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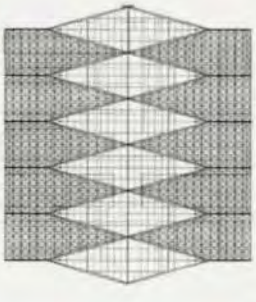
Arup is a global organisation of designers. It has a constantly evolving skills base, and works for local and international clients throughout the world.

We shape a better world

Front cover:
CargoLifter hangar, Brand, Germany (pp24-31) Photo: Palladium Photodesign



Editorial

This sixth Millennium Issue of *The Arup Journal* includes projects related to education, transportation, housing, sport, manufacturing, and telecommunications in four continents. It also includes one small instance of civilised society renewing and rebuilding where terrorists destroy. Following the bomb in the centre of Manchester, England, in 1996, the reconstruction includes the Arup-engineered footbridge (pp46-47) that links two buildings in the centre. In the shadow of acts of unprecedented urban terror, disruption, and destruction, the avowal to 'shape a better world' through the positive deployment of our wide range of skills and expertise must take on ever greater force and meaning.

The engineering design of university buildings has engaged the firm for decades in the UK, but the Jubilee Campus, Nottingham University (pp3-10) sets new benchmarks, with energy use figures around half those of comparable 'energy-efficient' buildings.

Though mainland Europe is not a new location for our work, the design of the new coach for the Spanish operator Irizar (pp11-15) marks a significant extension of the firm's skills base, in the first major project of Arup's vehicle styling activity.

Air transport is represented in two German projects that exploit the potential of tensile structures. The Munich Airport Centre Forum roof (pp19-23) covers an international focal point - comprising offices, shops, etc - for travellers using the city's new airport.

Conventional airliners will carry passengers for the foreseeable future, but freight will have an alternative. At Brand, 60km south of Berlin, the world's largest enclosed space has been structurally engineered by Arup as part of the design team for the CargoLifter hangar, to house a new generation of vast cargo-carrying airships (pp24-31).

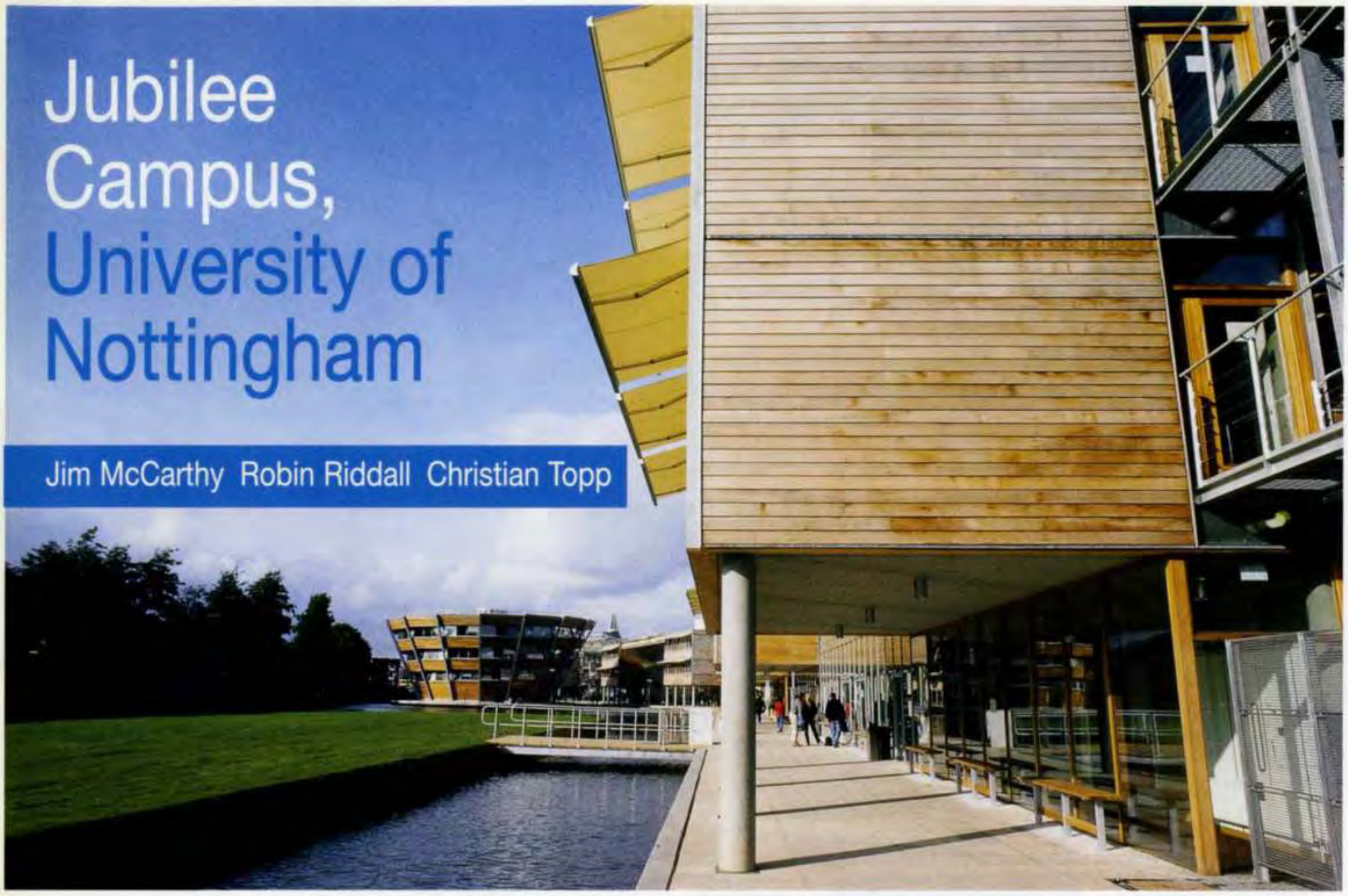
For nearly five years the Zimbabwean practice has worked on the Dandaro residential retirement village (pp16-18) in Harare. A new concept in old age care for Zimbabwe, it draws on South African models, and transportation engineering expertise from Arup's South African practice contributed to the project. Reciprocally, Arup Zimbabwe MEP specialists joined with their South African civil and structural colleagues, plus other local collaborators, on the design of the Ibhayi Brewery at Port Elizabeth (pp38-42).

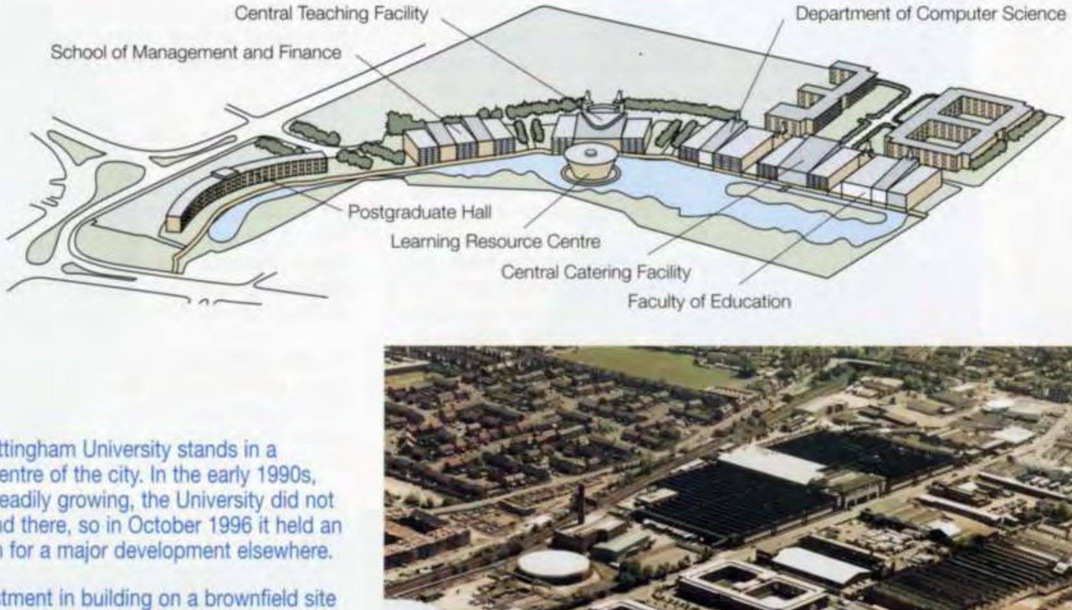
Different aspects of telecommunications and information technology on opposite sides of the world are represented by the roll-out programme of datacentres for IX Europe (pp43-46), and the IT installation for the Bank of China HQ in Beijing (pp48-51). And whilst preparations begin in China for the 2008 Olympics, among the permanent legacy of the 2000 Sydney Games is the International Tennis Centre (pp32-37).

