Potential of 0.05.

This building was completed in June 1990, and officially opened by HRH The Princess Royal.

Credits:

Infrastructure
Architect:
Feilden and Mawson
Main contractor:
Peter Birse Ltd.

Library (Phase 1)
Architect:
Colin St John Wilson and Partners
Main contractor:
Norwest Holst Construction Southern

Informatics Teaching Laboratory
Architect:
MacCormac Jamieson Prichard
Main contractor:
Beazer Construction London

Residences (Phase A)
Architect:
MacCormac Jamieson Prichard
Main contractor:
J. Rooff and Sons

Basic Medical Sciences
Architect:
Feilden and Mawson
Main contractor:
Kyle Stewart Ltd

Quantity surveyor: (all five projects)
Hamilton H. Turner & Son

Consulting engineers: (all five projects)
Ove Arup & Partners
Bob Hunt, Brian Towse (infrastructure)
Reg Green (RE)
Tony Langford, Robert Pugh, Chris Smith,
David Lewis, Pippa Connolly (structural)
John Berry, Alan Todd, Mohsen Zikri,
Stas Brzeski, Roger Olsen (mechanical)
Pankaj Raithatha, Mike Booth (electrical)
Tony Minchinton, Mike Ebsworth (public health)

Photos:
2: Martin Charles. 8: Feilden and Mawson.
9: Roger Olsen. 4, 6, 7, 11: Peter Mackinven.
10: Dr Petty. 3: Harry Sowden.
Illustrations:
Jon Shillibeer

ATRIUM FIRE SUPPRESSION SYSTEM

Introduction

The automatic sprinkler is one of the most widely-used fire protection systems today. It can detect, control, or extinguish a fire, limiting property damage and enhancing life safety in a variety of buildings and occupancies. In most, the conventional layout has a sprinkler head or heads placed ready to operate on temperature rise, and release sufficient water to control or extinguish a fire.

In the UK, *BS5306: Part 2: 1990*[1] is the design standard for sprinkler systems; it does not, however, address the particular problems associated with performance where there is an unusually high roof. The latter can firstly delay operation, and secondly mean that the discharge of the sprinkler may occur away from the fire location.

In recent years, architects have increasingly used atria in their designs to provide greater space and light.

Atria do, however, offer a particular challenge to fire safety engineering. Particularly when not enclosed, they can provide paths for fire and smoke spread throughout buildings. At present, building authorities restrict tall atria to circulation areas, fire loads are prohibited and therefore there is a potential loss of lettable area. Following discussions with Margaret Law, the need for a special sprinkler system was identified. Early in 1989 Rosehaugh Stanhope Developments plc commissioned Arup R&D to identify those features of a sprinkler/spray system most likely to be successful in controlling types of fire that can occur in atria containing combustible materials.

To protect the atrium base, the problem was to detect and control a fire at least as effectively as with conventionally-positioned sprinklers. In a standard system, the sprinkler head heat detector is designed to be less sensitive than other detectors, leaving very small fires to be extinguished by first aid appliances without triggering the system. This relatively low sensitivity had to be reproduced in the specialized application system. To conserve water supplies and limit water damage, it had to be applied to the fire area only, with a density of discharge corresponding with the *BS5306* Ordinary Hazard III criteria — the norm for commercial property.

Options

Bearing in mind architectural requirements for the system not to be intrusive, several ideas were investigated:

(1) Conventional sprinklers at the ceiling or atrium roof level, activated by a detector viewing the atrium or part of it

(2) Conventional sidewall sprinklers or a drencher curtain around the atrium perimeter to halt the spread of fire when it reaches the atrium

(3) Sprinklers around the perimeter of the atrium with an extended horizontal throw, activated by a detector as in option (1).

The following criteria were used in determining the preferred option:

(a) Means for detecting the fire and activating the sprinkler or drencher.

(b) Sprinkler efficiency in controlling the likely rate of fire growth.

(c) The required performance specification of the system and its ability to deliver an average minimum density of 5mm/min./m^2 to meet current guidelines.

(d) The maximum practical width of atrium protection.

Option (3) was eventually chosen as it covered all the design criteria we had earlier identified.

