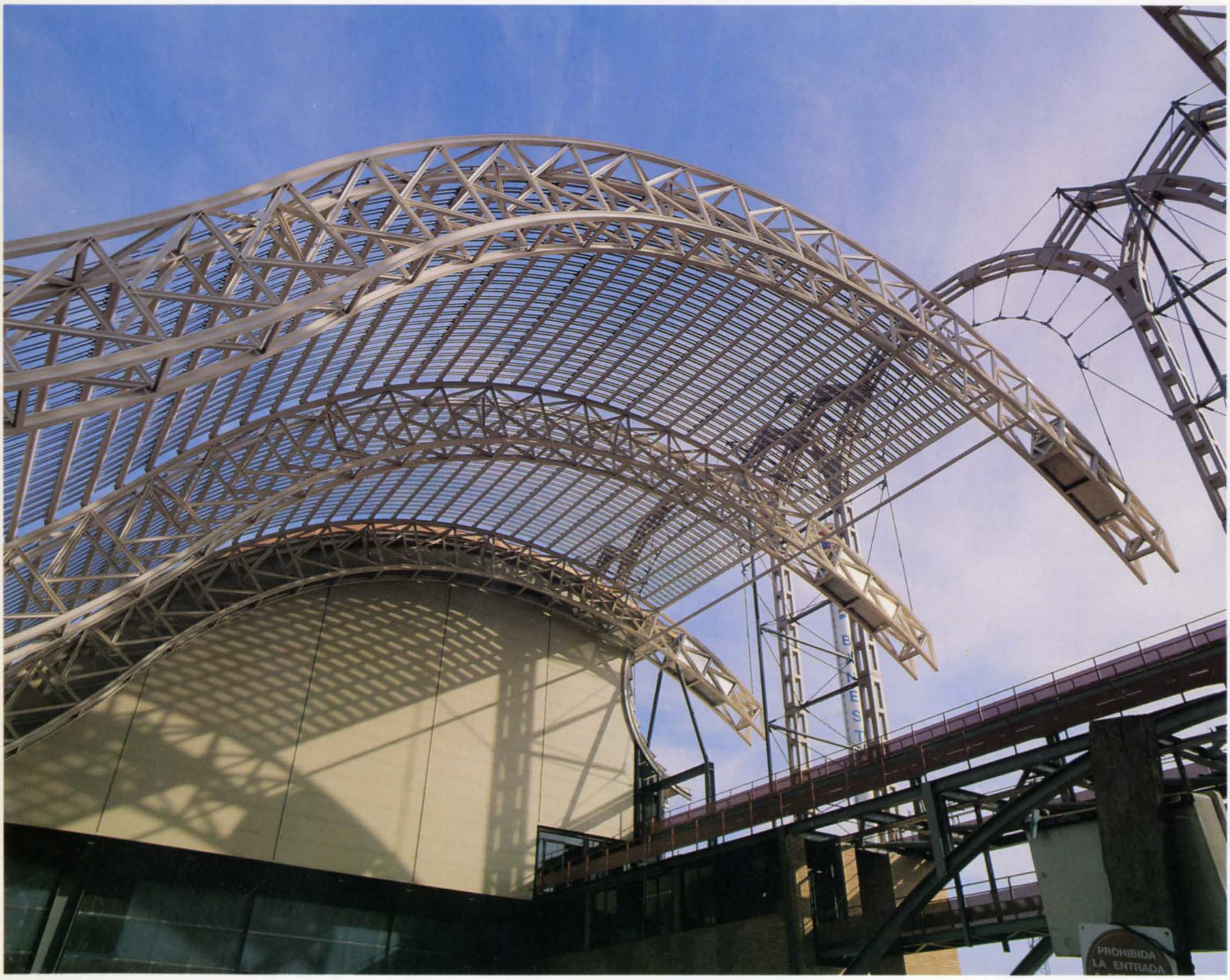
THE ARUP JOURNAL

AUTUMN 1992



ARUP

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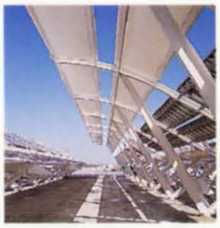
Front cover:
View from beneath canopy suspended from façade of Pabellon del Futuro, Expo '92, Seville (Photo: Fernando Alda)

Back cover:
The UK Pavilion (Photo: Reid & Peck)

UK Pavilion,
Expo '92, Seville
Ian Gardner, David Hadden



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Ove Arup & Partners were the structural and services engineers for the UK Pavilion, Expo '92 in Seville. This was constructed to conform with 'The Age of Discovery' theme.

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Greg Pearce, Peter Warburton

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Arup Associates prepared a design for a day care centre in Frankfurt, one of the objectives being to achieve a 'low entropy' building.

Usine Thomson CSF
Richard Hough, John Hewitt

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The brief for the Thomson Factory, 15km south west of Paris, required open spaces, a clear approach to circulation and scope for future expansion. Ove Arup & Partners International Ltd. were subcontractors to Renzo Piano Building Workshop for the superstructure.

Usine l'Oréal
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The new production and administrative headquarters building for French cosmetics manufacturer l'Oréal in north-eastern Paris was carefully planned for an owner-occupier client. Ove Arup & Partners International Ltd. were *bureau d'études* for the steel superstructure.

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Ove Arup & Partners used CFD (Computational Fluid Dynamics) extensively in plans for the internal environments of the proposed Munich Airport Centre and Centre of Contemporary Art, Luxembourg, with the aim of creating environmentally satisfactory buildings.

Pabellon del Futuro
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The Pabellon del Futuro was a major pavilion at Expo '92. Ove Arup & Partners International Ltd were invited to collaborate in the design of the pavilion's roof and dramatic stone façade.

UK Pavilion, Expo '92, Seville

Architect:
Nicholas Grimshaw & Partners Ltd.

Ian Gardner
David Hadden

Introduction

In December 1988 the Department of Trade and Industry invited nine firms of architects and designers to submit proposals for the United Kingdom Pavilion at Expo '92 in Seville. Within Expo's theme of 'The Age of Discovery' the DTI's objectives were to:

- Promote the UK as a strong, resourceful and open economy by displaying British enterprise and excellence
- Strengthen international trade and commercial relations with the UK
- Highlight our active participation in the European Community
- Alert visitors to Britain's appeal as a place for leisure and business
- Enhance Anglo-Spanish relations
- Stimulate a high level of business contributions to the Pavilion
- Demonstrate the excellence of British design.

To achieve these the DTI called for proposals which emphasized Britain's leadership in areas of technology and services, while conveying an image of cultural excellence in a forward-looking democracy. A 6200m^2 site was secured at the junction of International Boulevard (now Acacia Way) and European Avenue, locating the Pavilion near those of the other major industrial nations.

In March 1989 Nicholas Grimshaw and Partners Ltd. and Ove Arup & Partners were asked to develop their proposals to scheme design stage; Arups' initial appointment was as structural, geotechnical and building services engineers. Subsequent DTI commissions were for fire engineering, telecommunications, acoustics and lighting studies, as well as the structural and services engineering for the Exhibition fit-out works. Arups also designed the north and south fabric walls for the works contractor.

In addition to the UK professional team, the DTI also engaged EXHIBIT, a Spanish service company set up specifically for Expo '92, to assist the UK team with Spanish and Expo '92 regulations, submissions to the Expo '92 authorities, and advice on local construction practice.

1. Night time view from south east.

Funding was provided by central government and sponsorship from private companies: British Steel in particular made a major contribution.

Initial brief

In addition to their thematic objectives the DTI also set out certain operational and physical requirements. These included:

- Maximum freedom for the Exhibition designer with generous unobstructed floor space
- One-way circulation for up to 20 000 visitors per day, seven days per week, for Expo's six-month duration
- Access for the disabled
- A separate entrance for VIPs
- Shaded external queuing areas
- Strong UK identification on the Pavilion exterior
- Offices and welfare facilities for Pavilion staff
- VIP reception, dining and kitchen areas
- Concession areas for fine dining and retail sales
- Consideration of dismantling and re-siting the Pavilion after Expo '92.

The initial programme for the construction of the Pavilion was as follows:

Appoint UK management contractor:	February 1990
Commence construction:	September 1990
Complete base building:	August 1991
Complete exhibition fit-out:	March 1992.

In fact construction began in June 1990 and, with more overlap between the base building and exhibition fit-out works than originally envisaged, the Pavilion opened to the public on 20 April 1992, the first day of Expo '92.

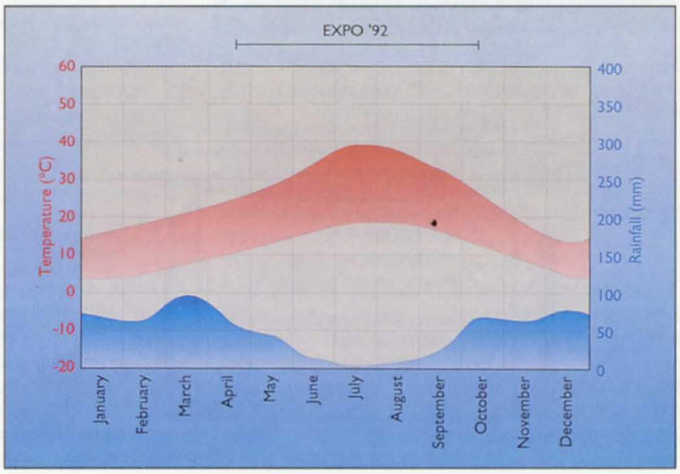
Principal design objectives

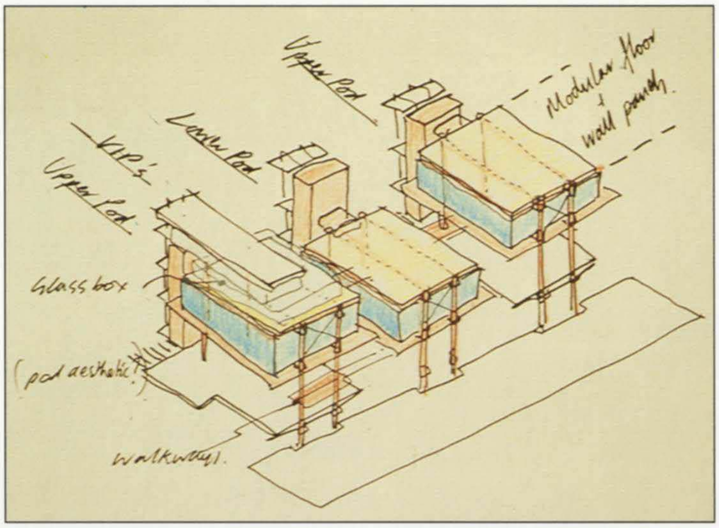
From the outset Grimshaw and his team were determined to create a piece of 'serious' architecture and avoid the Disneyesque. The 1851 Great Exhibition Building and the Festival of Britain pavilions 100 years later were seen as more appropriate points of reference. Off-site prefabrication of major building elements, preferably in the UK, was considered essential. A responsible energy policy, and a strategy for re-use either of the whole Pavilion or components, were important. And within this framework the single most significant factor in the evolution of the engineering design was Seville's climate, the location in southern Spain making it virtually unique in Europe. For much of the year and particularly from April to October, the period of Expo '92, hot, dry southwesterly winds are funnelled across the region by adjacent mountains. Summer temperatures are regularly in the upper 30s°C and can exceed 45°C. July and August rainfall is normally minimal, so it was ironic that in this of all years the typical weather pattern was broken, with some heavy rainfall and relatively low temperatures during the first half of Expo.

People have, of course, lived comfortably in Seville and Andalucía for centuries without the benefit of air-conditioning. The traditional local approach to the harsh summer is to use

2. Left:
Prevailing winds:
April to October.

3. Right:
Normal climatic
range in Seville.





4. Architect's sketch of interior pods and service risers.

shading in the form of inward-looking courtyards, external shutters on windows and fabric awnings over narrow streets; heavy masonry walls to stabilize internal temperatures; and water in fountains and ornamental pools to cool the air by evaporation. It was logical to adopt these principles for the Pavilion. The challenge was to do so in the context of modern materials and industrial techniques in a prefabricated building with modern user needs.

5. Travelators and east wall.

Overall form

The rectangular external envelope had* internal plan dimensions of 64.8m x 32m, and a height of 24.8m from lower ground floor to roof. Early press articles referred to it as 'the size of Westminster Abbey' - in cross-section at least a valid comparison. The longitudinal axis ran north-south, with the east wall as principal public elevation and the west wall facing various service buildings.

Only the lower ground floor occupied the whole plan area. The partial floors above housed the principal exhibition spaces within the protection of the envelope. The two enclosed theatre pods were located towards the north and south end walls, with two open decks between them to provide access to the central feature exhibit.

Visitor entry was via a bridge over an external lake onto the concourse level. The Pavilion had no internal stairs; visitors proceeded to and from the upper floors by inclined travelators, each 50m long and arranged in pairs on opposite sides of the building. From the concourse they could exit directly via a bridge at the north elevation or descend by a ramp to the restaurant below. Two 13-person hydraulic scenic lifts took VIPs from their own entrance to the VIP Suite on top of the south pod.

Environmental control and the building fabric

Rather than treating the interior as one space with uniform conditions throughout, the arrangement of envelope and specialized areas allowed a hierarchical approach to environmental control. Visitors queuing for an hour in the sun could be discomforted by a dramatic temperature drop on entry, but clearly 200 people seated in a compact theatre would produce a significant heat gain.

Floor levels

Lower ground floor
(gross area 2450m^2, level -1.7m)
Pavilion management offices
Commissioner General's suite
Main plant, switchgear and telecommunications rooms
VIP reception
Restaurant, kitchens and public toilets
Internal water feature

Concourse
(gross area 1370m^2, level +2.5m)
Welcome area
Sponsors' display area, shop and information point
Green room
Entrance and exit bridges
Service risers

Lower pod level
(gross area 580m^2, level +7.5m)
Lower central feature display deck
Visitor circulation/escape walkways
Service risers

Upper pod level
(gross area 1100m^2, level +12.5m)
Enclosed theatre pods
Upper central feature display deck
Visitor circulation/escape walkways
Service risers

VIP level
(gross area 360m^2 level +17.5m)
VIP suite
VIP kitchen and toilet areas
Escape walkways
Service risers

The solution was to provide a moderated environment within the envelope to which visitors could adjust before entering the fully conditioned inner spaces. Typical internal temperatures were 28°C on the Concourse level and 23°C in the pods and offices, but these were not fixed and reflected seasonal changes in external conditions.

The Pavilion orientation meant that direct solar radiation fell on the east wall for only 2-3 hours each day after public opening; the roof, south elevation and, in particular, west elevation were exposed to the sun's full strength for most of the day. The constructional forms of the principal surfaces of the building were in response to these conditions and extensive computer modelling with the Oasys ROOM program evaluated their effectiveness.

Roof

This was a lightweight sandwich of metal decking, insulation and waterproofing to minimize loads on the long-span roof members. At night the relatively thin insulation allowed some interior cooling. By day, curved south-facing shades on light steel frames

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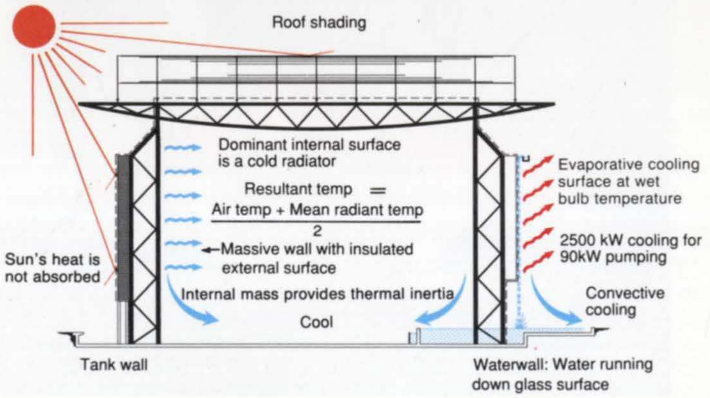
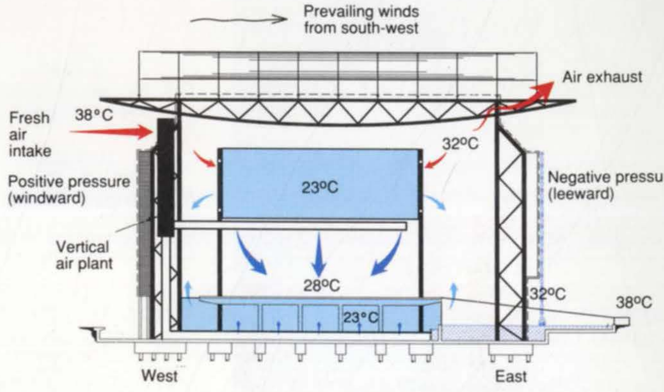
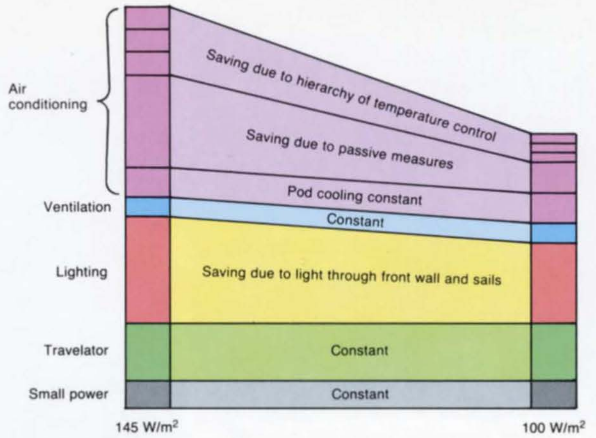
*At the time of writing, the Pavilion's future was uncertain.

6. Passive cooling techniques.
7. Hierarchy of environmental control.





8. Left:
Air-handling unit for envelope space feeding primary elliptical duct.



9. Right:
Energy saving breakdown.

shielded the roof from the sun and, with natural air movement across, limited its temperature rise. The shades themselves were mostly light-coloured fabric panels, although approximately 30% of the shade area was provided by banks of photovoltaic cells which supplied power for the east water wall.