Back cover:
The Irizar Coach (pp 11-15) Photo: Arup

Jubilee Campus, University of Nottingham

Jim McCarthy Robin Riddall Christian Topp





Introduction

The main campus of Nottingham University stands in a parkland setting in the centre of the city. In the early 1990s, with student numbers steadily growing, the University did not have the space to expand there, so in October 1996 it held an architectural competition for a major development elsewhere.

This led to a £50M investment in building on a brownfield site about 1km from the main campus to provide accommodation, faculty buildings, and teaching facilities for around 1000 students and staff.

1 top: General view of the Jubilee Campus.
2 above centre: principal buildings on the Campus.
3 right: aerial view.

4. Cowls on the School of Management and Finance.

The low-energy challenge

Arup had a wide-ranging appointment for the engineering design, starting with the original scheme for the competition entry, and finishing with commissioning and monitoring the building systems at the end of the project. The firm's involvement on the site will continue for some time; the innovative low-energy air-handling systems were partly funded by an EU grant under the Thermie scheme, and Arup is involved in monitoring the system over the first few years of its use.

However the achievements of the project lie not only in the economy of the design or in its sustainable aspects, but in the remarkable figures for energy use. These are summarised in Fig 5, with the inclusion for comparison of 'best practice' figures[2] for energy-efficient buildings. It can be seen that the measured energy use is half that of a similar 'energy-efficient' building. Fig 6 gives the equally important figures for the campus's CO_2 production, again in comparison to 'best practice', showing a 75% reduction in emissions when compared to a similar building.

The brief

The client required a wide range of facilities on the new campus - from student accommodation to a high-specification faculty building for the School of Management and Finance.

Underlying this was a strong desire for the development to address environmental issues, both in the choice of materials and in the energy demands of the building systems. Arup was part of the design team with the architects, Michael Hopkins & Partners, from early in the competition, and the environmental systems designed then were carried through to the final design.

The cost of the development was also important, it being funded partly from donations as well as by the client. The University wanted to build as much as it could for the budget and at the same time have a quality of accommodation appropriate to the functions of the buildings.

Energy use

How did the Arup team achieve the energy targets? Answer - through a combination of specifying low-energy systems and integrating the services carefully into the building frame. Several innovative systems were brought together to fulfil the required university building functions with a fraction of the energy consumption of traditional buildings.

The buildings are mechanically ventilated, of which the most visible sign is the rotating wind-cowls on the faculty roofs. These 5m high aluminium-clad cones sit on top of the air-handling units (AHUs), and track around so that they always face downwind, the prevailing wind thus assisting in the system's air extraction. The AHUs themselves are large - 5m x 5m x 5m - and contain heat exchangers, fans, and heaters. The size of the units and the associated ductwork allows for an air-handling system with low-pressure drops, so the fan energy required is kept low.

The amount of ductwork was also minimised to keep costs down; indeed, the only ducts are builderswork ducts below the AHUs that distribute supply air vertically down to the three levels below. The supply air is then channelled through the voids under the raised access floors, and distributed into rooms.

The buildings mostly have cellular offices, so the floor outlets were carefully located to avoid any sound paths from one room to the room next. Exhaust air from the offices is drawn into the central corridors and back along the exposed concrete soffits. The process of supplying and exhausting air via the concrete frame of the building makes use of the material's thermal inertia; the daily temperature cycle in the building is moderated by the temperature of the frame, smoothing off extremes of heat and cold during the day.

From the central corridors, the air is drawn towards the stair towers at low velocities, as the cross-sectional areas of the air paths were deliberately kept large. The structure has been carefully detailed to ensure that no downstand beams block this path. The air rises up the stair tower and goes back through the AHU, passing through a heat exchanger before exhausting though the directional wind cowl. Details of the AHU operation are described in the panel on the facing page.

Together with the architect, Arup ensured that the client's strong desire to address environmental issues during the development was fulfilled.

Super-efficient mechanical ventilation: the air cycle

The aim of 'super-efficient mechanical ventilation' is to provide heating and comfort levels of cooling whilst reducing energy input into the system. On the Jubilee Campus this was achieved by taking advantage of the thermal mass of the building frame, by using heat exchangers, and by minimising the fan power required.

The AHU at the heart of the system is housed within the 5m x 5m x 5m cube above the staircases in the faculty buildings.

The structural elements are used as thermal mass to provide comfortable conditions in the spaces, as well as air paths for the ventilation system to avoid conventional ductwork installations. False ceilings are avoided, to reduce costs and material use. Using this approach, the energy requirements for the fan power could be reduced from 3-4W/ l /s to only 0.5W/ l /s, which is well below even Scandinavian standards, thus providing the client with reduced operating cost. These targets were achieved by limiting the total pressure drop of the supply and extract system at normal operation to only 280Pa.

The ventilation system of the buildings is designed to minimise pressure losses by utilising ultra low pressure elements within the air handling equipment, using the building structure as air paths and wind pressure to natural ventilate the buildings.

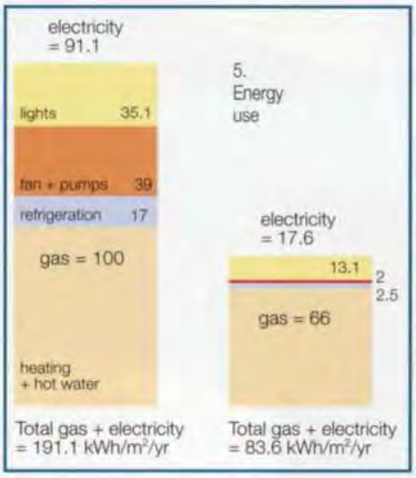
Large self-powered wind cowls exhaust air from the seminar spaces directed through the corridors. Fresh air is taken into the AHUs at high level and heat exchanged through large thermal wheels, providing only 50 Pascal pressure drop and 83% efficiency.

Highly efficient indirect gas heaters warm up the air only as necessary to provide heating in winter; evaporative cooling provides cooling to the fresh air in summer, ensuring comfortable internal conditions.

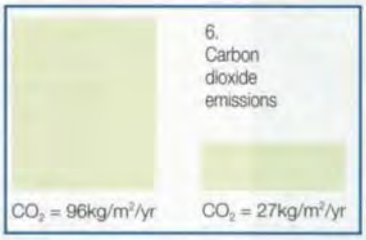
To reduce the fan power, additional air dampers are included within the AHU design to bypass components if not required.

Electrostatic filters are used to minimise pressure drop across the panels. The total energy demand during the year matches the photovoltaic cells output and therefore providing a zero CO_2 ventilation system.

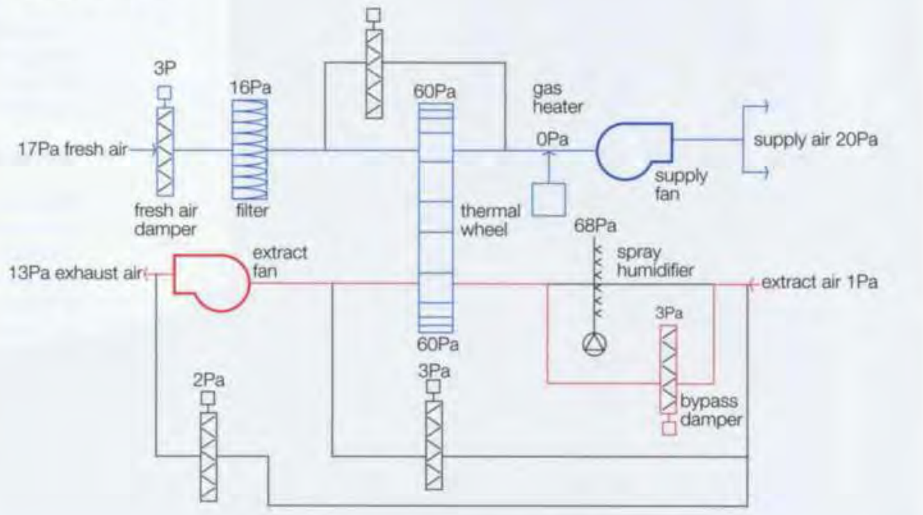
Part of the high efficiency energy strategy includes the use of natural light and, where necessary, highly efficient occupant-controlled lighting systems, within all areas. Local user control is provided in spaces where the client required manual adjustment.