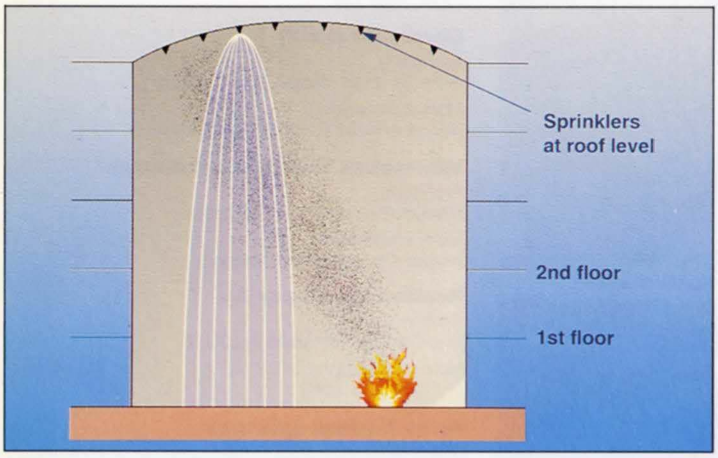
Development

Arups formed a consortium with Angus Fire Armour and G.P. Elliott Electronic Systems to research and develop an extended long-throw sprinkler in conjunction with a sophisticated infra-red detection and control system, which would only monitor designated atrium floor areas. The initial sprinkler research was undertaken at the Angus test facility at Bentham, Lancashire, whilst at the same time Elliotts at Merton, London, began to develop and test a modular system control panel, configured to suit specific project applications in conjunction with a computer mathematical model to determine individual zoning/masking requirements for each infra-red detector.

The system monitors individual atrium areas divided into two zones, each protected by two area and two zone detectors mounted at opposite ends on the parallel atrium edges.

Each zone of sprinkler nozzles is activated by three infra-red alarm detectors, two area and one zone irrespective of size of zone. Detectors are individually masked to see only the area/zone to be protected.

Area detectors respond to small fires to raise the alarm and zone detectors respond to larger fires by activating the sprinkler nozzles in that zone only. All other zones are initially



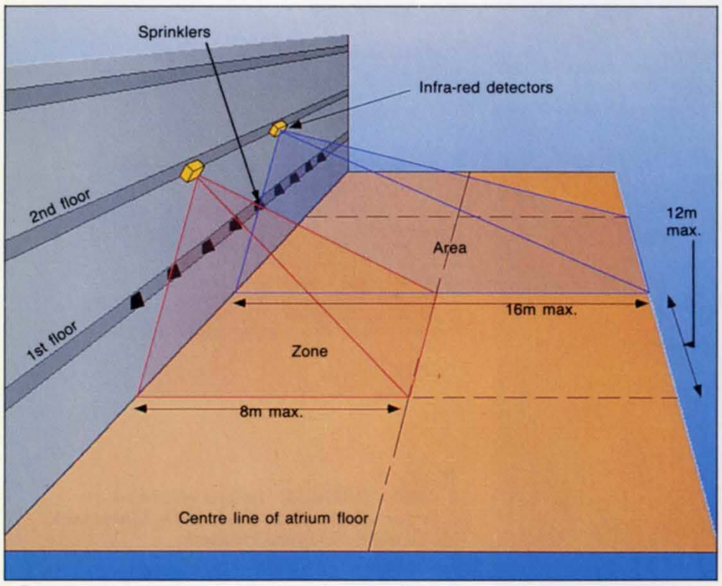
1. The conventional approach: sprinklers at high level.

3. Discharge pattern of long throw head.

Conventional sprinkler

Open long throw sprinkler

4. Types of sprinkler head.



2. Zoning arrangement.

5. Test demonstration at Cardington.

inhibited until automatic re-set occurs. The detectors are mounted approximately 7-8m high and the long throw sprinklers 3-4m above the floor area to be protected.

These heights can be increased to accommodate architectural or system design considerations. Each sprinkler head delivers approximately 120 litres/min. at a pressure of two bar. It is not envisaged that the system will operate in excess of two zones and therefore with eight heads operating, the total flow of 960 litres/min. for a period of one hour is within the water supply capability of an Ordinary Hazard III installation.

Following initial detection of the early stage of fire growth (100kW) by the area detector, the zone detector will signal initiation when the fire reaches 700-800kW via the GPE G120 fire panel. This also monitors the infra-red detectors, the sprinkler zone valves, flow switches and fault conditions.