East wall

The main public face of the Pavilion was glazed for its entire length with water pouring continuously down the outside. Patterns forming in the falling water gave the glass a dynamic, translucent quality which enhanced views in both directions. In engineering terms the water also limited the maximum glass temperature to around 24°C so that it remained below skin temperature, thus contributing to visitor comfort.

Submersible borehole pumps, powered by rooftop photovoltaic cells operating in parallel with mains-driven units, raised the water 17.5m from a lake along the east elevation, inside and outside the Pavilion, to distribution pipework at the top of the glass wall. Nozzles then directed it onto the glass; at 5m above the lake it ran into a gutter and fell the remaining distance in fine jets. Filtration and chemical treatment were handled in a dedicated underground plantroom. Solar energy provided around 50% of the 90kW required for pumping. Loss from the wall and lake was up to $100m^3$/day, equating to around 2500kW of evaporative cooling to the Pavilion and its environs.

West wall

Neither time nor architecture permitted the creation of a genuine masonry wall on the west side. Instead, water-filled stacked steel tanks provided enormous mass to act as a 'thermal flywheel' which, together with the concrete concourse and lower ground floor slabs, helped stabilize internal temperatures. By painting the tanks' outer surfaces white and insulating them, heat absorption was limited. The wall's internal face remained almost static at c.30°C, while external temperatures varied daily by up to 25°C.

End walls

Tensioned fabric formed the north and south skins, softening incoming light by day and allowing these elevations to glow spectacularly at night. To improve the thermal performance of the south wall a layer of external fabric 'flysheets' provided shade to the wall itself. This additional line of defence was not required at the north end.

Mechanical engineering and energy usage

The mechanical systems which complemented these passive temperature control measures were concentrated in the west wall. Four vertical air-handling units totalling $22m^3$/s capacity drew fresh air in at high level and distributed it through horizontal elliptical ducts below the pods across the Pavilion. These units also recirculated air from high level inside the building.

The offices and restaurant area at lower ground level had their own west wall AHUs supplying cool air though pressurized floor voids and circular floor diffusers which then spilled onto the concourse level. The north and south pods and VIP Suite each had their own plant above, drawing air from the general Pavilion space and conditioning it further before discharging it back into the envelope still cold enough to contribute to cooling.

Air was exhausted naturally through high level louvres into a negative pressure zone created by the building shape. A sensor monitored wind direction and opened the louvres on the leeward side accordingly. The upward movement of air within the envelope promoted stratification with the optimum conditions at concourse level.

In line with measures to modify the microclimate across the whole Expo site, cooling water was taken from a central raw water system, thus eliminating the need for cooling towers or condensers. Untreated water, extracted from the Guadalquivir upstream of Seville, was passed through two parallel chiller units and discharged into a collector drain to return it to the river.

The high internal heat gains from exhibits, and the organization of internal spaces required by the client, meant that the Pavilion was not the 'ultimate' low energy building. However, within the constraints it demonstrated how these techniques, some long-established, are appropriate in the context of modern materials, industrial methods, prefabricated buildings, and modern user needs. Energy savings of about $^1/_3$ relative to a more conventional building of similar size and purpose were achieved.

Electrical engineering

With 2MW installed capacity the electrical systems provided considerable flexibility for the users. An overall allowance of $150W/m^2$ in the exhibition areas gave a wide range of options for audio-visual equipment and lighting. Busbar systems in the west wall risers and horizontal distribution routes in the walkways and floor voids supplied these areas.

Due to the glazed east elevation, light fabric end walls, and translucent ventilation louvres, the building was well served with daylight. At night the lighting design created a spectacular sight. Sunspot luminaires at the top and bottom of the end walls made them glow and similar fittings at high level illuminated the structure. The rooftop shades were uplit by area floods and underwater spotlights enhanced the lowest 5m of the water wall. The interior was lit by fluorescent luminaires in walkway skirtings, handrail lights on the travelators, and downlighters recessed into the undersides of the pods and central decks.

Public health engineering

A unique feature of the public health design was the absence of rainwater drainage from the roof. Rainfall during the summer is usually low and by allowing water to pond to 75mm depth all but the most severe storms could be contained. In extreme conditions water discharged off the roof without control but was normally lost by evaporation, further contributing to cooling of the envelope.

Seven of the west wall tanks formed part of the potable supply system as well as being elements of the building fabric.

Structural design and construction sequence

The key objectives were for an assembly of identifiable parts, conveying to the observer how they were made and how they functioned, to be erected simply on site, with the prefabricated elements easily transportable. The steel superstructure demonstrated the philosophy of precise offsite fabrication by a skilled workforce in harness with erection requiring minimum temporary works. Many connections between steel members were made with a single pin, thus defining the structural action while allowing rapid assembly with potential for subsequent dismantling. This approach contrasted with that adopted on several other pavilions where extensive site welding was used, sometimes with a lack of finesse in the end product.

Foundations

The site lay in the Guadalquivir's flat floodplain, between the original watercourse and a relatively recent man-made canal: an area previously used for low intensity agriculture. The stratigraphy consists of fairly soft alluvial deposits over a layer of dense gravel at 18m depth with marl below. General level was 8-9m above normal river level.

10. Above: Pod structure being erected.

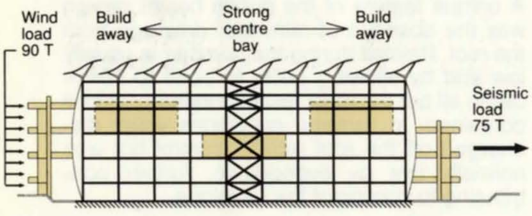
11. Right: Free-standing east wall structure.

12. Far right: External structure being assembled around internal pods.

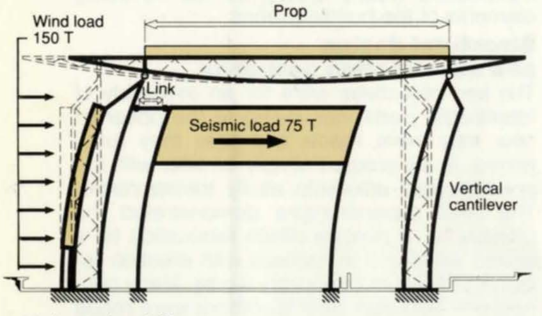
The limited load capacity of the upper strata and the concentration of column loads along main elevations and below the pods led to the use of 800kN driven cast in situ concrete piles with toe levels in the dense gravel layer.

Concrete substructure and concourse level

Conventional reinforced concrete pilecaps, the ground-bearing lower ground floor slab, and suspended concourse deck, followed piling. A locally obtained granular material known as albero, widely used in the region for footpaths, sub-base and in bullrings, formed the sub-base on which the ground-bearing slab was cast. Horizontal loads on the superstructure were transmitted to the ground by friction between the sub-base and the slab.



13. Longitudinal stability.



14. Lateral stability.

15. West tank wall, made up of mini-containers.

Internal pods and decks

The first superstructure elements to be erected were the north and south pods and central decks. Each comprised two identical floors, one 5m above the other. The upper central deck was at the same level (+12.5m) as the lower pod floors. Each floor included a concrete slab with composite metal decking supported on the bottom flanges of steel universal beams. The void between top of slab and the raised floor was used for services distribution.

The floor beams were carried by two parallel tubular steel Warren trusses spanning 20m between a pair of columns, each of which consisted of two thick-walled tubes battened together. The trusses acted compositely with the concrete slab and reduced in depth towards their supports. By splitting each column the visual bulk of an equivalent single member was avoided and the trusses passed between the two legs, allowing a single pin connection between supported and supporting members. Extending the upper trusses beyond the columns enabled a cantilever support system for the interconnecting walkways and travelators to be devised. Thus the access routes to the upper exhibition spaces related structurally only to the pods and decks which they served and visitors on the travelators had unobstructed views of the water wall.

The pods and central decks derived their east-west lateral stability from pinned connections to the envelope west wall at the tops of the pod columns. Independent bracing to the pods in this direction would have inhibited concourse level circulation, with moment frame action unacceptably increasing the pod column dimensions. As the pods and central decks were offset towards the west wall, linking the structures could be achieved without visual ambiguity.

North-south stability of the internal structures was provided by vertical cross-bracing between the columns to the central decks. The two pods were linked to this restraint system by the interconnecting walkways at +12.5m level. Erection of these structures was relatively straightforward and commenced with the assembly of the central deck frame. With its permanent bracing in place this was stable north to south. The adjacent pods could be immediately stabilized in the same direction by linking them to the central frame. Temporary guys and restraint from the concourse level slab secured all three structures east to west until they could be linked to the external west wall.

External envelope

Once the main internal elements were in place, erection of the envelope could proceed. This consisted of 10 identical tubular steel frames at 7.2m spacing, each comprising two vertical wall trusses 21.7m high to support a 32m span roof truss. The latter, which had radiused lower chords, were connected to the wall trusses by single pins at each junction. Each frame acted not as a portal but as a pair of vertical cantilevers linked by the roof member. Transverse horizontal forces on the envelope were thus resisted by bending in the wall trusses and axial force in the roof truss. The central bay of the envelope contained cross-bracing in both walls and across the roof to stabilize the structure longitudinally. This single stability bay, which aligned with the internal central deck system, had two important benefits. Firstly it allowed the envelope to adjust to thermal expansion and contraction without 'locking in' additional stresses. Secondly, once assembled it provided a fixed point from which erection of the rest of the envelope could proceed on two fronts without temporary works.The wall trusses north and south of the central bay were tied to it by slender horizontal tubes. Purlins spanning between the roof trusses tied them to the central bay as well as carrying the roof decking and finishes.

West tank wall

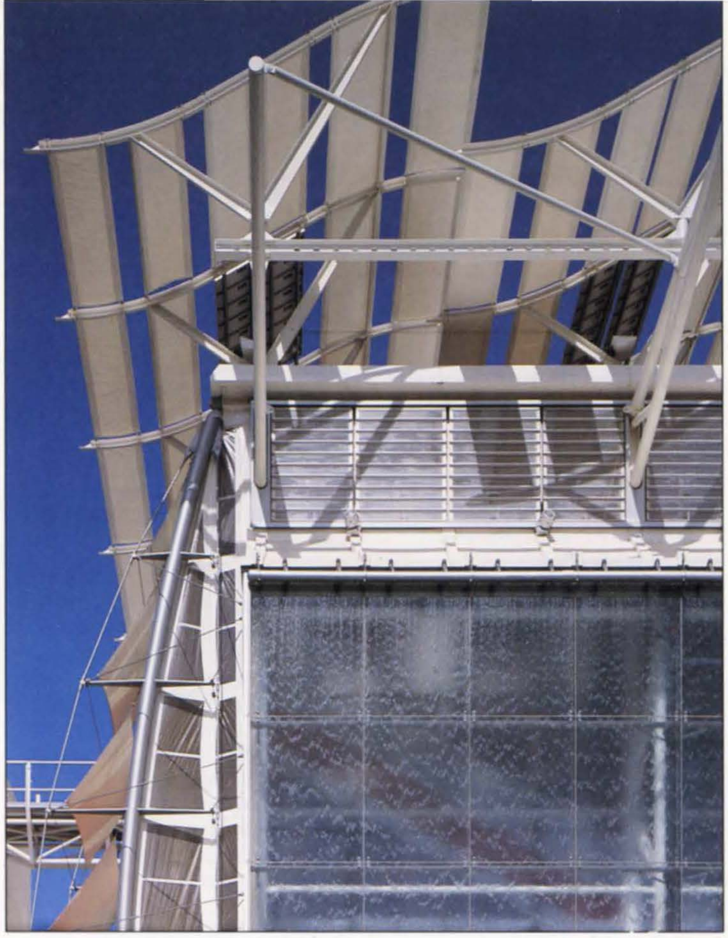
The west wall water tanks were 7.2m long, 1m wide, and 2.5m high, stacked on top of each other to a height of 15m. This prevented the use of standard pressed steel; instead each tank used freight container-type side panels, internal posts and corner blocks. These mini-containers were locked to their neighbours at each corner to give a wall of considerable in-plane strength, and tied to the envelope structure for out-of-plane restraint.

East wall glazing supports

The upper 12.5m of glazing was suspended, with each 1.8m wide by 2.5m high pane carrying the weight of those below it. Along the top edge a series of cantilever steel rectangular hollow sections supported the whole of this load, including the frictional drag from the water pouring down the glass. Wind loads acting on the glass were taken back to the envelope frames by horizontal extruded aluminium transoms.

North and south sail walls

25m high and 32m wide, these consisted of PVC-coated polyester textile membranes in 4m wide bays between nine tension braced



16. Above: Junction of envelope structure, glazing transoms, and water delivery pipework.

17. Right: Top of east wall.

masts, each with a curved tubular steel spine with tapered tubular spreaders projecting from each side. The ends of the spreaders were linked by continuous steel rods, one on each side of the spine and terminating at the top and bottom of the mast. The rods were prestressed against the axial stiffness of the spine. Each mast was in effect a vertically-spanning beam subject principally to wind loading, and resisting it by changing the prestress forces in the rods - one increasing and the other decreasing according to the wind direction. The masts were restrained laterally by horizontal rods at the ends of the spreaders anchored back to the end frames of the envelope. At the top of each mast the connection to the envelope roof allowed relative vertical movement to prevent the transfer of vertical loads.

The membrane was fitted as a set of panels directly between the tubular spines by rivetted luffing grooves on each side of the tubes, each panel being biaxially prestressed to give damping and stiffness. The curved form of the membrane provided the necessary load carrying capacity.

Roof solar shades

Pressed steel tapered V-frames carried the rails supporting the fabric roof shades and the photovoltaic cells which supplied power to the water wall. The V-frames were stabilized via a moment connection to the roof purlins which, being continuous, resolved wind-induced moments by their reactions on the roof trusses.

Seismic design

In addition to gravity and wind loads the Expo '92 rules required the Pavilion structure to withstand an earthquake of Intensity VII as defined in the Spanish seismic code. The building form meant that in the north-south direction relatively straightforward equivalent static load analyses for the internal and external structures could be carried out. In the transverse east-west direction, however, the linking of the pods to the envelope made this approach inappropriate. A dynamic analysis of a typical frame was therefore carried out by setting up the input data using the Oasys GSA program and transferring it into PAFEC for execution.

Transportation

Early on, the design team discussed with leading fabricators and British Steel the strategy for transporting structural members from the UK to Spain. The route finally adopted was to take elements up to 25m long and 7.5 tonnes in weight by road from Warwickshire to Plymouth, ferry to Santander in northern Spain, and by road to Seville. On a good run the whole journey took five or six days.

Fire safety strategy

The Expo '92 regulations were understandably onerous regarding fire safety requirements. Had they been applied at face value to the Pavilion the resistance periods called for would have made impossible the clear expression of the structure which was achieved. Utilizing fire engineering methods Arup R&D were able to demonstrate that with appropriate measures to control fire size and smoke generation and the provision of suitable escape routes, occupant safety could be ensured with reduced periods of structural fire resistance. Thin intumescent coatings could then be used to protect the superstructure steelwork.

Construction contracts

Pavilion construction was procured and organized by a UK management contractor. Furthermore all but five of the 40 works packages were carried out by UK firms, often after competitive tendering by both Spanish and British contractors. The locally handled activities were bulk excavation, external works, general builderswork and waterproofing — it was truly a pavilion made in Britain and assembled in Spain.

The Pavilion during and after Expo '92

Throughout the duration of Expo the Pavilion attracted excellent crowds and high praise from many quarters. In June it received an award from the Energy Pavilion for its imaginative use of solar power and water to control internal conditions.

In the Building Category of the British Construction Industry Awards it also received a High Commendation as well as a Special Commendation as an outstanding ambassador for British design and construction.

As yet its post-Expo fate is not known. The original design competition entry idea of reusing components of the building elsewhere could take the form of a package of pumps, solar panels and west wall tanks becoming a water supply and storage system for a village in the developing world. Ideally the building would remain in use on site and the DTI have appointed agents to promote its sale. It may even be dismantled and rebuilt elsewhere and the 'kit-of-parts' approach to much of the structure, services and fabric could make this idea viable. Ultimately, it illustrates that there is no inherent conflict between high technology and 'green' issues, and in any future use this fundamental statement should not be lost.

Credits

Client:
Department of Trade and Industry

Architect:
Nicholas Grimshaw & Partners Ltd.

Structural and services engineers:
Ove Arup & Partners Richard Haryott, Ian Gardner, David Hadden, Matthew King (structure); Martin Hall, Peter Berryman, Jonathan Cairns (mechanical services); Tom Harris, Eric Budzisz (electrical services); Brian Sherriff, Glen Mason (public health)

Cost consultants:
Davis Langdon & Everest

Exhibition designer:
RSCG Conran Design Ltd.

Water wall designer:
William Pye Partnership

VIP area designer:
YRM Interiors

Management contractor:
Trafalgar House Construction Management Ltd.

Steelwork works contractor:
Tubeworkers Ltd.

Mechanical and electrical works contractor:
Rotary International Ltd.

Photos:
1, 5, 17: Cover Reid & Peck. 8: P. Berryman
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Illustrations:
2, 3, 9: Trevor Slydel. 4: Nicholas Grimshaw & Partners Ltd. 6, 7, 13, 14: Geoff Lavender.

Frankfurt School

Architects: Arup Associates

Greg Pearce   Peter Warburton

Introduction

In 1992 Arup Associates were selected as one of six European practices to participate in an International Design Competition sponsored by the City of Frankfurt. The competition, for a day care centre in the suburb of Sossenheim, aimed for a 'low entropy' design concept, attempting to minimize not only the amount of energy required to operate the building but also to construct and eventually demolish it. Competitors were also required to suggest solutions for an extension to an existing primary school on an adjacent site, and to masterplan the whole of the combined site.

Site organization

The site is within a residential district adjacent to a planned motorway by-pass. Pedestrian access is from the north via a walkway from Am Kunzengarten, and from the south boundary adjacent to the motorway.