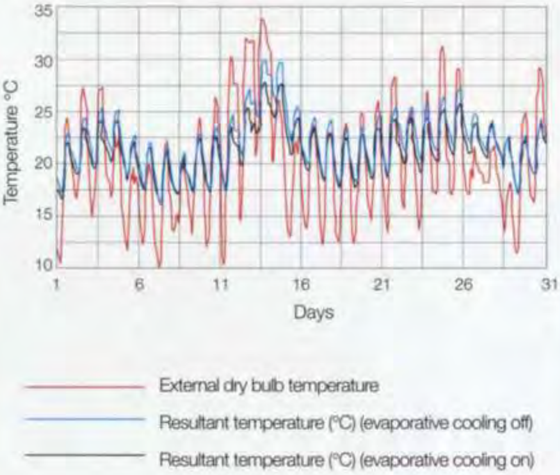


5 & 6 above and below:
Progress toward sustainability
(left) Good practice base model
(right) Jubilee Campus buildings



7. Ventilation schematic.





Calculations were done using a computer simulation program ROOM (a finite element stratified layer thermal analysis program), part of the Arup building analysis suite, running with real weather data. A special routine was written to analyse the evaporative cooling and to integrate it into the overall process. The evaporative cooling effect increases with increases in outside temperature.

8 above:
Temperature profile for the month of July:
ventilated slab, and evaporative cooling on and off.

9.
Interior of lower part of AHU, with engineer beneath thermal wheel, looking through bypass damper.

An evaporative humidifier in the AHU provides additional cooling in the summer. Exhaust air can be humidified just before passing back through the heat exchanger, which as well as raising the air humidity also lowers the temperature. By passing this air back through the heat exchanger, the incoming air is cooled and no humidified air re-enters the building.

As a further step towards saving CO_2 emissions, the development generates its own electricity. 450m^2 of photovoltaic cells are integrated into the atria glazing and generate the equivalent of the energy demand of the fans in AHUs, providing a zero CO_2 ventilation system.

Costs

Whilst the brief allowed all the buildings to be developed along 'green' lines, the Arup team was well aware that the University did not have the funds for elaborate experimental systems. The budget was no different from that of any other of the University's developments, at around £1000/m^2 for the faculty and amenity buildings, and £16 000 per room for the post-graduate halls of residence (at prices current in the third quarter of 1996).

The University adopted a construction management form of contract to get a contractor involved in the project early on, and to enable them to package the design information and market-test the packages. The contractor led the value engineering for many of the work packages, prior to the appointment of the trade contractors.

These sessions addressed not only the costs but also the environmental aspects of the work. The contractor made a point of tackling issues like reducing site waste and recycling materials on site, to fit in with the project's environmental principles.

Disciplines

Arup was responsible for the engineering design across a wide range of disciplines:
structures / heating and ventilation /power and lighting / piped services / geotechnics / civil engineering / acoustics / fire, / transportation / planning supervision / communications / controls.
The firm also provided the resident engineer staff.

One advantage of being involved from the competition-winning stage meant Arup could demonstrate the advantages of bringing in a wide range of engineering expertise early in the project.

10 left:
Solar shading on the School of Management and Finance.

11 right:
5m x 5m x 5m AHU, with cowl above, between two wings of the Department of Computer Science.

Thermie

Arup was able to take full advantage of the grants available from the EU for energy-efficient buildings. The Thermie (Technologies Européennes pour la Maîtrise de l'Energie) scheme provides matched funding for innovative energy systems in buildings. Arup had previously worked with the same architects on a JOULE- (Joint Opportunities for Unconventional or Long- term Energy) funded project, and therefore had experience of the applications process.

The team was not awarded the funding at the outset. Due to the project programme, the application was made and then the design carried on whilst the application was processed.

This meant that Arup had to identify elements in the energy systems that could be omitted in the base design, and then added at a later date if the application is successful. The funding was to be spent on the rotating wind cowls in the exhaust side of the AHUs, and on the photovoltaic cells powering the AHU fans.

The design was well advanced when news arrived of the success of the Thermie application. The full amount applied for - £740 000 - was granted: the largest amount awarded to date under this scheme for a single project.

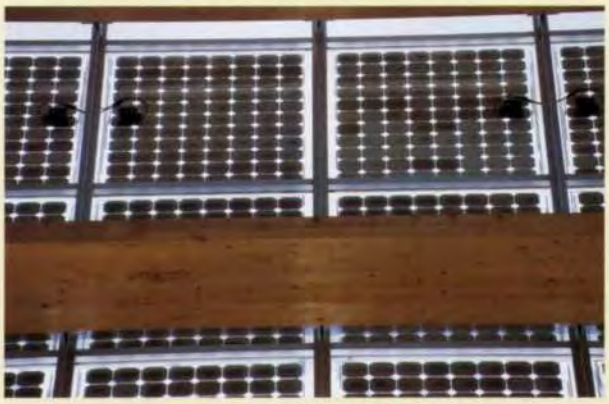
The scheme requires a team of partners, one requirement being that not all partners are from the same EU country; it is preferred if one partner is a university.

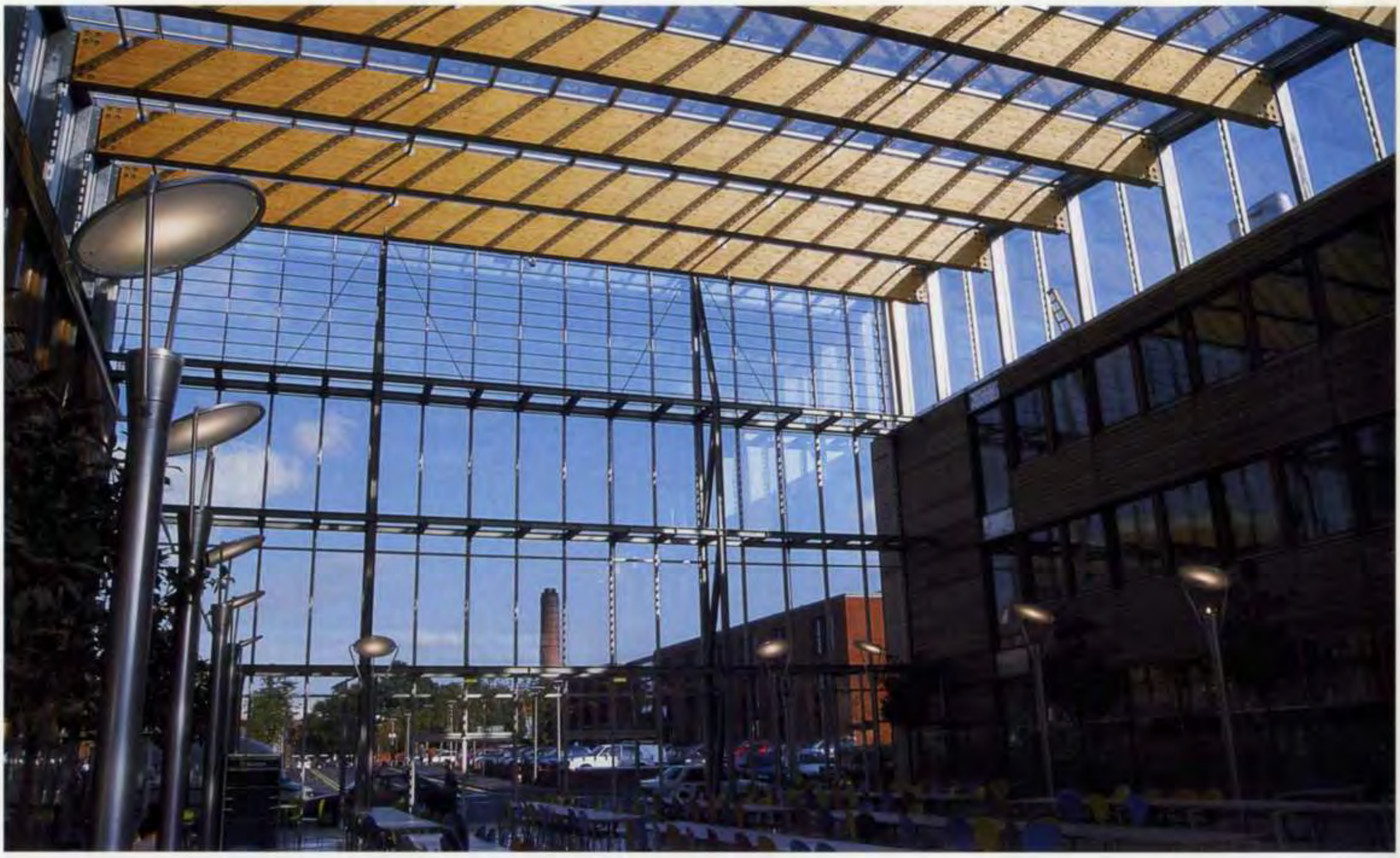
The University of Nottingham and the architect teamed up with ABB in Sweden, who were to manufacture the AHUs, to form the team to design the low energy ventilation systems. Arup was contracted as the engineer to the partners awarded the grant.