On receiving the initiation signal, the panel activates the Multiple Jet Control, discharging water through the open long throw sprinklers within the zone of operation.

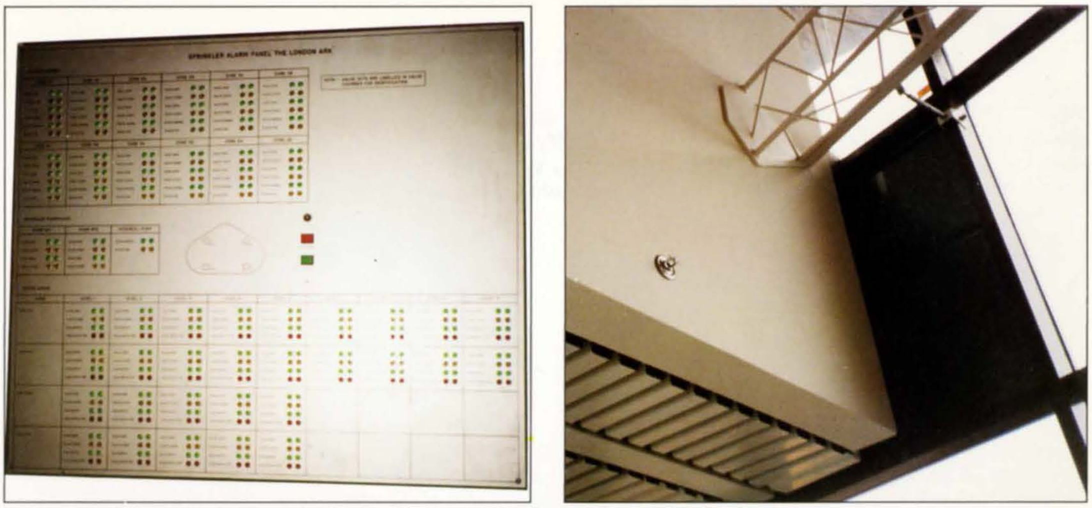
Testing

After nearly two years' research and preliminary field trials, a public demonstration of the system was held at the Cardington Laboratory of the Building Research Establishment for representatives from the London District Surveyors Association, London Fire and Defence Authority and fire insurers. Three tests were made over a simulated atrium floor area of 16m × 24m, divided into four zones of 8m × 12m to represent a typical plan layout. Fires were ignited at the worst positions, i.e. adjacent to another zone, at the extremities of the area or of zone detector viewing angles.

In the first test, screens were used to determine the system's ability to detect small heptane fires of about 50kW without activating adjacent detectors.

Depending on the fire location, detection response was 5-37 seconds. The object of the second test was to determine the system's ability to detect a small fire of approximately 100kW, suitable for extinction by hand-held appliances without activating the sprinkler system or other zone detectors. Detection response was between 19 and 80 seconds. The final test had to determine the system's ability to detect large fires of approximately 800kW and activate the relevant zoned sprinkler system. This test was also used to determine the capability of the sprinkler nozzle to control the fire at a calculated peak rate heat output of 0.8MW.

The field trials and public demonstration achieved their objectives and subsequently a favourable response was received from the London District Surveyors Association. Both the detection devices and long throw sprinklers are now approved by the Loss Prevention Council. The system has been installed and commissioned at The London Ark, Hammersmith, in six areas where conventional sprinklers would not be appropriate due to the high roof. There is potential for the system in new and existing buildings, as it allows greater flexibility of use for the atrium base or any area where a high ceiling makes the installation of conventional sprinklers impractical.



6. (above) Sprinkler alarm panel and 7. (right) unobtrusive sprinkler head at The London Ark.

8. Indoor terracing at The London Ark; the sprinklers are positioned above the terracing on the facing wall.

Reference

(1) BRITISH STANDARDS INSTITUTION. *BS5306: Part 2: 1990.* Fire extinguishing installations and equipment on premises. Part 2. Specification for sprinkler systems. BSI, 1990.

Credits

Client:
Rosehaugh Stanhope Developments plc

Co-ordinating engineer:
Arup Research & Development
Peter Bressington, Stan Peacock

Development sub-contractors:
Angus Fire Armour Ltd.
G.P. Elliott Electronic Systems Ltd.

Illustrations:
Trevor Slydel

Photos:
3, 5: Stan Peacock; 4, 6-8: Peter Bressington

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