In the Arup Associates plan the two new buildings are situated against the northern boundary of their respective sites in order to optimize southern exposure while creating south-facing playground areas. Planted earth covers the north face of each building, with double-skin glass façades on the southern exposures to shield traffic noise. A new north-south pedestrian route is linked to the primary internal circulation axis of each building by a covered entry tower, and a footbridge is proposed to give access from the neighbourhoods opposite the motorway.

Spatial organization

The day care building is organized around four basic elements: the 'lean-to', the 'wall', the 'thermal snake', and the 'glass box'. The wall is the building's primary organizing element, and defines the circulation spine. To the north, the lean-to huddles against it and is covered (top, bottom and sides) in planted earth. The lean-to contains shared support facilities and protects the primary spaces from the northern exposure. Over the wall, on the southern side, the primary spaces are enveloped by a semi-circular glass box orientated due south. Within the space, the rooms are defined by a massive serpentine wall - the 'thermal snake'. If the glass box is a solar energy 'generator' then the ground floor slab and the thermal snake are its 'batteries', storing and releasing heat throughout the day.

The kindergarten (3-6 years) is on the ground floor, with day care (6-12 years) on the first floor. The radial planning arrangement not only tracks the sun's path, but also reinforces the social structure of a school with the communal hall as its focus.

Architectural concept

The daycare centre is conceived as a brightly illuminated, climate-controlled glass envelope with a variety of activities occurring in a loosely structured space. Small, intimate places are set within larger, more open and active places. The entire roof over the main spaces would be translucent (of *Kapilux*, which gives a shimmering, diffused light).

The clear glazing of the classroom roofs interrupts the main roof. Here, daylight is modulated by operable external louvres combined with smaller, internal louvres set perpendicular to those above, giving a clear light without glare. The small enclosed group spaces, darker than their surroundings, are intended for smaller, more intimate and sedentary activities. On the ground floor, these rooms may be darkened completely for daytime naps.

The internal space is designed to be shaped and adapted by the occupants themselves to suit changing requirements. The small group spaces incorporate devices for opening and shutting or lightening and darkening the rooms to make ever-changing special places for the children. On the ground floor these rooms are treated as 'hide-away houses' for the younger children. Above they become 'tree-fort look-outs' for older ones, with retractable tent roofs and shutters. Sliding panels and acoustic screens allow the classrooms to be transformed by the teachers and students into appropriate environments.

Low entropy concept

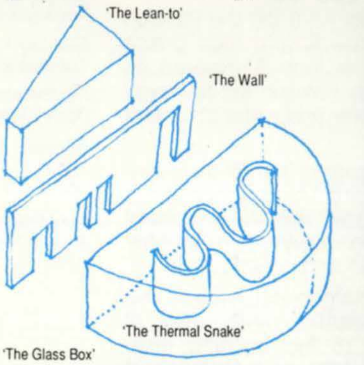
The brief required the design to keep the surface area of the building low, minimize the volume of low energy consumption building materials and heating energy and maintenance requirements, and maximize use of passive solar heating and re-usable materials.

To achieve this, the curved, south-facing passive solar glass wall with sun screening and night shutters is also a ventilation pre-heater. When combined with an efficient ventilation system the insulation material content of the walls and ground can be optimized to achieve the 50kWh/m^2 target heating energy. In summer the large group room roofs open to provide natural ventilation to the whole building.

Ventilation air is supplied by a CO_2-controlled variable air volume 0.9m^3/s plant with solar pre-heating from solar panels and the thermal wall, heat recovery coils, and heating coils fed from the CHP plant.

Substantial daylighting through the glass wall and roof should reduce electricity consumption, even on overcast days. The clear glass rectangular roofs incorporate internal screens to control high summer sun-angle direct glare, but maintain useful solar gain. The glass wall incorporates external daylight penetration reflectors just above head height to direct daylight deep into the ground floor rooms. It also incorporates internal glare control louvres split between high and low level so that independent control of daylight and glare can be achieved while maintaining solar gain. The concept allows all rooms in the building to benefit from daylight from any direction.

1▲



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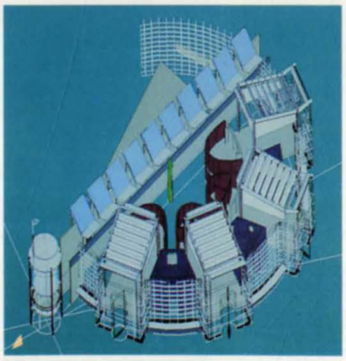


3▼

1. Architects' model:
view from new motorway bypass.

2. The four basic elements.

3. Aerial axonometric.

The artificial lighting gives a good colour rendering, an adequate level for reading and writing, and a level of glare control that maintains visual comfort. To meet these requirements and also to minimize energy consumption and lamp replacement costs there are discharge lamps throughout the building. To minimize energy usage, control of artificial lighting is achieved by central manual and time controlled switching. During school hours local switches are provided to all areas.

Excavation has been kept to a minimum to save energy and to prevent entering the high water table. Excavated earth is re-used against the north wall of the building to reduce heat energy consumption.

As natural gas is not available, an oil-fired combined heat and power (CHP) plant is installed, sized on the maximum heating demand of 70kW. The electrical power would feed the building and into the supply for the Sossenheim area in parallel as demands change. Heating within each space is a low thermal capacity hot water system with individual room control feed from the CHP plant. Each space incorporates thermal capacity to even out the swings in temperature so that passive solar gains are more useful. Hot water is solar pre-heated from the solar panels and is further heated in heat exchangers fed from the CHP plant.

The footprint area of the building has been kept small to allow rainwater to enter the ground naturally; hard landscape surfaces drain to gravel strips. The roof drainage is collected above ground in gutters and channels to discharge into a collection tank, used for garden irrigation in the summer months. To minimize cold water use, the hand washing taps are spray type, WC suites are low water usage type and urinal cisterns are valved, to operate only when the building is occupied.

A central hot water storage vessel is heated from the solar energy system with instantaneous boost from the CHP plant. Hot water distribution to fittings is by gravity (not pumped) with flow and return pipework. Hot water circulation is automatically shut down during non-use of the building.

Conclusion

Two first prizes were awarded to two Frankfurt practices; Arup Associates' scheme was subsequently selected for the exhibition 'Kindertagesstätte als Niedrigentropie-Haus' held during August and September 1992 at the Galerie und Arkitekturforum AEDES in Berlin.

Credits

Client:
Stadt Frankfurt am Main
Designers:
Arup Associates Architects +
Engineers + Quantity Surveyors

Usine Thomson CSF

Architect:
Renzo Piano Building Workshop

Richard Hough
John Hewitt

Layout

The 1989 brief for a new factory for the French electronics manufacturer Thomson CSF, at Guyancourt, 15km south-west of Paris, called for generous open spaces, a clear approach to circulation, and allowance for future expansion. As architect, Renzo Piano proposed using *'le shed'*, in parallel rows, oriented to allow northlights (Fig.1). The varying lengths of the sheds met initial layout requirements, while inviting future expansion towards the car parks. On the east edge, the sheds nestle against the curved *'mur technique'* which contains the main plantrooms, while on the west edge courtyards and gardens finger in and out amongst the sheds.

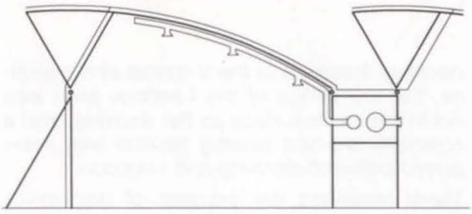
1.

Between the 14.4m wide production spaces, secondary 3.6m zones provide for circulation of people and materials at ground level, and of services at high level. Air-handling units occur on the flat roofs, and some services reach across the production space following the soffit of the curved roof (Fig.2). Craneage takes many forms, often free-standing, but sometimes on travelling bridges which span between the rectangular frames, thereby allowing the curved shed roofs to function simply as lightweight enclosures. Generous amounts of natural daylight are reflected off the curved roof cladding and through the tall inclined glazing, but with the external cladding overhang available to control direct sunlight.

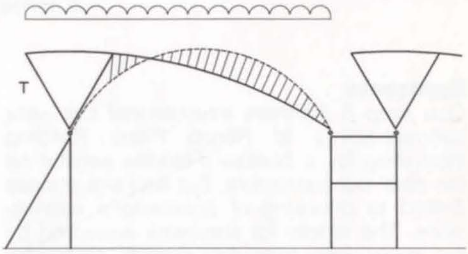
Structure

Factories depend for their proper functioning on such considerations of orientation and layout, circulation and servicing, 'climatization' and lighting. Structure often plays a very minor role. It is typical of Renzo Piano's architecture that the structure exists in support of these other requirements, yet still enjoys a life of its own.

The intention here was to use the efficiency of an arch roof, shaped to incorporate the daylighting and shading. Tensions in the front tubes T (Fig.3) close the arches and fix the leading edge of the sunshade cladding. The bending that results in the curved tube is proportional to the structure's offset from the dotted thrust line, and is much less than in a simply supported beam over the same span.



2. Section through end bay.



3. Roof arch section.

The arch thrusts are balanced, more or less, bay to bay, along the full 17-bay (300m) length of the building, and are finally received by external propping at the end walls (Fig.4). Since each bay absorbs its own thermal movements by a small flexure of the arch, there was no need to consider expansion joints, despite the building's length. Out-of-balance arch thrusts can arise from wind drag, or variable wind suction, snow load or suspended loads, and these are taken by rigid frame action in the rectangular portals straddling each circulation zone (Fig.3). The choice to 'twin' the arch members in a V-configuration led to the more interesting pyramids of tubes at the front edge, as well as shorter spans for the glazing and sunshade cladding systems surrounding the pyramids.

Structure at low level also appears externally, to frame the walls and to identify bay widths and interior floor levels.

In order to expose the structure in this way, the cladding passes from outside of structure to inside of structure at various locations, requiring consideration of (amongst other others) differential thermal movements. The V-arch configuration helped in this respect by allowing the (external) pyramids to be separately and individually stabilized by internal structure, so avoiding long lengths of longitudinal stabilizing members at different temperatures.

Fire walls divide the interior space into compartments. North-south walls and partitions fit between the two legs of a V-arch. Gable walls fit similarly, allowing a roof overhang for shading of the gable glazing. Both there and for shading the northlight glazing, it is only the external skin of the double skin cladding that extends out beyond the insulated body of the sheds. The internal sheeting spans 7.2m between arches (Fig.5). The external sheeting is then fixed to longitudinal purlins that occur between sheets.

4. Left: Props at end bay.
5. Right: Placing the inner cladding deck.

6. Installation of ties.

Contracts

Ove Arup & Partners International Ltd were subcontractors to Renzo Piano Building Workshop for a bureau d'études service on the steel superstructure, but with site phases limited to checking of contractor's submissions. The tender for steelwork accepted by the client was from the French contractor Durand, who was also chosen for the main cladding package. This had the substantial advantage of simplifying matters at the structure/cladding interface, although it involved accepting one or two of their non-conforming proposals on the structure. In particular, they proposed lightening the already light arch members by underslinging ties in the fashion of a shallow kingpost truss (Fig.6), and changing the arch members from tubes to I-sections. Both of these changes could be accepted within the wider parameters that had been set for the structure, and the client decided to accept them as part of Durand's offer.

Their more detailed proposals included an even closer integration of structure and cladding: for example the sub-purlins between the two layers of metal decking on the curved roof surface were to be fixed through the lower deck and into the arch member, to serve as points of stability for the arch, thereby minimizing the number of explicit longitudinal ties visible beneath the decking. Because of the V-format of the arches, the top flange of the I-section arch was not in the same surface as the decking, and a specially pressed closing section was interposed between decking and I-section.

There remained the process of discussing and agreeing modified joint details with architect, contractor and bureau de contrôle, and soliciting and checking calculations. The Parisian bureau d'études dealing with substructure and services, GEC Ingénierie, took responsibility for supervising workmanship during fabrication and erection. The building won an architectural award from *Le Moniteur* in 1991.

Credits

Client:
Thomson CSF
Architect:
Renzo Piano Building Workshop
Bureau d'études superstructure:
Ove Arup & Partners International Ltd.
Bureau d'études substructure et fluides:
GEC Ingénierie
Bureau de contrôle:
CEP
Entreprise charpente métallique:
Durand
Photos:
Ove Arup & Partners

7. Gable end.

Usine l'Oréal

Architect:
Valode et Pistre et Associés

Richard Hough
Mike Banfi

Introduction

Following an architectural competition in 1987, Paris architects Denis Valode and Jean Pistre were commissioned for the new production and administration headquarters building for French cosmetics manufacturer l'Oréal, at Aulnay-sous-Bois in north-eastern Paris. The image they used in their proposal was of the three white petals of a flower (Fig.1); each petal draped over one of the three *unités de production*.

OAP International Ltd. were included in the *groupement maître d'oeuvre* as *bureau d'études* for steel superstructure, and also acted as subcontractors to Valode et Pistre for technical services on the petal cladding system.

Geometry

The white petals were to be achieved by an external open-jointed panel system, supported by an external purlin grid above the waterproofing membrane, and oversailing the body of the building below. Decisions on the panel geometry were needed first because they affected the layout of the buildings beneath. The panel surface was to be a surface of revolution, generated by two opposed circular arcs joined at a common tangent, with a vertical axis of revolution at the centre of the courtyard garden.

Doubly curved surfaces are most easily understood at sections and edges. Thus the choice to cut the surface on straight lines at its junction with the lower, perimeter, *boîte* structures revealed its reverse curvature, as did cutting it at the radial corner corridors, and the gable ends. The jointing pattern for the panels (Fig.2) was chosen because it had a high degree of symmetry, hence repetition of panels, and contained within it the lines needed to accommodate the parallel-sided corner corridors.

Space frame : Analysis

With panel geometry determined, the walls and space frame layout could be fixed. The production processes made a clear-span structure desirable. The length of radial spans near the gable walls (over 60m) made two-way spanning desirable, at least for the corner zones. A radial and circumferential grid of V trusses was developed (Fig. 5), suspended between wall posts set inside the glass walls on all four sides.

In choosing members for the space frame, the intention was to accentuate the inverted pyramids (P in Fig. 5), with their four tubular fingers propping the underside of the roof surface. Inclined ties reach down from both radial and circumferential directions to pick up the bottom, apex joint, of these pyramids. The bottom chords of the radial trusses within the space frame also became tie-rods when the wind tunnel test results proved favourable

1. The winning model.

2. Roof panel jointing system.

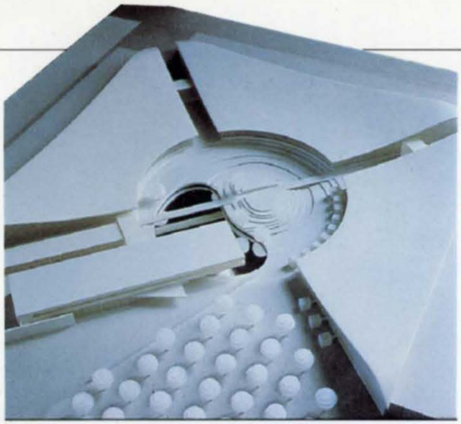
3. Strain gauge testing of prototype joint.

4. Site fabrication of radial truss.

5. Half-model of one roof unit.

6. Mid-span propping during erection.

7. Installation of interior deck and insulation.



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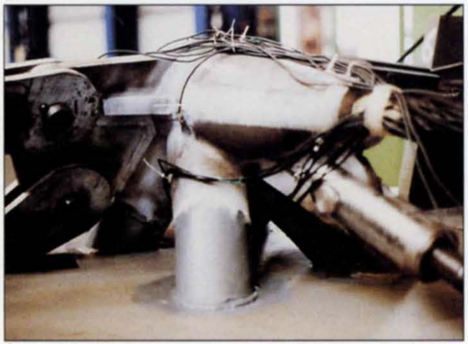


3.

4.

in terms of peak suctions across the roof. The circumferential bottom chords remained as compression-capable tubes, however, because of high local suctions near gable ends, which required the circumferential trusses to receive some negative bending.

With such a large proportion of tension members, and with frequent local reversals of shear and torsion in the trusses under different loadcases causing tensions to appear and disappear, a non-linear analysis was called for, and this was carried out on the Fablon program.

Wind tunnel

Bristol University's wind tunnel was used to investigate suction patterns across the roof, particularly at the bluff gable edges, and with various orientations of incident wind. Arups were able to relax their initially conservative interpretation of the limited code advice, so that by the time of final negotiations with steelwork contractors, a steelwork tonnage saving was tabled that covered the cost of the wind tunnel test and re-analyses of the space frame, plus a small net saving for the client.

Space frame: Design

In Arups' pre-tender role, they specified all member sizes and drew indicative joint details to secure their appearance. The successful tenderer, SMB of Bretagne, was responsible for joint calculation, plus checks on residual erection stresses arising from method of erection, movement calculations to pass on to the cladding contractor, and the load take-down to pass on to the foundation contractor. SMB chose to subcontract OAPIL for the non-linear analyses involved in those studies. Arups' post-tender role under the client contract was to check SMB's submissions and proposals, and check conformity with the specification during fabrication and erection.

6.

The detailed design item of most interest was the large casting at the apex of the pyramids. In discussions with the architect, the number of variants was reduced by permitting the welding on of gusset plates to receive the inclined tension members. The casting method proposed by SMB left rather less bridging metal inside the joint than expected. To verify structural adequacy, it was agreed that strain gauge testing would be a more effective route than finite element analysis, so a 500 tonne rig was fabricated, and prototype castings were fitted with strain gauges at all the predicted points of stress concentration (Fig. 3). The gauge readings settled down to a pattern that implied stress variations under service load well within the yield strength of the steel. In addition, the castings had suffered no gross deformity at twice maximum service load. It was considered that reasonable criteria for fatigue and for ultimate strength had been met.

Space frame: Construction

Of the various proposals tabled at tender, the final choice of construction method was to fabricate entirely on site, using a 70m long jig for the radial trusses (Fig. 4). Because of the need for accurate alignment, the castings with their threaded tie-rods were installed first, followed by welding of the pyramid tubes and top tubes. For the inclined ties, SMB chose to combine a threaded tensioner with the pin detail.