Thermie funding requires that the building performance is monitored and reported on once the building is operational. The Building energy management system (BEMS) on the Jubilee Campus monitors all the building services in the campus building, and can be used to record the energy consumption.

Researchers in the University's Department of the Built Environment are monitoring the results from the BEMS and reporting back to the Thermie authorities. A BREEAM (Building Research Establishment Environmental Assessment Method) pre-assessment of the building is also being carried out, and concluded with an 'excellent' rating.

12. Ceiling photovoltaic cells in atrium of School of Management and Finance.





13 above:
Central Catering Facility.

14 below:
Looking past the Central Teaching facility to the School of Management and Finance; note light fixture - designed by Arup.

At the heart of the competition design was the schematic for the 'air cycle' for the faculty buildings (Fig 7, p 5). This was developed into the final scheme which remained true to the original concept. The mechanical and electrical design was closely integrated into the building fabric, giving not only an efficient use of space but also a calculable cost saving in terms of duplication of building elements - for example, the shape of the structure removed the need for air ducts in most of the building. This tight integration resulted from an appointment covering many disciplines, giving the engineer control over the building form during the project's initial stages.

Brownfield development – urban generation

This development has successfully taken a brownfield site in a light industrial area in Nottingham and turned it into a sustainable urban landscaped park setting for several university buildings.

Environmental objectives

At the masterplanning stage the University set ambitious goals in respect of environmental objectives, with declared aims for energy, traffic, waste, and ground management. The latter included promoting new habitats for wildlife and ecology and enhancing the visual amenity, whilst preserving the biodiversity in the existing woodland.

A high quality landscape setting was proposed, central to this strategy being the creation of a 1.1ha lake longitudinally through the site As the major feature of the development it has several functions: together with other associated watercourses it provides:

- an attenuation facility for run-off generated from the development, prior to discharging at a controlled rate to the off-site drainage system
- a valuable new wildlife habitat
- a social amenity for students and the general public, including a link to a public cycleway
- a buffer between the buildings, adjacent residential properties, and existing woodland along the site's southern boundary
- a defined and restricted edge to the main pedestrian corridor.

Lake design

To maintain acceptable water quality, targets were set and the necessary management systems identified. In line with best practice, a protective management approach was proposed, to be implemented by:

- treating run-off before it enters the lake to remove suspended solids, hydrocarbons and nutrients
- providing extensive aquatic planting to help oxygenate the water and provide a habitat for zooplankton
- re-circulation systems (sadly the proposed wind pump did not prove viable, and small mechanical pumps were ultimately specified)
- water top-up during periods of drought; in the short term the provision of a groundwater borehole was not feasible, but development on an adjacent linked site will allow the lake to be topped up via a borehole
- a system of air diffusers, given that until a stable ecosystem within the lake is established an acceptable water quality will be difficult to maintain.

These help to oxygenate the water, assisting in the removal of toxic gases and nutrients. This reduces risk of algae growth and improves invertebrate growth.

A sustainable infrastructure

The University is committed to using products from renewable sources and to recycling waste. To achieve these objectives, the infrastructure elements included:

- a cut/fill balance, ensuring that all excavated materials remained on site
- encapsulation of unsuitable materials to allow their use in landscape areas
- use of re-processed materials, particularly concrete and brickwork
- use of a geocomposite clay liner, which avoided the customary use of petroleum derivative-based membranes.

PVC in particular was highlighted as a major polluter in manufacturing and disposal, and so was avoided throughout the project. It was replaced by low smoke and fume (LSF) insulated cabling, and high density and medium density polyethylene (HDPE/MDPE) ducts and pipework. In addition, sustainable cladding to buildings in the form of Western Red Cedar from renewable sources was specified.

The site

The site formerly housed the main warehouse and distribution area of a Raleigh bicycle factory, and some chemical processes to do with manufacturing had gone on there in the past. To the south was the Sturmey Archer factory where saddles, spokes, and hub gears were made. Underground service trenches linked the two factories. Searches of existing documentation revealed that a canal had run along the east side of the site until the 1950s, and more investigations at the Coal Board indicated that coal had been mined at three levels below the site, with a shaft somewhere on the site. This shaft was abandoned in the 1840s, and no records survived showing exactly where it was. Some evidence indicated that prior to that there was a mediaeval village on the north end of the site.

Arup had much to do on the site before construction could begin. The site investigation was more far-reaching than usual, including local archaeologists being asked if they wanted to excavate any part of the mediaeval site - they did not.

Also, as contamination 'hotspots' were likely to have been left behind from the factory processes, remediation had already been carried out when the team arrived. The new development is extensively planted, however, so Arup did further chemical tests to ensure that the plants would thrive.

The contractors were alerted about the mineshaft, and the design team had to be satisfied that the worked seams under the site did not affect the foundations. The contractors spent some time digging trial pits on the site, searching for the mineshaft, the main concern being that it might not have been adequately capped after it was abandoned. However, no evidence of it came to light in the area of the new buildings so it was concluded that the shaft is either well backfilled or elsewhere on the site.

The buildings

There are seven principal buildings: the three faculty buildings (Education, the Department of Computer Science, and the School of Management and Finance); three amenity buildings (the Learning Resource Centre, Central Catering Facility, and Central Teaching Facility); and postgraduate halls of residence.

The low energy systems described in this article are incorporated into the faculty buildings - three similar buildings where the combination of cellular offices and teaching spaces is best suited to the low energy ventilation system.

The Central Teaching Facility houses three lecture theatres (100, 200, and 300-seater), stacked on top of each other with raking seating. Here the ventilation demands are higher and the plant more conventional, though it still makes use of the stair towers for exhaust air.

15.
Lecture theatre
in Central Teaching Facility.

The structure is in reinforced concrete with precast beams spanning radially from front to back, following the splayed plan of the theatres. The spaces between the beams are used for air supply through the floors, and extract in the ceiling. The shapes of the lecture theatres, coupled with carefully designed acoustic panels in the ceiling and absorbent boards at their rears, makes for good acoustic performance and acoustic efficiency.

The Learning Resource Centre is the Jubilee Campus centrepiece. It is located in the lake, joined back to the promenade running alongside the lake via a timber-decked causeway. The building houses the campus library and a 24-hour computer laboratory accessible to all the students, and its form is derived from its use. The footprint is circular, and the floor plate is one continuous spiral around a central core containing a lift and staircase. The floor plate makes three and a half revolutions and gets wider as it rises up the building, resulting in the inverted cone-shape of the building. The structure comprises 16 radial steel frames with a vertical column on the inside end of the frame, and an inclined column at the other end. The book stacks are arranged in the radial beams towards the inside of the building (away from daylight); desks are by the windows, and shaded by the overhang of the floor slab above. The building Is naturally ventilated, with the automatically controlled windows on the leeward side of the building opening to assist with air extract. One brief requirement was that the computer laboratory should be easily enlargeable if necessary at a later date. By making the building on a continuous ramping floor plate, the wall between the computer laboratory and library can be moved one segment at a time to gradually increase the size of the former.

The halls of residence are in conventional cross-wall masonry construction on improved ground. Precast planks were used for the floor slabs, with prefabricated toilet/shower rooms delivered to site and craned into place. This amount of prefabrication helped keep costs down and improve the programme. The toilet pods were finished to a high standard, and this approach helped to reduce the number of trades on site.

Conclusion

HM The Queen officially opened the new Jubilee Campus on 9 December 1999.

The project was completed on time for the 99/00 academic year at which point all the buildings were fully operational. Acclaim followed from both the trade and national press. The Estates Department at the University and the Steering Committee of senior University staff are reported to be delighted with the development, which is now a showpiece for the University.