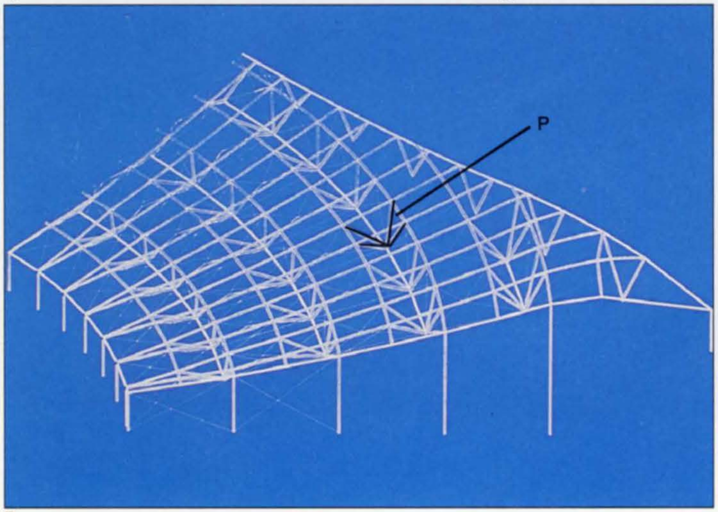
For erection, SMB's proposal was to prop the radial trusses at just one, midspan, location, before inserting the circumferential members and de-propping (Fig. 6).

Analysis showed that this proposal left a residual self-weight stress pattern in the space frame, but not sufficient to require a change to any member.

Panel construction

Panel types investigated before tender included powder-coated, aluminium-faced honeycomb, aluminium plate, grc, grp, and enamelled iron. A detailed performance specification was prepared, aimed mainly at aluminium panels. The successful tender was from SMAC Acieroid, using *Alucobond* with stiffening ribs.

The roofing build-up started with internal acoustically perforated metal deck, spanning up to 5m between the top chords of the radial trusses in the space frame. To receive the



5.

7.

8. Interior from viewing gallery.

deck, the tubular top chord was fitted with a T-section on top. Steel stools stood up from the top chords, at node points of the space frame, ready to receive the external purlin system. Insulation, vapour barrier and bituminous waterproofing membranes were then fitted around the stools, up to the waterproof cap. The external, galvanized purlin system was then mounted on the stools, with frequent expansion joints in both directions to release any build-up of differential thermal strain between internal and external steelwork.

Panels were fixed to the external purlins by a stainless steel fixing which clamped to the top flange of the purlin, allowed three-directional tolerance in position, and allowed the release of differential thermal strain between panel and purlin system beneath. With so many functions to fulfil, the fixing became the subject of a lengthy design development and testing process. Apart from its geometric capabilities it also had to take a point load downward and a wind suction upward.

Choosing a viable setting-out and tolerance control system for the panels also involved some discussion, as the ongoing loading of the space frame, due to erection of the underslung catwalks, temperature effects, and application of the panels themselves, all led to small horizontal and vertical movements of the roof at any location. Combining the cladding and structure contract packages might have made co-ordination easier. Equally of course it might have hidden from the *maître d'oeuvre* the nature of the careful co-ordination that was in fact needed.

9. Inside the courtyard.

10. Roof nearing completion (panels at cleaning cradle tracks yet to be installed).

11. Administration building on ornamental lake.

Other structures

The *boîtes* that flank the *unités de production* are long sheds containing plantrooms and process rooms that serve the activities in the unités. Ducted and piped services run from the former to the latter via floor-mounted frames. This way the space frame and clerestory glazing are kept clear of services: only the circumferential viewing walkway is suspended from the roof.

For structure, the *boîtes* use a portal frame with trussed horizontal beams and trussed longitudinal beams, of the same depth as purlins. The space frame roof bears on the portal columns via the V columns in the clerestory glazing zone. Stability for the space frame is provided some distance away by braced bays in the radial walls, near the garden. The V columns thus experience small rotations due to thermal and wind effects, and so applying horizontal forces to the top of the portals.

An access bridge for cleaning and maintaining the petal roofs travels on two circumferential rails set into the panel layer. A substantial structure in its own right, it is housed off the roofs, over one of the radial corner corridors.

Contracts

OAPIL engaged Thorne Wheatley Associés to help with pre-contract budget control, and an engineer from SETEC to assist with some of the site meetings. Apart from regular site attendance at Aulnay-sous-Bois, OAPIL made visits to Bretagne for steelwork fabrication, St.Dizier for the castings, and Cholet for the cladding panels. The *bureau de contrôle* mission primarily addressed safety and security. The client engaged a *pilote* to help with site co-ordination and programming, but relied on the *maître d'oeuvre* team to manage the completion of the design in the post-contract phase, rather than on separate paid management of the project/construction management kinds. The client also had key figures who stayed close to the project and to the individual contracts. It was very much a case of a carefully tailored product for an owner/occupier/user client.

Credits:
Client:
L'Orèal
Architect:
Valode et Pistre et Associés
BET superstructure:
Ove Arup & Partners International Ltd.
BET Substructure, fluides:
SETEC Bâtiment
Bureau de contrôle:
Socotec
Entreprise charpente métallique:
Société Métallurgique de Bretagne
Entreprise panneaux petales:
SMAC-Acieroid

Photos:
1: The architect
3, 4, 6-11: Ove Arup & Partners

'Il Grande Bigo' Genoa

Architect: Renzo Piano

Peter Rice Alistair Lenczner

Genoa, Italy's most important port since medieval times, was the birthplace of Christopher Columbus. Although his voyage of discovery in 1492 was made from Spain, the Genoese still consider him as one of their own. Thus, whilst the Spanish decided to mark the 500th anniversary of Columbus's discovery of America with Expo '92 at Seville, the Genoese themselves chose to celebrate it with a slightly more modest exposition dedicated to the sea.

The architect Renzo Piano, himself Genoese, was chosen to design the various exposition buildings in the heart of the old port, the project being seen as an opportunity to revitalize parts of the harbour front area which had fallen into a state of decay over recent years. Piano's scheme involved the renovation of some of the old warehouse buildings and included a brand new aquarium (the world's second largest). However, as a thematic centrepiece, he wanted to build a large permanent structure emulating a ship crane, which would support both a fabric membrane roof over a public piazza and an elevator ride to provide panoramic views of the city. The old Genoese word for a ship crane, *bigo*, was adopted for the structure, for which Ove Arup & Partners were invited to be the collaborating design engineers.

The final design solution for the Bigo was arrived at after studying various alternative proposals. Essentially it consists of two independent sets of cable-linked, cigar-shaped booms fanning out from a small 'island' podium located in the dock water itself. One set of booms supports the tent roof over a harbour pier, covering the piazza, whilst the other set carries a vertical cable-car passenger lift from the quayside. Both sets are anchored down to foundations beneath the harbour water.

The tapering cigar-like form of the boom is achieved by a series of rolled conic sections with incrementally increased slopes. The largest boom, which supports the cable-car lift, is over 70m long.

The tent roof is supported from four tubular section arches which are in turn suspended from the tips of a pair of booms via sets of cables fanning from a special node detail.

The lower boundaries of the tent are tensioned against a series of inclined props around its perimeter. Particular attention was given to the design of the connection between the tent membrane (a PTFE-coated glassfibre material) and the boundary cable, as this would be readily visible from ground level.

Skylight strips are created between adjacent tent membrane areas attached below and on each side of the arches. These openings are covered by a series of glass barrel-vault forms supported from spine-tubes fixed between the tent suspension points. A carefully designed 'pantograph' mechanism incorporated into the suspension points ensures that each glass vault's inclination is automatically adjusted to fit the geometry of the tent surface each side as it moves under changing wind or snow loads.

Because of the unusual form of the tent structure and its location in the old harbour of Genoa, design wind pressures and distributions were derived after detailed analysis of the statistical wind data for the area and a wind tunnel test at the University of Bristol. Combinations of wind with hypothetical snow-loadings were also considered.

The cable-car elevator, as far as its designers were aware, was the first outdoor vertical passenger lift that had been designed to be supported laterally on only two cables; its unusual nature caused difficulties in finding a suitable manufacturer prepared to build it (it wasn't clear whether a car-cable or a lift specialist should be used). The motor room for the vertical support cables is located underground in the quayside, which also contains counterweighted balance beams to ensure constant tension in the lateral support cables. The lift-car itself rotates about a vertical axis on its 'cotton-reel' support chassis which is itself guided on the pair of lateral support cables. The rocking cradle support frame suspended from the end of the largest boom ensures equal tensions in the lateral support cables.

Alongside the harbour-quay wall, next to the Bigo itself and mounted on 15m masts, are a series of nine wind-mobiles designed by the Japanese sculptor, Shinju, with Arups acting as engineers. The sculptures spin about horizontal and vertical axes in the wind to create an animated visual effect.

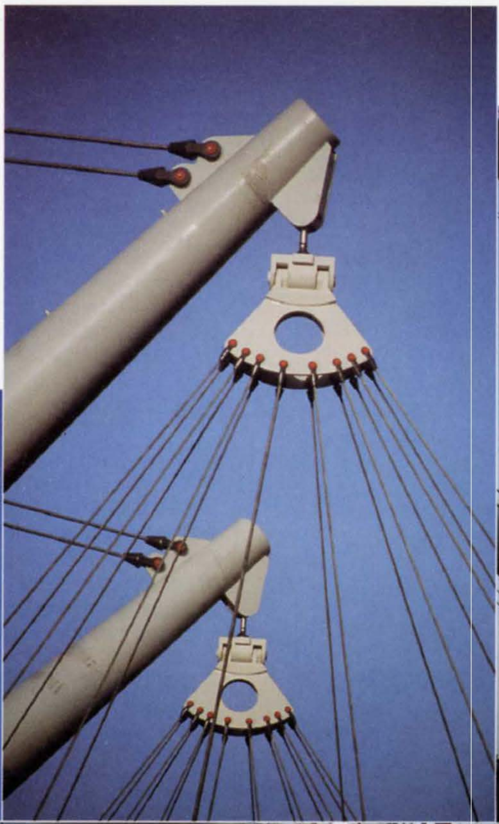
The Bigo structure has already become a well-known landmark within the city of Genoa since the opening of its 'Colombo 500' exposition on 15 May 1992.

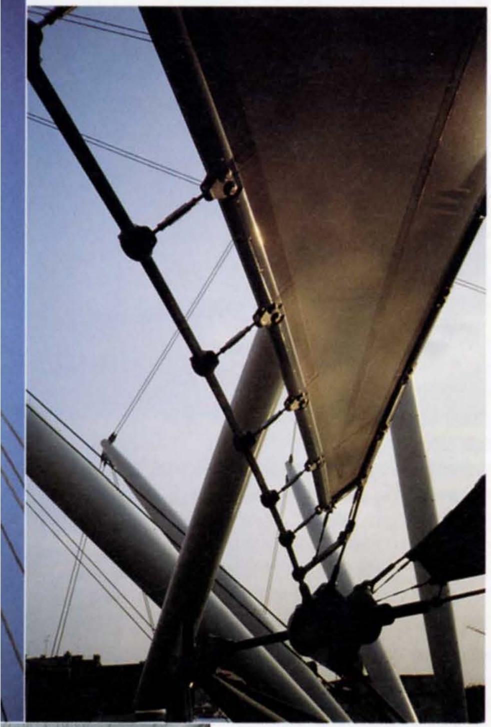
Credits
End client:
Ente Colombo '92
Project developer:
Iritecna
Architect:
Renzo Piano Building Workshop (Genoa)
Structural engineers:
Ove Arup & Partners International Ltd.
Peter Rice, Alistair Lenczner, David Kufferman, Sarah Meldrum, Sophie Le Bourva, Brian Forster, Edward Forwood, Darren Sri-Tharan
assisted in Italy by Sidercad SA
Steelwork:
CMF Sud
Tent roof:
Canobbio
Photos:
1, 4-7: Alistair Lenczner
2-3: C. Spandonari

1. Left: View of Bigo from landside with mast-mounted wind mobiles in foreground. Rotating cable car lift is seen during ascent.

2. Below: Close-up of top of largest boom which supports the cable car via a rocking cradle frame.

3. Left: Close-up of tops of boom supporting tent roof arches, showing fan cluster nodes suspended via single rod links.





4. Above: Tent edge detail.

5. Right: View looking down from cable car lift towards Bigo island podium and tent roof.

6. Below: General view from waterside showing tent over pier in front of Bigo with cable car behind.

7. Right: Interior view of tent edge detail at cusp points, showing pantograph device and glazed covers.

From intelligent buildings to intelligent planning

Tom Barker, Andy Sedgwick, Raymond Yau

Introduction

Buildings need heating and/or cooling dependent on the local external climatic conditions and functional requirements. If the site demands a deep-plan building or if high internal heat gains require close environmental control, then air-conditioning is usually required.

Automatic management and control of the complex heating, ventilation and air-conditioning plant are essential to make the system work. In addition, an 'intelligent' building automation system can also supervise automatically security surveillance, fire protection, telecommunications, office automation and lighting. An example of this type of intelligent building is the new Lloyd's of London (right), completed in 1986.

However, with the increased concern for lower energy consumption by buildings and protection of the environment by reducing their emission of ozone-depleting CFCs and greenhouse gases like CO_2, there is a growing emphasis on the use of technology to design more environmentally-efficient buildings.

These demands, or change of design attitudes, are resulting in new initiatives such as the prototype Green Building in the heart of the City of London, the Munich Airport Centre, and the new Centre of Contemporary Art in Luxembourg. The new design approach is to use powerful analytical tools during the design stage to provide less technology in the completed building, not more. Or, put differently, the future of building services engineering may lie in the concentration of complex, advanced technology in the *design* process, not the final building.

The resulting built forms will increasingly use passive solutions.

1.

Computational fluid dynamics

Computational fluid dynamics (CFD) is the representation of the fundamental conservation equations for momentum, energy and mass in mathematical form and the solution to predict fluid flow and convective heat transfer.

Applied to buildings, the method can predict detailed air velocity, temperature and contaminant distribution fields. The equations are based on the fundamental laws of physics and are represented in partial differential equations.

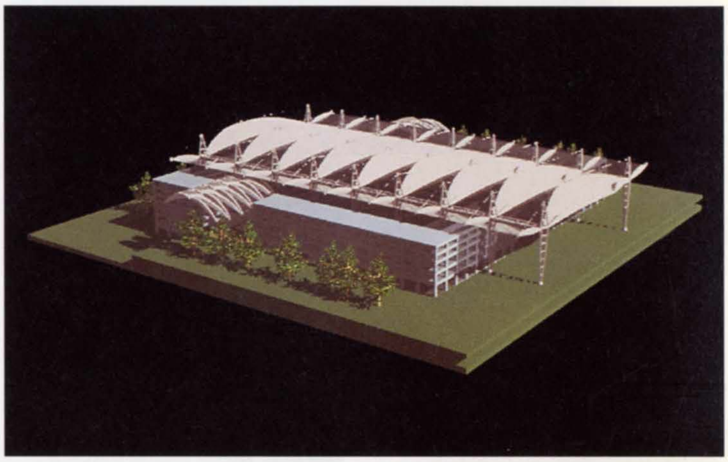
The momentum and energy equations are known as convection-diffusion equations since they describe how the velocity (in component form) and enthalpy (usually as temperature) are convected with the flow and diffused throughout the flow domain. To these, equations or relationships which define the magnitude of the diffusion characteristic in turbulent flow (a turbulence model) must be added. This involves solving additional convection-diffusion equations for the kinetic energy of turbulent fluctuations and its dissipation rate. A model of this type predicts the diffusion coefficient as a field variable rather than as a constant.

In order to solve the differential equations they must be represented in numerical form.

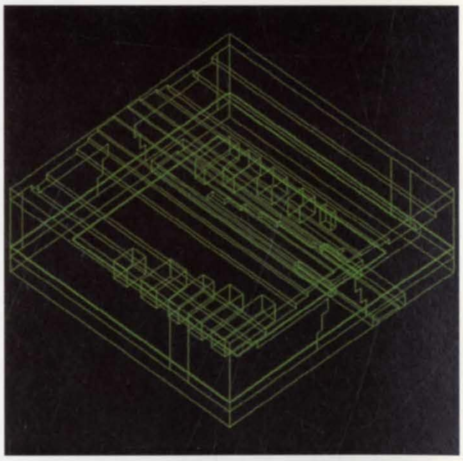
The most common method used is called 'finite volume' which is a form of the finite difference approach. The strong non-linearities demand that an iterative method be used, where an initial estimate of the solution is assumed at the start of the calculation which is improved upon at each iteration. At solid boundaries, such as walls, wall function expressions are used to predict shear stress and convective transfer coefficient.

Munich Airport Centre

The proposal for Munich Airport Centre, designed by Murphy/Jahn Architects Inc., USA, is an example of architecture engineered to avoid installing equipment. The Centre comprises a number of narrow-plan low-rise buildings arranged to form an internal rectangular plaza which is to be covered by a large vaulted lightweight roof several stories high, producing a vast enclosed volume. It provides access both to the lower levels of the complex, which includes a railway interchange, and to the surrounding buildings, to house office, conference and exhibition facilities. The offices are conventional (although they comply with strict German energy conservation standards). The concourse, however, might have been treated like the public areas of most shopping malls as a big, artificially heated, cooled and lighted volume, but the design team carefully considered the users. Most will be dressed for the weather, and occupancy periods will be short. These conditions suggested that the concourse could be covered to keep out rain, snow and wind, but left open to the air. On the other hand, if enclosing the space proved expensive, office rents would have to be high. However, by enclosing but not air-conditioning the plaza, it became more competitive.



2. Computer-generated image for Munich Airport Centre.



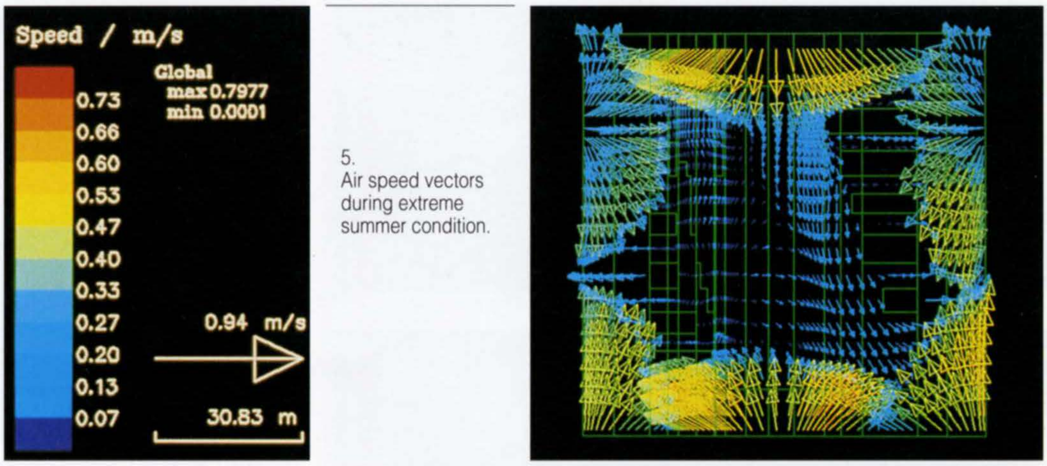
3. Computational mesh for CFD.

4. Daylight penetration into interior of office, generated by the RADIANCE light visualization program.

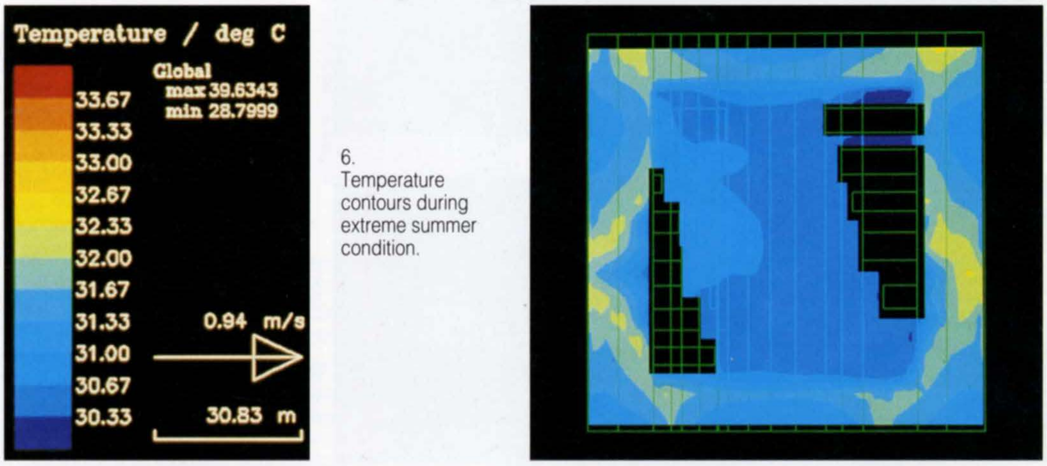
An analysis based on computational fluid dynamics (CFD) and dynamic thermal models was performed to determine the distribution of temperatures and air movement patterns and account for buoyancy effects generated by the height of the space and temperature differences between the plaza space and external ambient. The analysis also took into account the throw-away cooling from the air-conditioned buildings around the perimeter and the cooled kiosks at concourse level; the pulses of relatively cool air brought in by the trains would improve further the conditions. Overall, the air temperature inside is marginally less than the external air temperature, but the dry resultant temperature, which is the correct measure of comfort, is up to 8°C cooler. The same factors would operate in winter but in reverse. Heat losses from the surrounding buildings and the kiosks, along with the relatively warm air introduced by the trains, help to elevate the plaza dry resultant temperature to 5°C above ambient under overcast conditions. In sunny weather, the temperature would increase by a further 2°C: quite an accomplishment for a room made up mostly of open walls.

CFD models proved useful in examining other environmental aspects of the space. Since the plaza is not to be entirely enclosed, CFD models were used to assess the effects of wind at different heights above the concourse, and with various wind breaks in place near openings. For a normal wind speed of 3m/sec, the air velocities in the occupied zone vary between 0.25m/sec and 0.9m/sec, indicating an attenuation of 70% to 92%.

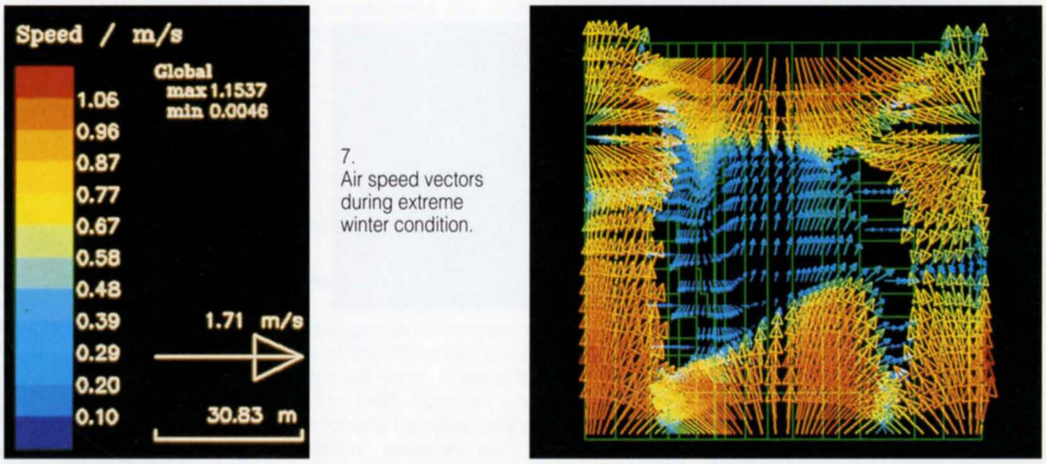
Detailed lighting analyses were also performed to examine the lighting level within the space as a result of having solar control on the roof.



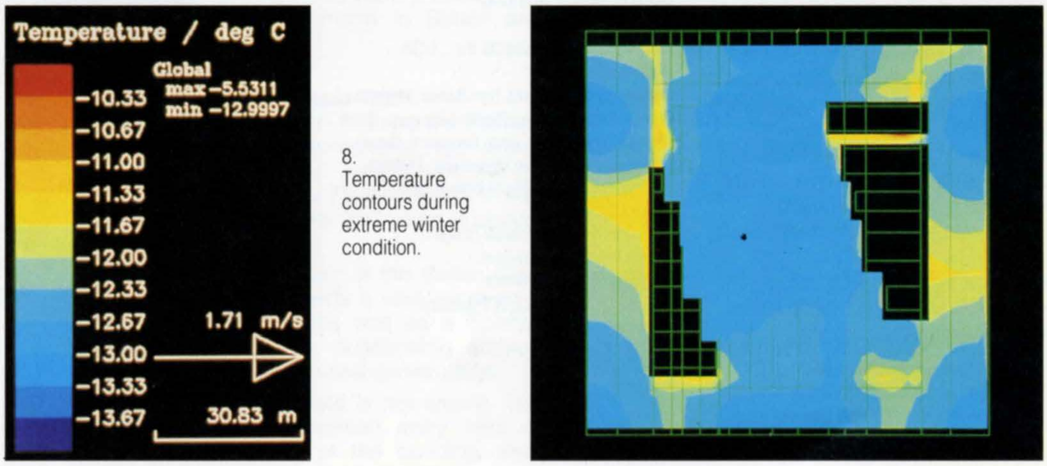
5.
Air speed vectors during extreme summer condition.



6.
Temperature contours during extreme summer condition.

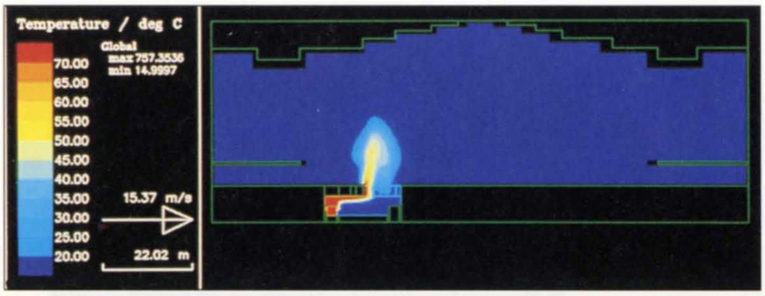


7.
Air speed vectors during extreme winter condition.

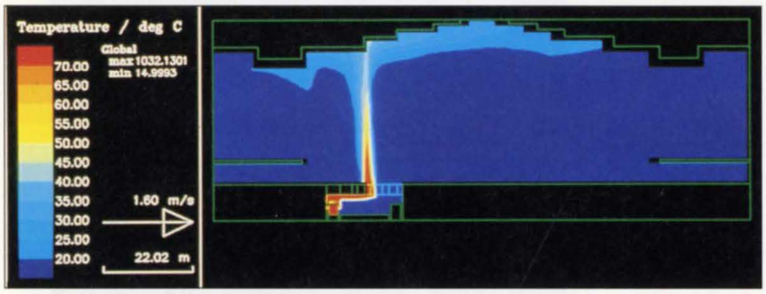


8.
Temperature contours during extreme winter condition.

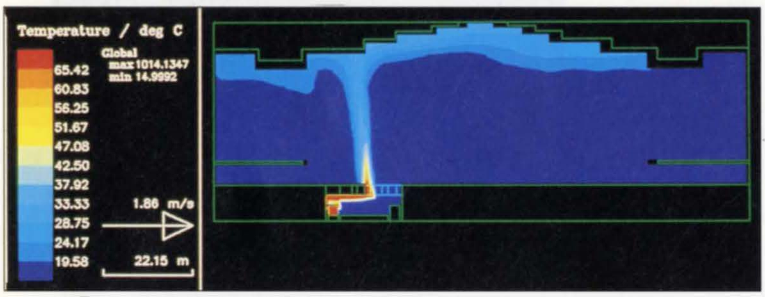
9-12. Munich Airport Centre: Fire study



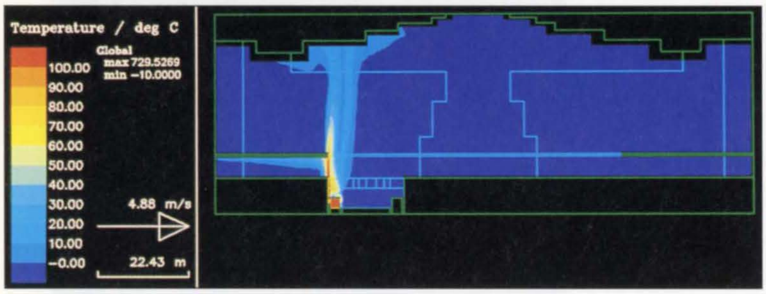
9. Temperature contours 30 seconds after fire starts.



10. Temperature contours 80 seconds after fire starts.



11. Temperature contours 150 seconds after fire starts.



12. Temperature contours 60 seconds after fire starts (external wind effect on fire is included).

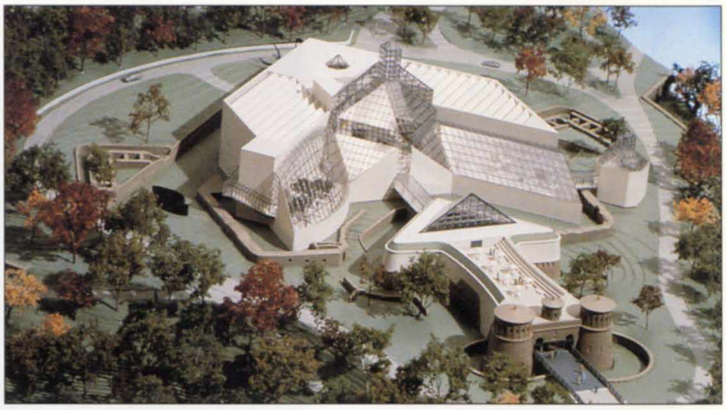
Fire is also a concern, even in a semi-enclosed space. To avoid the costs of sprinklers or other extinguishing devices, and in conjunction with fire engineers, several predictable fire scenarios involving fire originating on a train at the platform were performed using CFD. The transient smoke propagation analysis demonstrated to the fire authorities how hot a real fire would be within the space and the likely propagation of the smoke plume in time. The analysis showed that there was ample time for concourse occupants to escape even in a very hot and fast-developing fire.

The developer, Munich Airport Authority, is currently looking for prospective tenants for the Centre and planning permission is being sought.

Credits
Client:
Munich Airport Authority
Architect:
Murphy/Jahn Architects Inc., USA
Engineers:
Ove Arup & Partners Tom Barker, Mahadev Raman, Raymond Yau, Richard Gargaro, Geoff Whittle (mechanical); Andy Sedgwick, Steve Walker (lighting); Greg Hodkinson, Tristram Carfrae, (structural); Paula Beever (fire)
Illustrations:
1. *Photo:* Roger Ridsdill Smith
4. *Visualization software:*
UC Berkeley, California
2, 3, 5-12. Ove Arup & Partners

Centre of Contemporary Art, Luxembourg

13. Architect's model of Luxembourg Art Museum.



The new Centre of Contemporary Art in Luxembourg, designed by the American Architects Pei Cobb Freed & Partners, is planned to include a large south-west facing glazed enclosure. This enclosure forms three major spaces:

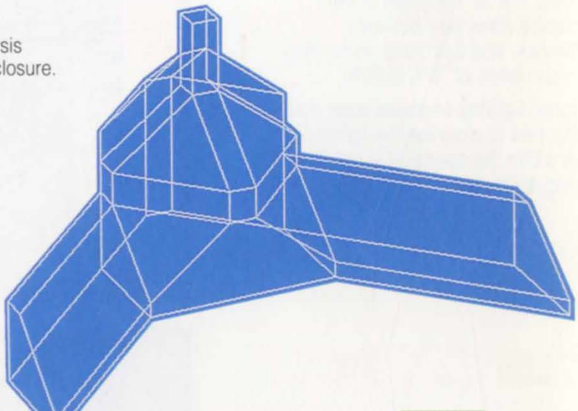
(1) Central Hall - used for orientation and museum entrance, also occasional parties and receptions
(2) Winter Gardens - containing a tea room and interior planting
(3) Indoor Sculpture Court.

Several ventilation strategies including none, natural, mechanical, and a hybrid system were examined using CFD and thermal modelling techniques, and a detailed thermal comfort analysis was performed with the assistance of Dr. David Wyon, a thermal comfort expert with the Swedish Building Research Institute. Wider parameters affecting occupant comfort were studied - it has been shown, for instance, that a wider range of conditions will be accepted if building occupants have some choice over their environment. This choice may be provided by openable windows and other simple operable devices or, in transient spaces, by having a number of zones at different temperatures and radiant conditions.

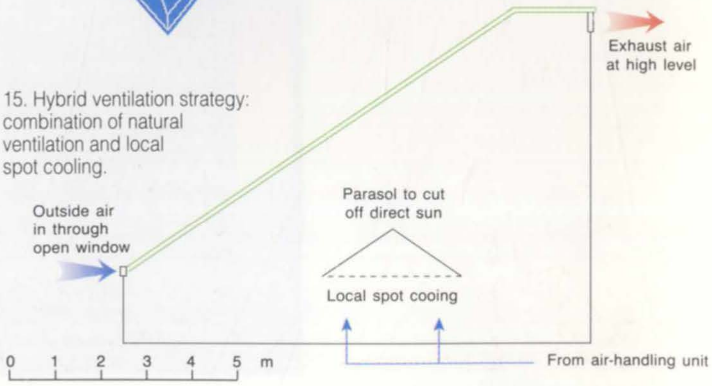
Also, if people are in direct contact with the external environment, then the reason for the prevailing conditions is so much more apparent to them, as a result those conditions are more likely to be accepted.

The analysis showed that even with the presence of mechanical air-conditioning, i.e. a conventional mixed air distribution system or low level displacement system, the dry resultant temperatures at low level inside the spaces were found to be several degrees higher than the dry bulb (air) temperatures which are

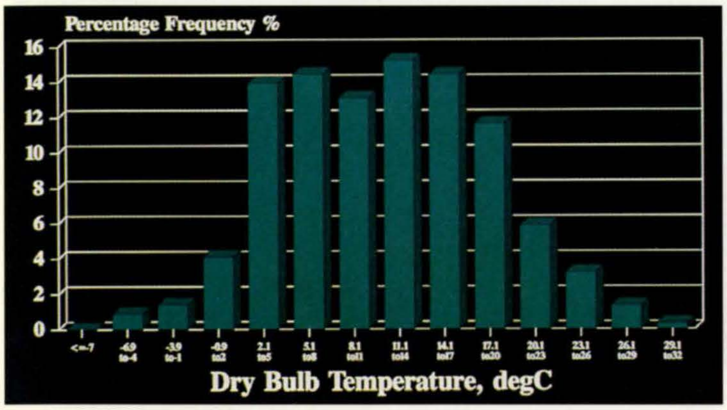
14. Model for thermal analysis of glazed enclosure.



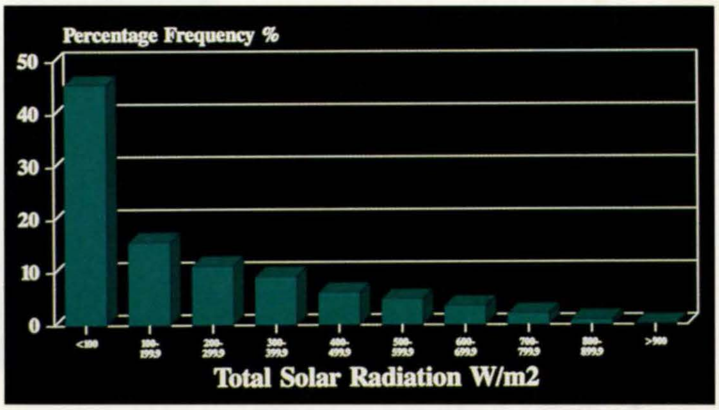
15. Hybrid ventilation strategy: combination of natural ventilation and local spot cooling.