Following the successful completion of the Jubilee Campus project, Nottingham University re-appointed the same design team to design the National College for School Leadership, the University having been appointed by the then UK Department for Education and Employment to provide a college building for head teachers. This project is currently on site, and will sit at the southern end of the Jubilee Campus lake, which is being extended southwards through the Sturmey Archer factory site.

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Energy efficiency in education buildings. DoE, 1995.
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Indoor+Built Environment, 9(2), pp87-96, March-April 2000.

Credits

Client:
University of Nottingham

Architect:
Michael Hopkins and Partners

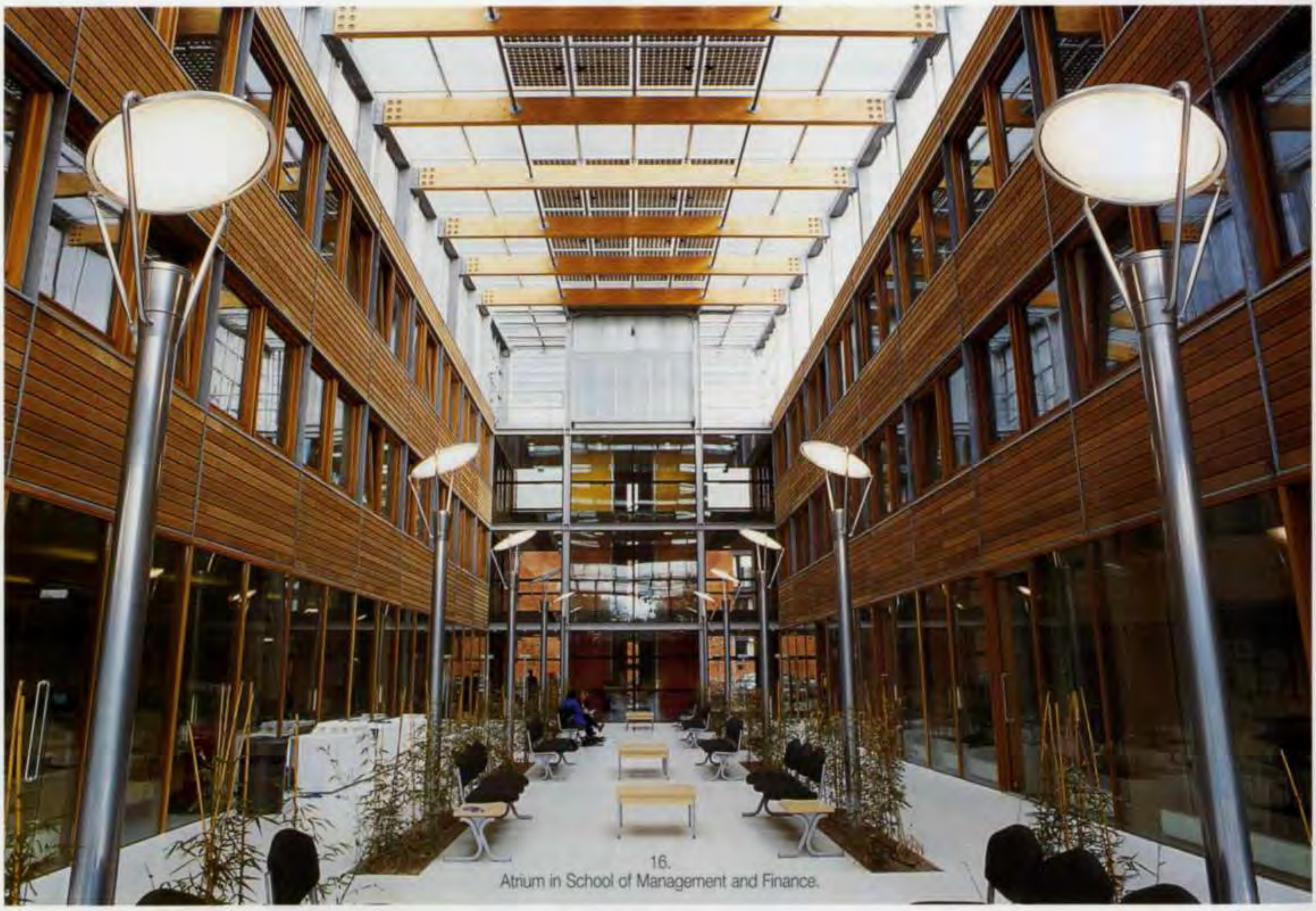
Building, building physics, and civil engineer:
Arup Simon Averill, John Berry, James Bown, Steve Cliff, Mike Edwards, Ian Fowler, Steve Gilpin, John Hopkinson, Nick Howard, Glen Irwin, Robin Lee, Jim McCarthy, David Mooney, Raf Orlowski, David Pritchard, Robin Riddall, Jonathan Roberts, Vaughan Sutton, John Thornton, Christian Topp

Quantity surveyor:
Gardiner and Theobald

Construction manager:
Bovis Midlands

Illustrations:
1, 4, 9-16: Paul McMullin
3: Kevin Tamer Photography
2, 5-8: Jonothan Carver

> The Jubilee Campus won the Building Award in the British Construction Industry Awards 2000. The Judges' citation reads: 'Highly sustainable design and immaculate construction have delivered a sophisticated but remarkably economical result. Students will be stimulated by the complex, which has established a new benchmark for university buildings.'



16.
Atrium in School of Management and Finance.

The Irizar Coach

Adrian Griffiths Graham Lewis

1. Family of running prototypes used for press launch of the vehicle in February 2001.

Introduction

The touring coach business is a specialised and unique sector of industry. At first sight it is clearly of the automotive fraternity, but the product's physical size and the relatively small number produced annually make it more of a craft than a true automotive product. Here, arguably, production meets craft: vehicle styling meets architecture. Where better for Arup's new vehicle styling activity to launch its first major project since the previously independent Design Research Associates (DRAL) joined in early 1999? This article outlines the history of the Irizar Coach project: from the first client approach, through early concept definition for the exterior and interior styling, to detailed surface definitions for tooling manufacture, thence to the press launch with pre-production vehicles in February 2001. The first production vehicle rolled off the line in Spain in May 2001.

Arup is proud to be part of this story.

Initial contact and design research phase

Irizar S COOP is one of the oldest coach builders in the world, with continuous production since 1889. Based in Guipuzcoa, a province of Spain's Basque country, it is the Spanish market leader and Europe's second biggest producer by volume. Irizar's 'Century' coach, in production since 1991, has received numerous Coach of the Year awards in Europe, its design flair separating it from more conventional competition. Irizar wanted to build further on this success, and approached seven consultancies, including Arup, to provide the design inspiration for a new vehicle. The firm was chosen because Irizar felt that it understood its ambitions and could deliver a product that was truly 'inspirational' - a word that came to characterise the project. Arup was also perceived as a 'styling' (design)-led organisation with a strong automotive background. Other terms recurring frequently during early discussions were 'innovation', 'creativity', 'character'.

The design cycle

Vehicle and architectural design cycles have similarities but also some striking differences, principally in the use of full-scale models very early on.

This allows the vehicle's visual impact to be assessed and the surface geometry for the production tooling to be generated. This 'styling' phase is undertaken in specialist vehicle design studios, using 'clay' (industrial modelling wax) to build models of exteriors and interiors which can be seen and touched (essential in assessment), as at Arup's vehicle design studios in Warwick, UK. Design development typically moves through several distinct phases:

1. Design research

The key elements of the client brief are defined.

Statements are generated, through brainstorming, which reflect the feel of the essential requirements (eg 'brave', 'futuristic', 'strong', 'chic'), derived from research in a wide range of product literature cued from architecture, fashion, jewellery, furniture, fine arts, etc.

This phase illustrates themes in sketch form and is known, therefore, as '2-D work'.

2. Design intent

The themes developed so far are reduced to a small number of more defined sketches and renderings. The work is still 2-D, and resolves to agreement on 'Theme Direction' from the client.

3. Design development

The preferred theme is developed through 3-D models. The client joins a series of 'viewings' (or design reviews) and work progresses in stages until 'Design Sign-off' - achieved when there is no conflict between style and engineering issues. The final design is then accepted by the client and further development frozen. These stages often start with scale clay models (typically 1/6) and progress to full-size, highly detailed models (front 5m and rear 3m for both exterior and interior).

4. Surface definition

The signed-off surface geometries are defined digitally and transmitted to the client electronically for the manufacturing tools to be made for the production vehicles (moulds or presses, depending on whether the components are to be made from plastics or sheet metal). This also allows the first prototypes to be assembled.

5. Production / engineering liaison

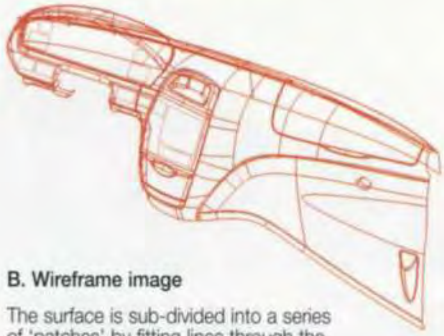
The designers ensure that design intent is carried over into the production arena, and any conflicts between style and engineering are properly resolved. At this point, the vehicle designer's brief is complete.

Historically, steps 3 and 4 were developed by hand-crafting full-size clay models and then 'digitising' the finished 3-D surfaces. More recently, computer-aided design techniques have reversed this sequence, the full-scale clay models increasingly being cut from 3-D mathematical surfaces computer-defined from the outset. The Irizar coach took elements from both these approaches.

Stages in creating a computerised model

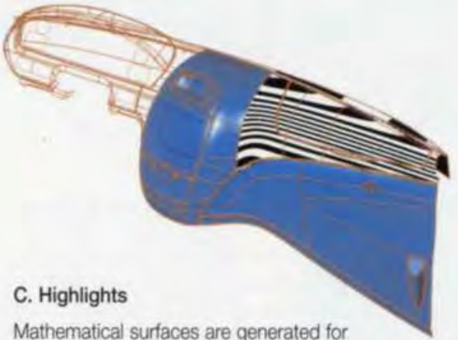
A. Image from cloud point data

The spatial co-ordinates of a large number of surface points are measured from the full-scale model using a digital scanner (See Fig 12) and fed into the computer, producing a 'cloud of points'.



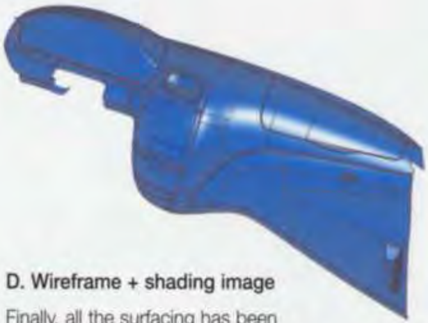
B. Wireframe image

The surface is sub-divided into a series of 'patches' by fitting lines through the points. Each patch defines a surface area where the spatial co-ordinates, slopes, and curvatures are defined at the boundaries.



C. Highlights

Mathematical surfaces are generated for each patch and then the reflection from the virtual surfaces are calculated to confirm that visual continuity of slope and curvature have been achieved across the surface and at the patch boundaries.



D. Wireframe + shading image

Finally, all the surfacing has been completed and the entire fascia panel is now uniquely defined mathematically.

All these thoughts and feelings were developed by Arup with the client during the design research phase until a brief for the product was agreed. Strong elements established by the team in the brief were:

- a powerful 'face' on the front of the vehicle ('down-the-road graphic')
- a feeling of energy in the overall shape
- a visual impression of safety and robustness
- a clear definition for the panel section to the vehicle sides, and 'flow'
- an overall 'Spanish' character and a stylish and distinctive 'personality' apt for a luxury touring coach.

These were demonstrated through a series of sketches (Fig 2), and excited Irizar's management team sufficiently to launch the project into its next phase of development.

Exterior and interior design

It was immediately clear that Irizar would be a challenging client. Rarely had Arup encountered so many senior managers with an intimate understanding of their product and such singular dedication and enthusiasm to make it successful in the global market-place. Apart from Irizar's key personnel, the team was completed by Sener, responsible for the engineered structure, and LKS, who would provide the relevant market research inputs. At the outset, all spent much time discussing the competition, analysing its good points and weaknesses and comparing them to the 'Century', and defining the essential improvements that had to be incorporated into the new design.

After this design research phase, agreeing initial parameters like height, width, length, wheel positions, etc, the design intent stage began (Fig 3).

2 left:
Early concept sketches during design research phase.

3 right:
Sketches produced at the design intent stage.

4.
Sketches of the definitive renderings that helped make the choice of design direction that the new product should take.

Within four weeks, the first sketch presentation was made to Irizar and the process of style selection began. Clearly, some sketches were too innovative and ambitious, whilst others more closely reflected the client's aspirations. With this critique, the designers could focus the follow-up work to the management team's requirements, and over two months narrowed the design intent phase down to three definitive renderings (Fig 4).

At this stage, the client relied heavily on Arup's advice on which design direction the new product should take.

5.
Developing the 1/6 scale models of the coach.

The renderings helped to narrow down and focus the design elements of the exterior, but only scale models (Fig 5) could convey a more consolidated feel for the exterior appearance to Irizar. After agreeing on a single exterior theme sketch, Arup accordingly began developing the 1/6 scale models. Why 1/6? Simply because this size is the optimum between being large enough to incorporate a reasonable amount of design detail and small enough to be transportable. Also when photographed they can be electronically blended into real backgrounds (Fig 6) to give an early realistic impression of the product.

6.
Model photograph electronically blended into real background.

On 14 September 1998, two models of the new vehicle were reviewed at Arup's Warwick studios. These represented a 3.5m (height) x 12m (length) coach (showing two-axle layout) and 3.7m x 12m and 15m coaches, (with the alternative lengths showing two-axle and tri-axle layouts). At the same meeting, the first sketches of the interior theme were reviewed (Figs 7 & 8). Clear, concise decisions were made regarding the exterior, and design theme direction was given for continued interior development. Detailed modifications for the exterior were discussed, and then it was agreed to proceed to full-size clay development.

These processes are second nature to a large automobile OEM (Original Equipment Manufacturer) with its vast financial resources, and Arup's experience and expertise derived from this industry. By showing Irizar how some automotive practices would directly benefit development of the new vehicle, Arup could import relevant best practices, apply them advantageously, and still work within the prescribed budget targets.

7 & 8.
First sketches of the interior from which the design theme direction was evaluated.

Full-size clay allowed Irizar to appreciate immediately the translation of the theme design into reality (Fig 9). At the same time, it enabled the engineers to consolidate their structural and component packaging design by monitoring progress on the full-size clay development both visually and by processing the digitised data generated as the clay model developed.

A series of style review dates was agreed with Irizar and several meetings held at Warwick to monitor and agree the 3D design development stages. As exterior development progressed, Irizar provided packaging and ergonomic 'hard points' (functional spaces that individual elements require in the overall structural package,) for the roof-mounted HVAC system, mirrors, glass requirements, motor packages and drive train, and occupants. Discussions also proceeded with the exterior lamp manufacturers, whilst the glazing suppliers visited Arup to assess the feasibility of the large compound-curvature front windscreen.

9.
Full-size clay development.

10.
Full-size models of front and rear ends were presented at the exterior sign off meeting.

During development of the exterior 3-D, enough dimensional data was generated to begin manufacturing the full-size interior armatures ('bucks'), which were completed by the beginning of March 1999. (These enable the review team to walk inside the interior structure and assess the design and ergonomics.) The designers assembled these in the studios and began developing full-size interior clay models in parallel with finalising the exterior models.

At the exterior sign-off meeting on 18 February 1999 (Fig 10), the full-size exterior front and rear ends were presented in light silver metallic paint, with front and rear lamps represented by full size, hard, see-through models.

After a constructive, enthusiastic meeting, the exterior received full sign-off.

During the 3-D exterior development programme, the interior 2-D was progressing (Fig 11), and by the time the interior full-size bucks were complete in March 1999, theme direction of the interior development had been achieved.

After exterior sign-off, the exterior front and rear ends were scanned by a laser-controlled camera (Fig 12) and 3-D cloud point data used to begin developing the exterior ('A' class) surfacing programme using Alias Surface Studio, an advanced computerised visualisation and surfacing tool (Fig 13). The total surface of the exterior was developed on-screen in Alias, giving Irizar a complete database of the surface geometry. Technically this represented a quantum leap into the future for Irizar, and their management team characteristically embraced this (Fig 14).