16. Percentage frequency distribution of outdoor dry bulb temperature in a year.



17. Percentage frequency distribution of hourly values of outdoor radiation.



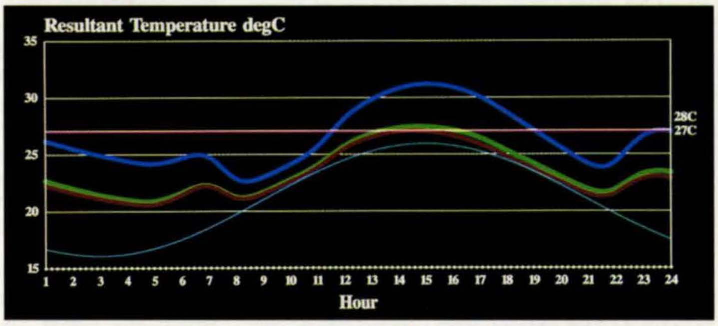
maintained at 21-22°C. A reasonable level of complaints could be anticipated.

The results from the natural ventilation strategy showed that by simply opening the windows at low level, the dry resultant temperature is significantly reduced by 10°C from 48°C (sealed box) to 38°C, compared to a reduction of 16°C achieved by a conventional mechanical ventilation system. The temperature difference between a peak temperature of 38°C and a comfort temperature of 28°C is 10°C, which is equivalent to that in the conventional mechanical ventilation system. Therefore, similar levels of complaints are anticipated.

A hybrid system combining natural ventilation and local spot cooling at low level within certain locations inside the space was examined. The locations can be shaded from direct sun by having a parasol on top.

Provision of local spot cooling enables occupants to choose whether to expose themselves to sunshine or shade, while remaining more or less in the same area, or traversing more or less the same space. The peak dry resultant temperatures were found to be around 27°C.

According to Dr. Wyon, opening the windows and having a view outside will change the occupant's level of expectation. This applies to both transitory visitors and staff working there permanently. The former - who will be there only for a short period - have the choice to leave the space.

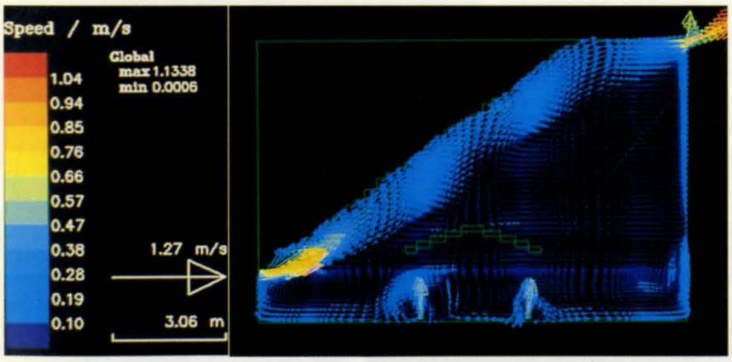


🟦 Low level shade 10%	🟩 Low level shade 50%	🟥 Low level shade 90%	— External Air Temp
— Wyon: Visitors	— Wyon: Employees, stand	— Wyon: Employees, sit	

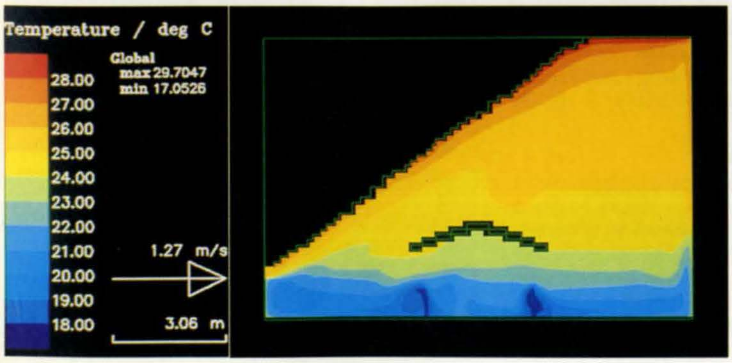
19. Summer simulation (July): low level resultant temperatures.

Those staying for longer, such as staff, have the choice to move out of the sun for a period of time but still accept 27°C and 28°C dry resultant temperatures with only some degree of dissatisfaction. With this system, 20°C air temperature and 27-28°C resultant temperature can be achieved. Occupants will feel comfortable based on a combination of the choice of shade/sun, a view outside, openable windows, local sensation of air movement and local spot cooling.

The Luxembourg Parliament is now considering the future of the Centre.



18. Summer airflow simulation hybrid system: natural ventilation and local spot cooling:
▲(a) air speed
▼(b) temperature



Credits

Client:
Administration des Bâtiments Publics, Ministère des Travaux Publics, Luxembourg

Architect:
Pei Cobb Freed & Partners, USA

Engineers:
Ove Arup & Partners Tom Barker, Raymond Yau (mechanical); Andy Sedgwick (lighting)

Illustrations:
13. *Photo:* Roy Wright, courtesy Pei Cobb Freed & Partners
15. *Illustration:* Jon Shillibeer
14, 16-19. Ove Arup & Partners

Conclusion

Some of the analytical tools now being applied to the design of current buildings are techniques borrowed from other industries such as aerospace, nuclear and telecommunications. Through the process of technology, transfer building designers are able to share design methods with the traditional high technology industries. The early use of these sophisticated tools can lead to a reduced requirement for technological devices in the completed construction.

The new design philosophy can be typified by the following objectives:

- Not using computers for digital control of VAV boxes to ventilate office buildings.
- Use of computers to design building forms for successful natural ventilation of offices.
- Not using computers to switch electric lights on via signals from an infra-red sensor.
- Using computers to optimize the design of building façades to maximize entry of sunlight and sky light.

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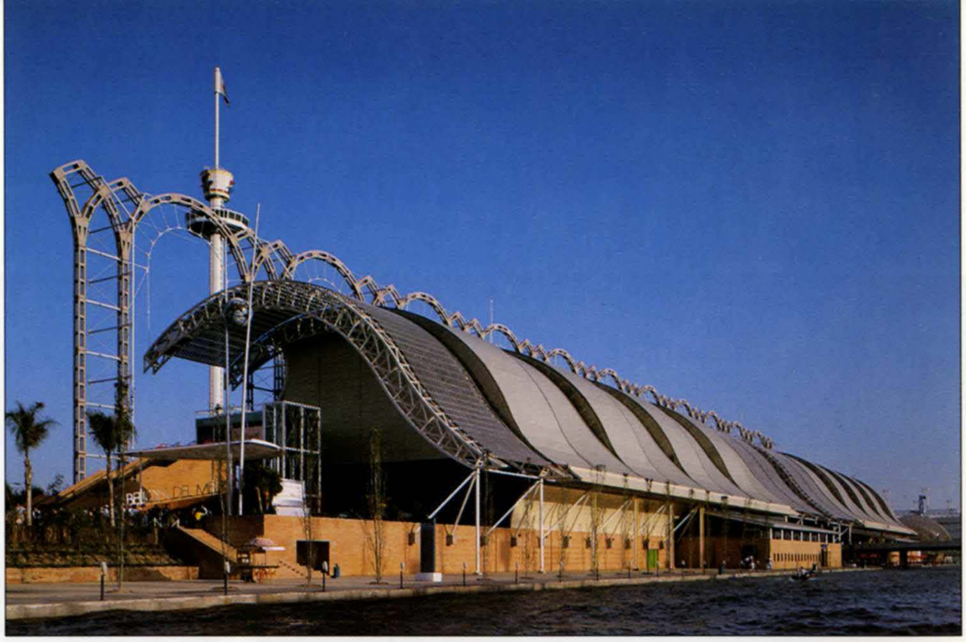
(2) YAU, M.H.R. *and* WHITTLE, G.E. Air flow analysis for large spaces in an airport terminal buildings: CFD and scale model tests. Seminar on CFD for environmental and building services engineers, Institution of Mechanical Engineers, 26 Nov 1991.

Pabellon del Futuro, Expo '92, Seville

Architect:
Martorell, Bohigas, Mackay

Peter Rice
Alistair Lenczner



Introduction

Ever since the Crystal Palace was put up in Hyde Park, London, for the Great Exhibition of 1851, international expositions around the world have been commemorated by innovative structures. The Eiffel Tower, the most famous example, was built for the Centennial Exposition held in Paris in 1889. Ove Arup & Partners were given the opportunity to help further the tradition of innovative engineering of past expos by designing the stone façade structure of the Pabellon del Futuro at Expo '92, Seville.

The decision to hold an expo at Seville goes back to 1976, when King Juan Carlos of Spain suggested that such an event would be a fitting celebration in the year of the fifth centenary of Columbus's discovery of America after having set out from Seville. Expo '92 SA was set up as the state body responsible for organizing the event on the Isla de la Cartuja, a flat piece of land between two branches of the Gualdaquivir River just west of the city itself. In addition to the pavilions representing more than 100 nations from around the world, which made it the largest-ever event of its kind, Expo '92 itself wanted to build a series of thematic pavilions around the general theme of 'discovery'. The job of designing the Pabellon del Futuro was awarded to the Spanish architects Martorell, Bohigas, Mackay (MBM), who invited Arups to collaborate in designing the roof of the building and, more especially, a dramatic façade.

Concept

MBM's basic idea was to create an tall, impressive structure running north-south along the long eastern side of the building, facing onto the adjacent ornamental gardens and beyond to the old city of Seville across the river. The façade would be used to support the wave-form roof over the north and south pavilion halls behind, and also the canopy over the central plaza between them. The continuity of the façade gives unity to the pavilion as well as being a dramatic backscreen to the garden. The architects allowed Arups a virtual free hand to formulate ideas for the façade structure. The original inspiration for the planar façade of the Pabellon del Futuro came from the image of a façade wall of the Ajuda Palace in Lisbon, which has been left freestanding within the unfinished building. It was decided to use stone as the pavilion façade's primary structural material, but in a completely new way to demonstrate how it could be brought into the 'future'. The natural characteristics of stone could, with the benefit of modern analytical, fabrication and construction methods, be exploited to create a minimalized structure distinct from the massive stone edifices of the past.

The use of stone: fabrication and analysis

Over the past few decades, stone within modern buildings has been used primarily for non-structural cladding and decorative purposes. However, expansive surfaces clad in stone still suggest the presence of a massive bulk behind, as was truly the case in the past when stone was used structurally — in great cathedrals for example. Hence the common preconceptions persist of how stone is used structurally. The whittled-down form of the stonework used at the Pabellon del Futuro will therefore surprise many observers.

The demand for precision-cut stone cladding blocks in the modern construction industry has led to the development of fast and accurate cutting machines, capable of producing hundreds of units in a tiny fraction of the time it would previously have taken. This technology, combined with the existence of strong and reliable adhesives, was exploited to create the pavilion façade's open stone units, which are made up of smaller stone subunits, arranged to minimize the volume of stone whilst maintaining the overall geometric dimensions necessary for structural stability.

Although the geometric stability theory of a stone arch is quite simple in principle, in practice the calculations required to demonstrate stability with a satisfactory safety factor are complicated by the fact that stone arch behaviour is non-linear once incipient hinges occur about either the intrados or extrados, the inside (concave) and outside (convex) surfaces of the arch. Thus laborious numerical and/or graphical methods have been used in the past to justify arch stability. However, the availability of Arups' own FABLON program, which allows the analysis of non-linear structural behaviour by dynamic relaxation, made possible a more direct analysis of the behaviour of the stone arch.

The problem of modelling the mechanical behaviour of a joint within an arch which could hinge either about its intrados or extrados (depending on the position of the thrust-line) was solved using sets of 'flip-flaps'. Each flip-flap in the computer model consists of a flattened pair of diagonal elements between a complementary pair of short edge elements, all of which are only able to resist compressive loads. Arch models analyzed in FABLON using this modelling feature for the joints correctly demonstrate the classic collapse mechanisms for unstable stone arches when loaded with a critical load-case. It was thus relatively simple to check a large number of hypothetical loadcases to justify a given design configuration.

General description

The basic form of the façade consists of 11 semi-circular stone arches, each with a centreline radius of 8.66m, spanning between 12 pairs of stone columns spaced at 22.4m centres in a single flat vertical plane. Each pair of columns, 28m tall, is linked by tubular steel horizontal cross-bars at 5m intervals, the first of these being 3m above ground level. These cross-bars are, in turn, connected to a vertical tubular mast set back from the stonework via sets of eight steel tie bars around a transverse tubular prop projecting forward from the mast between the cross-bars. Together with the stone columns, the triangulated steel lattice structure effectively completes a composite tower which behaves as a vertical cantilever from the ground to provide overall horizontal stability to the columns.

On top of the columns a secondary set of 'partial' stone arches spring from the bases of the primary arches to create a kind of capital feature which produces extra dead weight compression in the columns. The three-dimensional steel tie-rod system is extended up from the column into the capital to provide out-of-plane stability to the primary arches which are otherwise self-stable within their own plane.

Suspended within each primary arch is a ring of short steel bars concentric with the stone arch and linked to it by a series of radial tie-rods at 15° intervals. Long hanger ties project vertically down from each side of the ring to pick up the suspended loads of the roof (or canopy) trusses below. The radial configuration of the rods between the steel tension ring and the stone arch assures a near perfect loading to achieve a thrust path with the stone which follows the shape of the arch itself and transmits purely vertical load onto the columns below. Any difference of load between the pair of suspended beams within any arch is carried by one of the out-of-balance ties which pass from the ends of the tie ring to the column towers on each side.

Stone units and jointing

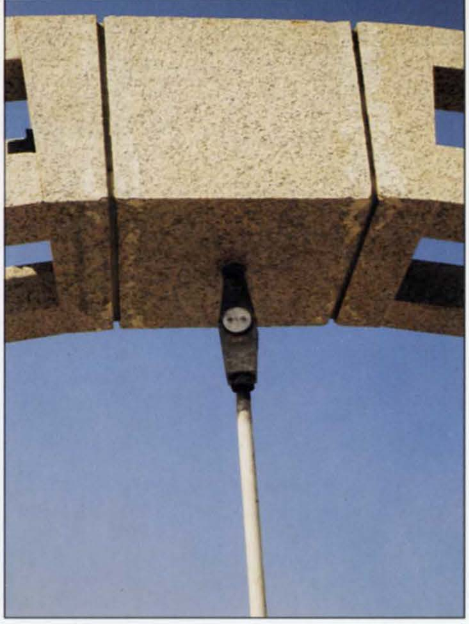
The open format of the 0.8m x 0.8m section stone units, similar for both columns and arches, is achieved by an assembly of alternating sets of four corner posts, each with a section 0.2m x 0.2m, with solid slab units. The units were fabricated by the stonemason Arquiedra at their works near Vigo in northwest Spain using a granite called Rosa Poriña, from a local quarry. This granite was selected for its consistent mechanical properties as well as its natural pink appearance, which was enhanced by flame-texturing the outside faces of the sub-units. The individual subunits were fixed together by a thin layer of epoxy adhesive on their interfaces. The only metal components used in the units are short stainless steel dowels used to help locate the components and provide mechanical shear connection across the glue planes. The completed units were subsequently packed and transported to the Seville site by lorry.

Within the primary and secondary arches, solid block units are used between adjacent open units. The joints between the arch units,

◄1. Completed structure showing roof form.

2. Steel components in tension ring inside arch. ▶

3. Arch stonework detail with radial tie connection. ▶



approximately 30mm wide, were cast in situ using a pourable grout. A de-bonded stainless steel dowel bar passes centrally across the joint to provide a mechanical shear key. The grout joint created will not resist tensile forces, and therefore prevents significant tensile stresses developing within the stone units on either side. The arch's strength is thus primarily dependent on its inherent geometric stability.

The joints between the stone column units differ from the arches. Each 5m unit works effectively as a pin-ended column which cannot transmit shear loads across it (the shear loads are transmitted via the steelwork). The vertical loads pass between stone units via four bridge-type laminated bearing pads (neoprene and steel sandwiches) placed in each corner of the cross section.

The flexibility of these bearings prevents significant shear loads being induced in the stonework due to any small imposed sway deflection to the column tower.

Façade steelwork details

The mechanical connection between the stone columns and the steelwork is made by special steel castings which pass into slots made in the stone units at their joints every 5m. Vertical shears are transmitted by the steel tie-rod system to the stone columns as part of the vertical cantilever truss action. The tie-rods' geometric system point is offset 0.5m from the centreline of the stone column and therefore the cast steel pieces at each end of the cross-bars have to resist the bending moments induced due to this eccentricity.

Because the tie-rods within the steelwork make numerous different spatial angles with the connection nodes, it was convenient to use an end connection which had radial symmetry about the rod axis. The standard threaded sleeve connection design for the project has the additional advantage of automatically adjusting for any small angular imperfection between the axes of the connecting pieces as well as absorbing length tolerances as the sleeve is tightened. The fabrication of this kind of rod-end was found to be significantly cheaper then the more classic pin/fork rod-end alternative.

Another steelwork detail specially developed for the project is the load-setting device for putting small pretension in the sets of tie-bars to alleviate possible de-tensioning from thermal effects. Using pairs of special load calibrated conical 'spring' washers, a threaded turning block on the end of the transverse props was tightened against the end node to a predetermined precompression. This automatically creates known pretensions in the eight ties connected to each prop. Once the washers are squashed hard against their respective components, the total stiffness of the system becomes the same as if the washers were 'solid'.

Roof steelwork

The roof form desired by MBM was a curved wave, descending down towards the canal behind the pavilion. Its structure consists of a series of parallel S-shaped steel trusses equally spaced at 11.2m centres. Successive pairs of trusses span simply from suspension points below individual arches in the stone façade, over the pavilion hall space and down to simple steel tripod supports at the rear of the building. The form of the shear bracing used on the sides of the trusses was inspired by the axle linkage system used in Spain's articulated 'Talgo' trains.

The solid roof cladding over the exhibition spaces is replaced by a slatted sun-shade system above the central plaza and beyond the northern and southern enclosures of the building.

To prevent the possibility of uplift under high wind loads, the support trusses for the canopy have counterweights added at their suspension points from the stone façade.

◄ 4. Close-up of granite column unit with facade tower being erected in background.