During theme development of the interior (Fig 15) the team spent many hours discussing how it could be improved; how the passenger environment could be made more comfortable and easier to use; and how Arup could reinforce the perception that, as well as more luxurious and appealing, the interior was far safer with regard to structural rigidity, more innovative in its sculptural form, and of higher quality. Higher perceived quality was achieved using automotive-inspired detailing - more considered than a purely engineered solution - and by better quality materials and methods of manufacture.

The entrance received particular attention as an area of potential improvement. It has to look inviting, with a stairway wide enough to make entry and egress easy and safe. Also, the whole entrance area needed to appear large and light for a perception of space and airiness.

The interior development proceeded along similar lines as the exterior, with the 2-D themes being translated into 3-D full-size clay. Again, this allowed Irizar to 'see and touch' the individual components, as well as enable fine tuning and adjustment as engineering feasibility caught up with aesthetic development. The interior, by its nature, was far more complex to develop than the exterior surfaces, but the well-integrated and cohesive team reacted quickly and positively to changes and modifications. Inevitably, unpredictable problems and difficult areas were encountered, but the team met these challenges and resolved even more strongly to produce 'the best interior'.

The interior was signed off in December 1999 (Fig 16) and, as with the exterior, the process of scanning and 'A' class surfacing began. But a major change took place in the facia design. Originally there was to be a separate, stand-alone instrument nacelle, but it was decided that a fully integrated instrument surface would be better.

Many original facia forms were totally changed, and the decision to delete the separate driver's door helped to free a larger surface area for switches and controls (Fig 17). This also benefited driver compartment safety, as well as giving better driver ergonomics.


11.
Definitive interior rendering.


12.
Exterior front and rear ends being scanned by laser-controlled camera.


13.
Advanced computer visualisation.


14.
Total surface of exterior developed on-screen: a quantum leap into the future.


15.
Theme development of the interior.


16.
Interior at sign off stage, December 1999.


17.
Deleting driver's separate door gave larger surface area for switches and controls.

18.
Full-size foam models of seats.

Seat design

An addition to the initial design theme for the interior was the resolve to include innovative seating in the total interior design programme. Seating constitutes about 55% of a coach interior's initial aesthetic impact, and Irizar was not content to settle for the usual slabs of upholstered foam. They wanted an expression of the inspiration evident in the rest of the interior concept, so Arup designed new seats from scratch.

Lazzerini was the chosen supplier, and meetings were held at Warwick with Irizar and Lazzerini to explore the possibilities to develop a seat that would complement the rest of the interior. Apart from initial sketches, the complete seating programme was designed using Alias Design Studio (Fig 18). Full-size foam models were made and shipped to Lazzerini in Italy, and the seat development programme was initiated.

Pre-production liaison

Once sign-off was achieved for both the exterior and interior forms, GRP polyester moulds were produced and shipped to Irizar for developing running prototypes and the manufacture of tools for surface panels and final interior components (Figs 19 & 20). Final surface digital data was also transmitted to them. A long period ensued of occasional visits to Spain to resolve engineering and production conflicts, plus the many small adjustments and modifications inevitable in any design process.

Throughout this period, Arup managed to preserve the clear design intent conveyed by the full-scale clay models, and a family of running prototypes was used for the press launch of the vehicle in February 2001 (Figs 21& 22).

19 & 20 above and below:
Final interior components
in running prototypes.

Conclusion

The new Irizar represents a total departure from the development process of its predecessor. It has transplanted design and development processes from the mainstream motor industry, the most innovative and dynamic manufacturing industry on earth.

The design team adopted those processes, and adapted and controlled them to suit its vision of what the 'Century's' replacement should be.

Irizar's management encouraged the team to innovate. They had the courage of their convictions, and were determined to embrace new technology and take their product boldly into the future.

Credits

Client:
Irizar S COOP

Design team leader:
Arup Ian Beech, Richard Carter, Jerry Chung, Pam Cox, Rob Egan, Martin Farren, Adrian Griffiths, Ian Grindell, Syd Hall, Aram Kasparian, Graham Lecornu, Graham Lewis, Gary Perkins, Paul Richardson, Mark Robinson, Paul Taylor, Jon Whitlock

Manufacturing engineers:
Sener Ingeneria y Sistemas, SA

Marketing consultants:
LKS Consultores

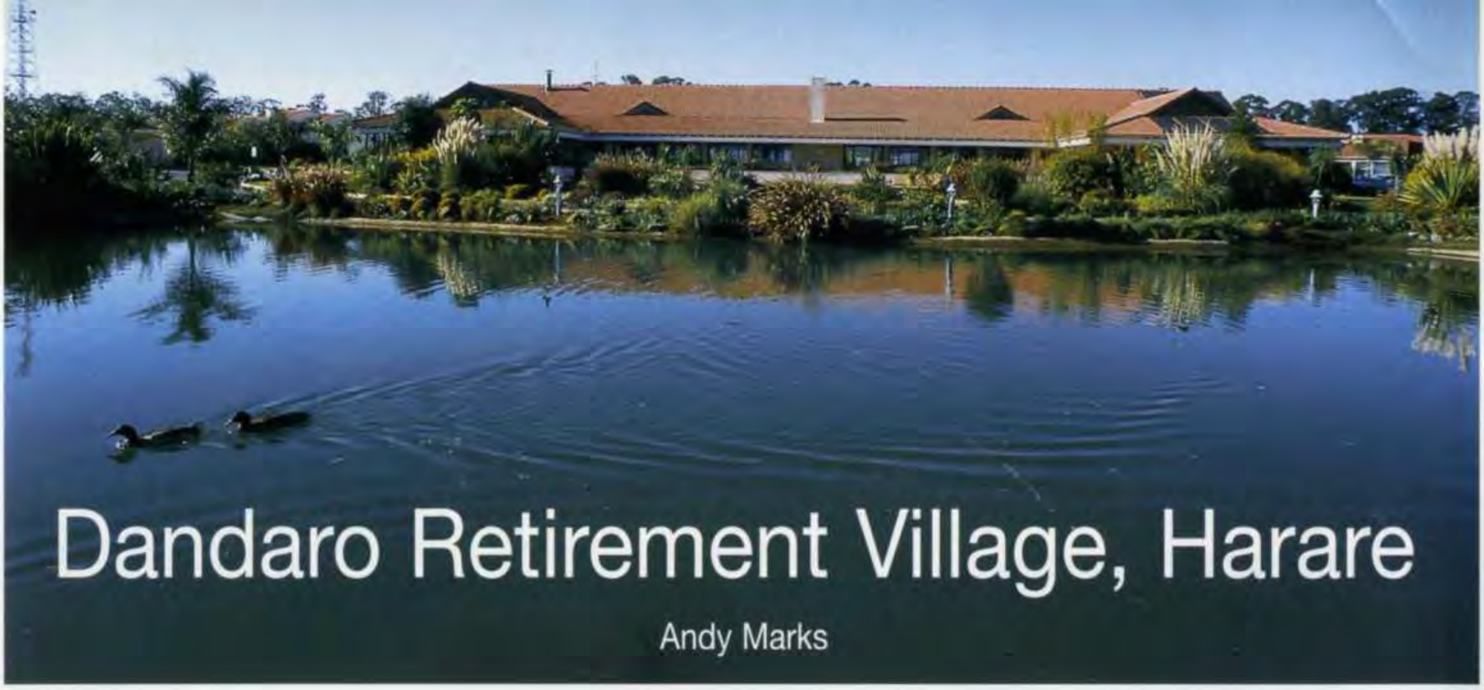
Illustrations:
Arup

21 & 22 below:
Running prototypes at press launch

> 'The Arup team is very proud to have led the development process which contributed to the production of the new Irizar coach.'

Dandaro Retirement Village, Harare

Andy Marks



1 top:
The extensive irrigation pond forms a serene focus to Dandaro.

Introduction

The Dandaro Retirement Village, set in the Borrowdale vlei in Harare, Zimbabwe, was conceived in 1995 by Wenham Investments, a first-time developer in this area, and completed late in 2000. It nestles between the wealthy northern suburbs of Alexandra Park and Borrowdale, with excellent access off the dual carriageway Borrowdale Road, 5km from the city centre.

Dandaro (a Shona word meaning 'a gathering or meeting place') is the first retirement village of its kind in Zimbabwe, and was modelled on specific market research in Southern Africa. Residents must be 50 years or older, and range in mobility from active business executives and farmers through to those in its medical centre requiring full-time nursing and permanent wheelchair access. The result is a highly serviced, high quality, residential retirement village, quite unlike the traditional and simpler 'old age homes' which focus more on the elderly and infirm.