5. End detail of transverse prop with load setting device. ▶

Construction sequence

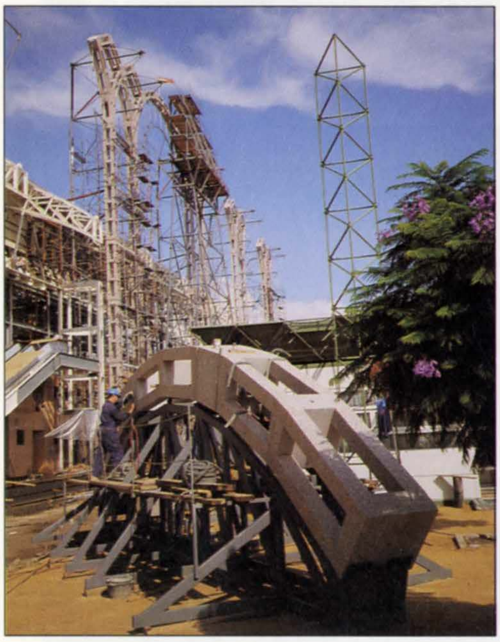
6. A to G

▼ **A.** Ground assembly of 5m tower module incorporating a pair of open stone units and triangulated steel elements.

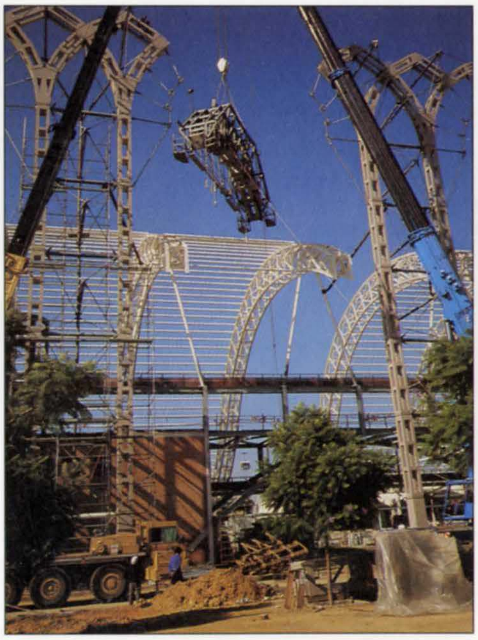
▼ **B.** Lifting of a 5m tower module as other modules are assembled at ground level.

▲ **C.** A tower 'capital' module nearing completion of ground level pre-assembly.

▲ **D.** 'Capital' being lifted into place after being turned to the vertical at ground level.



▲ **E.** Stone arch being pre-assembled on its ground jig.



▲ **F.** Arch being lifted to span between the capitals of two adjacent towers.

▲ **G.** A completed tower and pair of arches ready for load transfer of the temporarily propped roof trusses.

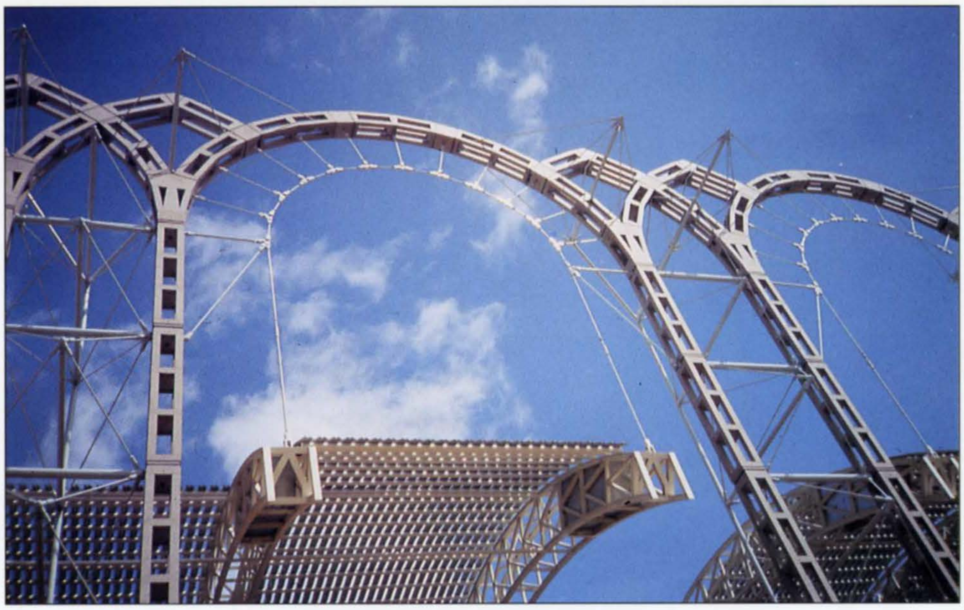
Getting it built

Although the chiefs at Expo '92 were impressed by the proposal for the stone façade, they were initially sceptical about its technical feasibility and whether it could be built. It was only after Arups had made several visits to Seville to explain the design in detail and discuss questions raised by the Expo '92 engineers that the client was finally persuaded to allow the project to go ahead as proposed.

In order to alleviate worries expressed about the apparent fragility of the stone structure, Arups analyzed various severe hypothetical loadcases to prove its robustness. These included accidental breakage of individual stone elements and very large geometric imperfections.

Arups also proposed a construction method for the façade which was sufficiently developed to include detailed descriptions of special lifting jigs with adjustable parts. This showed how it could be built without the use of any temporary support scaffold, with stone and steel elements preassembled together at ground level and then lifted as a complete self-stable unit into its final position. To avoid construction programme problems it was proposed that the roof over the pavilions could be temporarily propped at its façade end, with its weight transferred to the stone façade once it was completed. Arups' proposed method was eventually to be adopted (with some minor modifications) by the contractor, Entrecanales.

Arups' continuous on-site supervision of the construction of the stone façade provided important reassurance to Expo '92, especially when the contractor encountered some difficulties with some of their lifting methods. The stone façade was successfully completed in time for the roof loads to be transferred well before the opening of Expo '92.


▼ 7. Completed arch.

Conclusion

At the inauguration of the Seville Expo on 21 April 1992, the Pabellon del Futuro stood out as one of the most prominent features. The building is destined to be one of only a few of those on site expected to remain after the closure of Expo '92 in October 1992. It is hoped that the façade structure will be a recognizable memento of the event in years to come.

Credits

Client:
Expo '92 SA
Architect:
Martorell, Bohigas, Mackay (MBM)
with Jaume Freixa
Structural engineers:
Ove Arup & Partners International Ltd.
Peter Rice, Alistair Lenczner, Tristram Carfrae,
Bruce Danziger, David Glover, Darren Sri-Tharan
Contractor:
Entrecanales y Tavola SA
Stonemason:
Arquiedra SA
Photos:
1: Reid & Peck. 2, 3, 6G: David Glover.
4, 5, 6A-F, 8: Bruce Danziger. 7: Alistair Lenczner.

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PROJECT NEWS

The **EUROPEAN TRANSONIC WIND TUNNEL** at Cologne is nearing completion, on time and within budget, to provide the European aerospace industry with advanced aerodynamic test facilities. The Industrial Engineering group are part of the industrial Architect team formed by a consortium of companies from the four contributing nations and chaired by Mike Shears of Arups. The Queen visited the ETW on 20 October 1992.

CRANFIELD INSTITUTE OF TECHNOLOGY LIBRARY opened recently. OAP were structural engineers for this £7.5M building, designed by Sir Norman Foster & Partners. Work began in December 1989 and it was handed over in September 1992.

THE STOLICHNY BANK, MOSCOW, a 3000m^2 office building designed by Murray O'Laoire Associates of Limerick, started on site in September. OAP Limerick and London are undertaking the engineering design and completion is expected in October 1993.

On 16 September the £44M contract for the Hall 10 complex at the **NATIONAL EXHIBITION CENTRE,** Birmingham, was topped out. OAP Birmingham provided structural engineering scheme design and performance specifications and monitored design and construction on this 39 000m^2 extension to the existing facilities. Architect: Seymour Harris Partnership.

The refurbishment of **HOLBORN BARS**, the Prudential Assurance headquarters designed by Victorian architect Alfred Waterhouse, was recently completed. OAP were structural and services engineers for the project, one of the largest of its kind in London. Architect: EPR.

The **STEVENS BUILDING, ROYAL COLLEGE OF ART,** was opened on 8 July 1992. OAP were structural and services engineers for the new and refurbished listed buildings on the site. Architect: John Miller & Partners.

Planning permission has been granted for Thames Water's first **SEWAGE SLUDGE INCINERATOR** in East London, and planning committee approval has been given for a second. Neither involved a public enquiry. Arup Economics & Planning managed the production of the Environmental Statements for both proposals, with technical contributions from several Arup groups and external specialists.

PARTNERSHIP NEWS

*The **NEWCASTLE OFFICE**, under the leadership of **MIKE BROWN**, recently celebrated its 25th anniversary.*

*'The Idea of Building', a book by **STEVEN GROÁK**, Technical Development Co-Ordinator for Arup R&D, has been published by E & FN Spon. Commissioned by The Building Centre Trust to mark the 60th anniversary of The Building Centre, it is a wide-ranging analysis of the contemporary context for building design.*

***JO KENNEDY** of OAP Building Engineering was transferred to the class of Fellow of the Institution of Civil Engineers on 9 June 1992. She is the fourth woman Fellow and only the second in the last 20 years. She has also been appointed as a trustee of the Science Museum.*

*Several OAP engineers have received **AWARDS** for technical papers:*

***BARNABY JORDAN** of OAP, London, the AE Wynn Prize of the Institution of Structural Engineers for his performance in the 1992 Part 3 Examination; **STEVEN LUKE** of OAP Cardiff, this year's branch prize by the Institution of Structural Engineers Wales for the best paper within the year; and **FRANC COLES** of OAP Bristol received the annual Stevens Award for the best paper by a non-member of the Institution of Lighting Engineers. **GEOFF PEATTIE** and **SAEED MOJABI,** also of OAP Bristol, were awarded the Frederick Palmer Prize by the Institution of Civil Engineers for their paper 'The Design and Construction of the Basement of the Galleries Shopping Centre, Bristol'.*

*Each year, the Partnership sponsors two of its staff to be Project Managers on Raleigh International expeditions to teach volunteers and supervise construction. This year, **ANDREW KIRBY** went to Sarawak and **TIM MCCAUL** to Zimbabwe.*

***PETER RICE**, one of the great structural engineers of his generation, died on 25 October. During his many years with Arups, he was principal designer for many projects, contributing some of the most original and imaginative concepts in 20th century structural engineering. He had been honoured by the building professions, most recently becoming the 1992 RIBA Royal Gold Medallist in June.*

***DAVID GORDON,** the Director leading the Arup Civil Engineering Infrastructure Group, and Deputy Chairman of Civil Engineering, died suddenly on 22 September. He joined the Partnership in 1973 and was appointed as a Project Director in 1979. In 1980 he joined the Hong Kong office where he was a Director and remained until 1984 when he returned to Ove Arup & Partners London.*

NEW COMMISSIONS

ST. HELIER HOSPITAL, CARSHALTON, ENGLAND

OAP have been appointed as structural and services engineers for a £10M paediatric hospital for St. Helier NHS Trust. Construction is due to begin in spring 1994. Architect: Avanti Architects.

M25 WIDENING

The DoT have appointed the Highways Group in Coventry to design and supervise the widening of 40km of London's M25 between junctions 23 and 28. It will be increased by four lanes in both directions within the existing fencelines. Construction commences in autumn 1994.

SCOTTISH EQUITABLE HQ

The Arup Communications group have been commissioned to prepare, design and implement a communications strategy and system for Scottish Equitable's new headquarters in Edinburgh.

BRIDEWELL, LONDON

Arup Associates have been appointed by Haslemere Estates to prepare scheme design proposals for a new development on a large site at Bridewell in the City of London.

KCRC HQ, HONG KONG

The Kowloon-Canton Railway Corporation are relocating their Corporate Headquarters from Sha Tin to Fo Tan in the New Territories. Arups have been appointed as civil/structural consultants for the 12-storey building to be constructed in the Permanent Way depot, which is also being upgraded. Architect: Ng Chun Man & Associates.

EUROPA HOUSE, FRANKFURT

OAP have been appointed for the multidisciplinary engineering design of this 100 000m^2 commercial development with architects Murphy/Jahn. The design work will be carried out in New York and London and also in Sweden by Skanska Teknik who Arups employ as a subconsultant for the substructure design.

TECHNO CENTRE, VALENCIA

OAP are working with Sir Norman Foster & Partners on a new 7500m^2 Spanish headquarters and warehouse facility in Valencia for Techno SPR - the a high-tech furniture company. The brief calls for a low-energy building and a capacity for tripling the accommodation on site.

IMPERIAL WAR MUSEUM

Following their award winning Phase 1, Arup Associates have been appointed to design the first stage of Phase 2.

ERA

OAP have been appointed by Environmental Risk Assessment Ltd. to advise on the consequences of contamination and measures to overcome them.

ARUP FOCUS is published quarterly by Ove Arup Partnership.

Written by: Patrick Morreau
Hélène Murphy

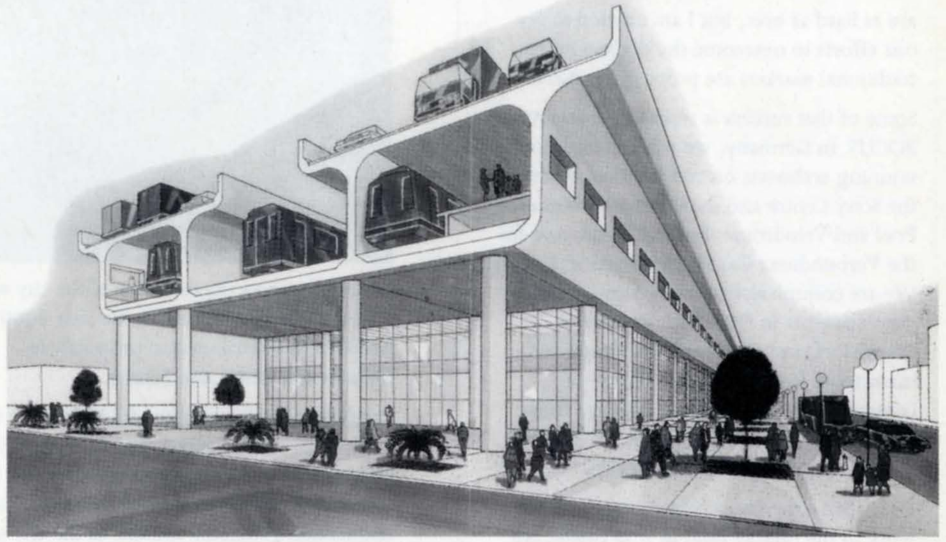
Editing/Layout: David J. Brown
Hélène Murphy

ARUP Focus

Autumn 1992

MAKING THINGS MOVE

Infrastructure plays an important part in creating - or reviving - economic prosperity. It takes many forms, from water distribution in developing countries to the development of new rail and air networks. Ove Arup Partnership is playing its part in these projects throughout the world, particularly in the field of transportation.



Trains à Grand Vitesse

Some of Arups' transportation commissions have been reported in previous issues of ARUP FOCUS: the Bangkok Elevated Transport System (*right*), work on London Underground's CrossRail and Chelsea-Hackney lines, and their appointment by the French Government to evaluate the SNCF proposal for the 300km TGV route linking Valence, south of Lyons, to Montpellier and Marseilles, with future extensions to the Côte d'Azur and Barcelona. The TGV commission examined the relative merits of improving services on existing railway corridors or of building a completely new route. Arups' report has been submitted to the Minister of Transport and their recommendations will be part of the data submitted to the public enquiry. As a result of this work, the firm has been appointed by the City of Avignon to study the possible relocation of the SCNF-TGV station closer to the city centre.

Channel Tunnel Link

In October 1991, the Secretary of State for Transport announced the Government's decision to adopt the route proposed by Ove Arup & Partners for the high speed rail link between London and the Channel Tunnel.

This route is now being developed by an Arup team working within British Rail. The issues include options for the Thames crossing, various nature conservation and archaeological sites, station sites, freight terminals, and potential development along the route.

The Arup Transportation group designed the pedestrian circulation at Liverpool Street Station, London.

British towns and counties

Throughout Britain, communities are looking for ways of reducing congestion, improving their public services, and finding new methods of moving people around. Ove Arup & Partners is engaged in several studies to improve transportation in various parts of the country. The Edinburgh Western Corridor Busway Study examines fast bus links between the airport and the city centre; also in Edinburgh, Arups are replanning the St Andrew Bus Station and, in Doncaster, designing a public transport interchange. The firm is working on a multi-modal transport model of the Southampton urban area, and in Wales has developed an integrated transport strategy for West Glamorgan which relies less on major road construction and more on improvement to existing public transport.

Multiple skills

Projects such as these require transportation specialists. But often those specialists need the support of economists and planners, of acoustical and vibration, civil and geotechnical engineers, of project and construction managers; all these are to be found within the Partnership. In recent years, Arups have become one of the world's leading transportation consultancies. They have achieved this by combining their various skills into effective project teams. Their growth is evidence of their success.

COMMENT

Nigel Thompson

In the Spring issue of ARUP FOCUS, I wrote in this column of the difficult times faced by the construction industry and the design professions associated with it. Six months later, times are as hard as ever, but I am pleased to say our efforts to overcome the decline in our traditional markets are proving successful.

Some of that success is reported in this ARUP FOCUS. In Germany, we worked with the winning architects on competition entries for the Sony Centre and the Olympic Swimming Pool and Velodrome, both in Berlin, and for the Verbundnetz Gas Headquarters in Leipzig. We are commissioned on two major office developments in Frankfurt, another in Düsseldorf, and to develop a strategy and masterplan for reclaiming 150km^2 of contaminated land in Brandenburg. These multidisciplinary commissions are evidence of the effectiveness of Arup GmbH.

Our Japan experience is growing, as is our work in the Middle East: in Abu Dhabi, we have been appointed to design and supervise the 120km Madanat Zayed-Liwa highway. Our work in the United States is growing; we are gaining new commissions in Thailand and elsewhere in South East Asia. Even in the UK, the story is not altogether a gloomy one: our roads, transportation and environmental services groups are increasingly busy.

In October, I went with a British Government trade mission to China. It was a fascinating experience and I was again impressed by the opportunities to be found there. I am glad to say that Arups have been taking advantage of those opportunities; through our Hong Kong office, we have completed more than 30 projects in China and are at present working on construction worth more than US$400M, including the first section of the 140km Guangzhou-Shenzhen-Zhuhai Super Highway and the Shajiao C Power Station. In Hong Kong itself, our appointment for the KRC Headquarters is reported elsewhere in ARUP FOCUS.

One purpose of ARUP FOCUS is to keep you - our clients and other friends - informed of our achievements. I am pleased to be able to say that Arups are continuing to move forward into new ventures in new territories. I am confident that, thanks to the support of our clients and the commitment of our people, we shall continue to do so.

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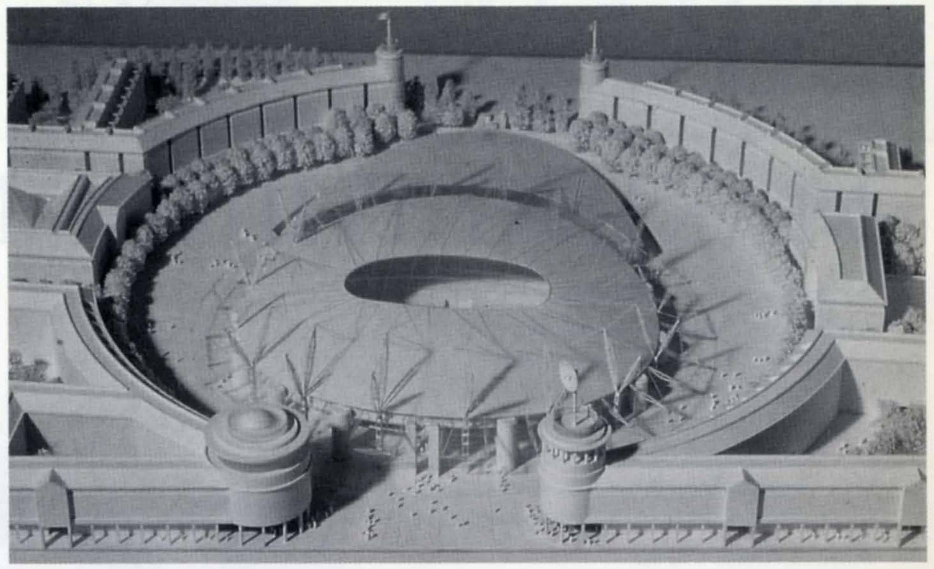
TOWARDS THE OLYMPICS 2000



In the run-up to the selection of the city to host the Olympic Games in the year 2000, Arups have contributed to proposals by Manchester, Berlin and Sydney.

Paradoxically, an unsuccessful bid can be the catalyst for urban revival. The firm played a leading rôle in Birmingham's bid for the 1992 Games and, although the bid failed, the civic enthusiasm generated assisted in the city's rebirth: a new convention centre, new hotels, further expansion of the National Exhibition Centre - for all of which Arups were the engineers. And it might be said that Birmingham's experience inspired Manchester's bid, with which the firm is also closely involved.

Manchester
Ove Arup & Partners are engineers for the 16 000-seat Manchester Arena, part of a £220M development. Construction starts early next year and, in 1995, it will open to accommodate basketball and other athletic events for the Olympics and after. Arups are part of the AMEC team preparing proposals for other Olympic facilities; they are engineers for the infrastructure of the 55ha site and, with Arup Associates, are designing the 80 000-seat stadium, the focal point of the Games. The Birmingham office are engineers for one of the shortlisted entries in the design-build competition for the Velodrome, to be the National Cycling Centre when the Games in Manchester are over.

Berlin
While the winners of the competitions in Manchester have not yet been selected, results were announced during the summer for some of the Berlin Olympic 2000 competitions. Arups took part in three: for the Boxing Hall, where they were fifth; the Velodrome and Swimming Pool, which they won with the French architect Dominique Perrault; and the Olympiaquartier, which includes a 15 000-seat arena (*left*) and 180 000m^2 of mixed use redevelopment: the Arup-Stanhope Properties design-investor bid is one of two now being considered by the Berlin Senat.

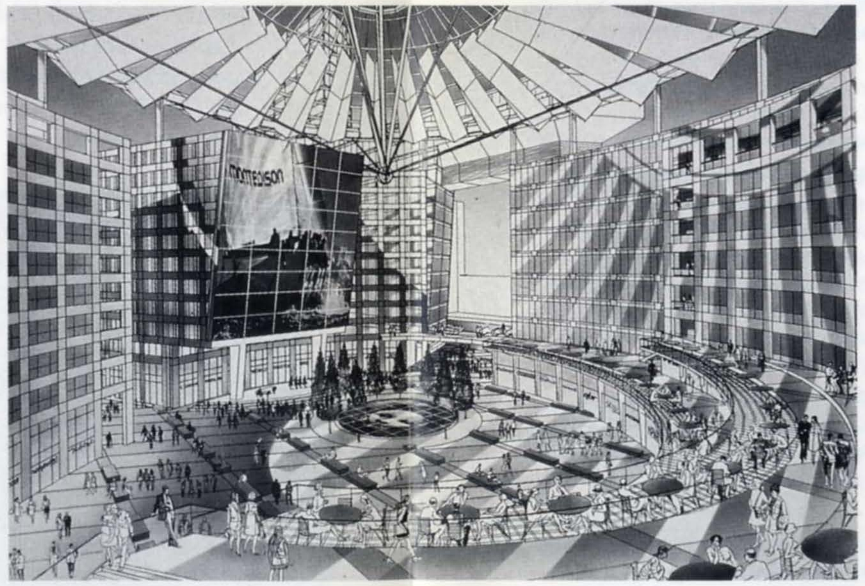
Sydney
In Sydney, OAP Australia are civil engineers for the 660ha Homebush site, a seriously contaminated and derelict area, to become the site for 16 of the 25 Olympic sports. Among these will be the Aquatic Centre, for which they are building services engineers. Now under construction and due for completion in 1994, the centre will have four swimming pools with seating for 22 500 spectators, expanding to 44 000 if Sydney wins the race for the Games.

AWARDS

BCI Awards
Bracken House (architect: Michael Hopkins & Partners) won the Supreme Award in the British Construction Industry Awards 1992. The British Pavilion, Expo '92 (architect: Nicholas Grimshaw & Partners) was awarded a High Commendation in the Building Category and a Special Commendation for being 'an outstanding ambassador for British design and construction'. Other projects which received High Commendations were Dornoch Bridge (main contractor: Christiani-Morrison Joint Venture), Hammersmith Ark (architect: Ralph Erskine), and the Museum of the Moving Image (architect: Future Systems).

RIBA Awards
Among the RIBA Regional Awards were Legal & General House (architect: Arup Associates); Ponds Forge, Sheffield (architect: Faulkner Browns); Stansted Terminal (architect: Sir Norman Foster & Partners); the Avenue de Chartres car park, Chichester (architect: Birds Portchmouth Russum); Bracken House; the ITN Headquarters building (architect: Sir Norman Foster & Partners), Blackwall Yard (architect: Richard Rogers Partnership) and Allied Dunbar Training Centre (architect: BDP).

SONY BERLIN

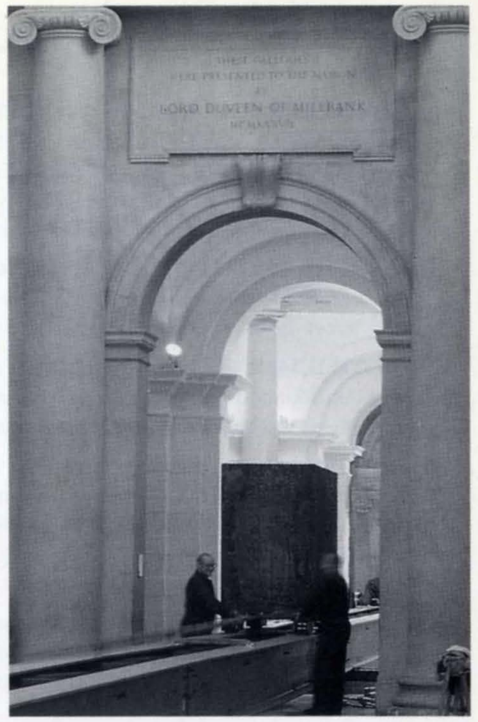


Ove Arup & Partners New York supported Murphy/Jahn Architects of Chicago in the winning competition design for the Sony Center in the Potsdamer Platz, Berlin. The centre comprises Sony's European headquarters, other office buildings, hotel and residential accommodation, retail, a multi-screen cinema and underground parking - altogether a total floor area of about 220 000m^2. The distinctive feature of the winning design is the 'Sony Forum' (*above*), a large elliptical urban event space with a fabric and glass tent-like roof. Arups were responsible for the structural, services and building environmental design of the competition entry.

MORE MUSEUMS AND GALLERIES

During this year, the firm received several commissions for museum projects around the world. In Oxford, it completed a feasibility study for an extension to the Ashmolean (architect: Stanton Williams); in the USA, it is appointed for the Cy Twombly Gallery at the Menil Foundation in Texas (architect: Renzo Piano), while the New York office are engineers for the 15 000m^2 Chicago Museum of Contemporary Art (architect: Josef Kleihues).

Arups in Auckland are engineers for the Museum of New Zealand, and OAP Japan are structural engineers for the Museum of Fruit in Yamanashi by the architect Itsuko Hasagawa. This extensive complex devoted to fruits, their cultivation and uses, will start on site in April 1993. A smaller but unusual commission was the strengthening of the foundations and ground floor of the Tate Gallery, London (*right*), to support sculptures by Richard Serra weighing 74 tonnes and appropriately named 'Weights and Measures'.



Two important European museums for which the firm were structural and building services engineers opened in October 1992. In Madrid, close to the Prado and the Centro de Arte Reina Sofia (another Arup project), the Museo Thyssen-Bornemisza is a 10 000m^2 art gallery designed by Rafael Moneo. It is housed in a 19th century palace, so picture conservation requirements presented particular challenges to the design of the air-conditioning and air-filtration system and to the lighting, which Moneo designed in conjunction with Arups.

On 31 October, the Queen of the Netherlands opened the Kunsthal in Rotterdam; designed by Rem Koolhaas, it provides the city with its first gallery with space to accommodate major touring art exhibitions.

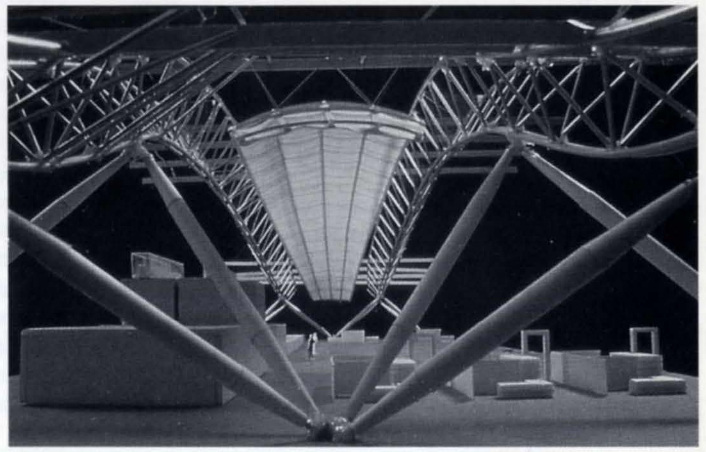
THE JAPANESE EXPERIENCE

Every year, staff from Arup practices around the world gather in London for a seminar sponsored by The Arup Partnerships to share knowledge and experience on a topic of common interest. This year, the subject was 'The Japanese Experience', and, on 16 and 17 October, 56 people from 14 countries reviewed the technical, business and cultural aspects of working with Japanese clients, architects and contractors, in Japan and elsewhere.

Arups have had a presence in Japan since 1987, opened an office in Tokyo in 1990, and have been involved in the planning and design of more than 30 projects with architects from Japan and other countries. Notable buildings include Century Tower in Tokyo, the Kansai Airport Terminal (*right*), now under construction, and the Kobe Institute (a branch of St Catherine's College, Oxford). The Museum of Fruit and the Nagano Ice Hockey Stadium are both now being designed in Tokyo.

At the same time, Arups are working for Japanese clients in Britain and Germany, in Ireland, Turkey, Africa and South East Asia. The experience has been rewarding in many ways, not least in the exchange of engineers between Japan and the UK. Not only are engineers from Japanese contractors and design firms on secondment to Arups in Britain, but Yuko Mabuchi and Arata Oguri, graduates of Tokyo Metropolitan University and Tokyo University respectively, have joined the firm and are working in London before returning to the Tokyo office.

The Japanese Experience Seminar reaffirmed the high importance of Japan to The Arup Partnerships worldwide and confirmed the need to continue and further develop relationships with the Japanese construction industry.



Peter Rice

The Autumn 1992 edition of *The Arup Journal* includes articles by Peter Rice on two of his latest projects, the 'Bigo' monument in Genoa and the Pabellon del Futuro at Expo '92 - both designs imbued with his characteristic structural exuberance, imagination, and daring. Sadly Peter, one of the great structural engineers of his generation, died on Sunday 25 October 1992, after a year's illness borne with great fortitude. His death extinguishes one of the brightest lights of engineering in contemporary architecture.

Peter Ronan Rice was born in Ireland in 1935. Significantly his secondary education was broadly based and stimulated his subsequent development beyond narrow professional confines. This enabled him to acquire that broad understanding of context which so many engineers sadly lack. He graduated from Queen's University Belfast with a degree in Civil Engineering in 1956 and joined Ove Arup & Partners for a year before returning to University - Imperial College - to undertake postgraduate studies. He rejoined Arups in 1958.

For the next seven years he worked mainly on Sydney Opera House, contributing to the early geometric and model studies and carrying out analytical studies after the final scheme had evolved. He wanted to see the structure built, so in 1963 he went to Australia to join the Resident Engineering Team which supervised the construction.

Peter Rice's involvement in Sydney Opera House was seminal in his later work. The building had not yet acquired its prominent position as an icon of twentieth century architecture, but as a young, gifted, dedicated engineer he was deeply influenced by its poetic concept, as well as the subsequent debates and controversies.

He wanted a break after his stay in Australia and spent a year as a visiting scholar at Cornell University. Before choosing Cornell he wrote to a number of leading engineering schools in the United States explaining what he wanted to achieve during this meditative period away from practice. He was not interested in additions to letters behind his name but "...I would like to study the application of pure mathematics to engineering problems. I think that a more thorough understanding of the nature of the equations used to solve structural problems in design could lead to a better conditioned solution and ultimately to a better choice of structural components..."

Photo: Tristram Carfrae

He was to give full expression to these ideas in his later work.

He returned to Arups in 1968, when he started to give full rein to his burgeoning talents. Creative relationships with architects who were themselves to become leaders of their profession were established. He developed ideas on lightweight roof structures with Frei Otto, but his involvement with Renzo Piano and Richard Rogers on the design of Centre Pompidou in Paris marked the start of increasing recognition of Peter Rice as an engineering designer with unique qualities. The seeds sown by his Irish secondary education, his year at Imperial College, his colleagues' influence, and his involvement with Sydney Opera House were beginning to blossom. The design and in particular the detailed elements of the structure for Centre Pompidou marked the beginning of the full expression of his talents.

From 1977 to 1983 while remaining a director of Arups, Peter Rice together with Martin Francis and Ian Ritchie, established a small consultancy, RFR, in Paris. It says much for Peter's personal talents that he was asked to carry out specialist services for a number of prestigious projects in France. In 1983 he became a main board Director of the Ove Arup Partnership and a Trustee of the Partnership in 1991. At his untimely death his professional career was in full flower.

He had become the principal designer with full engineering responsibility for a wide range of important projects. As well as being important engineering achievements in their own right, many of these have been innovative in their use of materials and structural form. Indeed, the overriding theme of Peter Rice's work has been steadily to explore the limits of forms and the use of materials in creating dramatic structures which have become features of the modern urban context. In exploring these limits he has often extended what was considered to be achievable, partly by the development of technique and also partly by creating an imagery that others have then been able to take up and seek to emulate. For example, he has advanced the general confidence in the use of glass as a structural material.

At present there is a tendency for a pulling back from the future and a settling for the comfort and presumed security of the well tried. Peter Rice always maintained the validity of applying his considerable intellect and engineering skills to his work and approach and regularly produced outstanding successes. His position was international and he was a much sought after collaborator to many of the world's leading architectural practices.

Peter Rice's recent projects included: Charles de Gaulle Aerogare 3, Paris; the Marseilles Airport Terminal; the New Groningen Museum, Groningen, Netherlands; Nuages Tête Defense, Paris; and the Terminal Building at Kansai Airport, Osaka, Japan; as well as the 'Bigo' and the Seville Pavilion.

Peter Rice was made an Honorary Fellow of the Royal Institute of British Architects and an Honorary Member of the Royal Institute of Architects Ireland. He received several medals and awards, as well as being sought after in the UK and elsewhere as an informative and entertaining lecturer.

But probably his finest hour came when he was awarded the Royal Gold Medal for Architecture by the Royal Institute of British Architects in June 1992. His illness had already taken its toll yet his address to an enthusiastic audience when he received the Medal was inspirational, his patent joy at receiving the award infectious. The esteem in which he was held by the international architectural fraternity could be judged by the galaxy of architectural stars who had come specially for the occasion to pay their tributes to him.

Peter was a thoughtful and sensitive man. Whatever he said on whatever subject was always considered, never superficial. His interests were broad. He loved football, and he and his family were enthusiastic Queens Park Rangers supporters. An outing to the races was a treat and he liked reading poetry and philosophy. He enjoyed working with talented young engineers: there are a number of rising young potential stars who owe a great deal to Peter for his guidance and inspiration.

He was a devoted family man. His wife Sylvia gave him undemonstrative support through all the years and provided a quiet haven when he sought refuge from his taxing schedule. She, together with their children, three daughters and a son, were a close and devoted family. Their loss is irreparable.

Peter Rice's death is tragic in that it came at a time when he was just beginning to give full expression to his talents. His optimistic presence in a pessimistic world leaves a void which is difficult to fill.

Jack Zunz