Dandaro, therefore, is aimed at older people living in large family residences who want to downsize. Their specific requirements are for a secure community, north-facing homes, no steps, plus the high degree of servicing and community and health care facilities; these factors dictated the design brief. Virtually all the residents are car owners, with many having two cars and requiring double garages. This high mobility is essential, as public transport is poor and shopping facilities are 2-3km away.

The overall development involves 388 residential units on 26ha with a mixture of flats, semi-detached units and detached houses. A community centre, the health care facility, a bowling green, and a tennis court were included as communal facilities for all residents.

Development strategy

Initially Wenham Investments appointed Fleet Utria as architect and Arup as consulting engineer to undertake the overall scheme design and then detailed design for the Show House first phase. Arup was later appointed for all engineering disciplines, together with the overall co-ordination of a tightly packed infrastructure and buildings.

Soon after the developer had bought the land from the city of Harare, a small amount of seed capital was utilised to build the Show House. The project was then marketed and units sold from the plan to finance each phase. At this stage Arup worked with the developer and the architect in drawing up the phasing plan, which needed to be market-driven and hence flexible.

At the beginning of each phase, the infrastructure was installed but each housing unit only built as and when it was sold, with deposits and progress payments designed to ensure a positive cash flow.

After Phase 1 was complete, the market showed much greater demand for the detached units and so the adjacent stand was purchased and a link road planned to incorporate the new Phase 5. This necessitated a somewhat awkward one-way system around the second sub-station, together with the re-routing of numerous services.

Phase	*Flats (eight units)*	*Semi-detached (six units)*	*Duplexes (four units)*	*Detached (one unit)*	*Other*	*Start construction*	*Complete*
1		24	24	17		Sept 1996	Oct 1997
2	48	48				July 1997	Aug 1998
3		18	20	12		July 1997	May 1998
4	80	12			Community centre	April 1998	Nov 2000
5		12	42	31	Health care centre	Jan 1998	Aug 2000
Units	*128*	*114*	*86*	*60*			
Total units = 388							

Table 1:
The five-year phasing of Dandaro Retirement Village.

Design

The buildings are visually linked by common themes of brightly coloured features with russet brick walls and red tiled roofs. The community centre incorporates exposed timber roof trusses, which give the dining room and lounge a warm sense of space.

Arup's multi-disciplinary team designed and co-ordinated the civil and structural engineering to ensure that all the buildings would be adequately serviced by the necessary utilities. These had to be balanced with the client's requirement to maximise density but at the same time optimise the amount of space for individual occupants.

Transportation

Dandaro's main access was to be through a new signalised junction off the Borrowdale Road. Specialist design input for this from the transportation section of Arup's South African practice was needed, as the junction was shared with a new 5000-seat church for Hear the Word Ministries. This initial assistance subsequently led to transportation engineering being added to the range of expertise within Arup's Zimbabwean practice.

Roads and stormwater

The soils survey indicated a variable profile, predominantly of decomposed phyllite with a California Bearing Ratio of 3. The main access and circulation routes were designed for a traffic of 100 000 cumulative equivalent 80kN axles, whilst the cul-de-sacs were designed for 50 000 equivalent axles. The entire development was surfaced with a 20mm premix and curbs channelled the stormwater to a piped underground system.

The topographical survey showed that the adjacent Borrowdale horse racing track, covering 50ha, drained through the centre of the development. The design team investigated various alternatives for diverting this and settled on a concrete-lined trapezoidal drain in a new adjacent road reserve. This was designed for a 1 in 12.5 year return period and resulted in a significant structure whose capacity was tested during the floods of early 2001.

Water and sewerage

The city of Harare struggles with a limited budget, which is mainly directed to maintenance with little allowance for new work. Accordingly, the developer himself was made responsible for installing the 1.3km 250mm diameter asbestos cement outfall sewer, together with a 200mm diameter bulk water supply main.

Arup proposed a new and better way of organising co-ordination in the congested service corridors, through utilising a local co-ordinate system for all manholes, junction boxes, valves, hydrants, etc. This was straightforward from the design side, but slightly more complicated for the contractors. Eventually, to assist the contractors, the entire site was pegged on a 50m grid and all services and structures positioned off this.

The potable municipal water and fire hydrant systems were designed to accommodate a municipal fire tender, as the City of Harare Fire Brigades provide emergency services within the development area.

Irrigation

The landscaping, with indigenous trees and exotic flowering shrubs, forms an important aspect of the residents' quality of life. Zimbabwe has two distinct wet and dry seasons with 97% of the annual rain falling from October to April and only 3% between May and September. During the dry season, hosepipes are often banned and thus it was essential to provide sufficient borehole water to maintain the landscaping requirements. This was achieved through constructing a large central water pond into which the two boreholes pump continuously. This became a feature for Dandaro, with the tranquillity of the water and its attraction of wild birds and fish, which the residents have introduced. The pond is then used as a reservoir for irrigation through a series of booster pumps and the network of pipes, sprinklers, sprays, and standpipes - plus the occasional fishing competition.

2.
Site plan

Electrical

ZESA, Zimbabwe's electricity utility, supplies four 11kV-400V 500kVA sub-stations linked by underground cables. These distribute Medium Voltage (MV) power underground to 29 feeder pillar-mounted Distribution Boards through registered land survey servitudes on which no permanent structure can be built. These proved a major constraint for the developer and required careful co-ordination, particularly at conflict points with other services. The MV distribution network was then designed in service corridors to feed the individual units by underground cable.

Arup designed an extensive network of IT, satellite TV, communications, alarm and telecom nested PVC ducts and brick draw pits from the control centre at the gatehouse to each individual unit. This provides direct communication with the security personnel, together with access to satellite TV and alarms.

Structural

The structural input on the project was extensive although repetitive. The design team analysed numerous different dwelling combinations for efficiency and cost. The founding depth was 1.5m below the silt clay ground level and the analysis investigated the viability of deep reinforced strip footings or a combination of pads, stub columns, and ground beams. Reinforced strip footings plus load-bearing brickwork was the selected option, with the floor slabs cast on imported fill. To access the first floor units the flats utilise a circular wheelchair ramp made of concrete with steel handrails. The community centre uses a series of ring beams to support the feature laminated exposed timber roof trusses.

3.
Foreground left: access road crossing the irrigation storage pond, behind the community centre.

Construction

The construction spanned a period of five years, with several different contractors and contractors' personnel. Arup's consistent involvement and use of a co-ordinated services layout, together with a pegged local grid, proved effective in ease of setting out and accuracy in installation of services and buildings. These tied into the individual title surveys both for the buildings and the registered land survey servitudes.

Due to the phased nature of the construction, careful management by Arup was required at the interface between the infrastructure and building contractors. Conflict areas revolved around locating materials stockpiles to minimise their conflict with infrastructure services, plus ensuring the disposal of building waste and co-ordinating the phased completion of services and units.

This was particularly critical as purchasers had often sold their previous residences and were committed to moving in on a specific date. The difficulties of the initial phases were significantly reduced through specific co-ordination meetings and the emphasis on co-ordinated services installation.

4.
Wheelchair access.

Conclusion

During the five-year construction period, while Arup's multi-disciplinary involvement has steadily delivered this co-ordinated quality development, Zimbabwe has gone through major political and economic changes, which have increased the sense of insecurity in the older generation northern suburban dwellers. This, together with the farm occupations, has encouraged relocation to Dandaro, or at least the early purchase of a secure retirement home.

Though Dandaro is Harare's first private retirement village, it will not be the last. It is a highly successful project and is now over-subscribed with a long waiting list to either rent or buy. As a result, other similar developments are on the drawing board and a lot of interest has been shown in the Borrowdale Brook Village where Arup is part of the design-and-build development team, even with Zimbabwe's building costs escalating at 70% per annum.

5..
Community centre lounge and dining room.

'The success of Dandaro Retirement Village will be followed by others in Harare, in which Arup's involvement will continue.'

6.
The front of the health centre.

Credits

Client:
Wenham Investments
(Pvt) Ltd

Architects:
Fleet Utria Architects
Architectural Partnerships

Quantity surveyors:
Casling Rigby McMahon

Civil, structural,
transportation,
and electrical engineer:
Arup Shake Chambati,
Josephine Chigamba,
Chris Furukiya, John Hanlon,
Cornelius Kagoro, Andy Marks,
Cuthbert Makoni, Alan Mason,
Farai Mavhiya, Idea Musaka,
James Oputan-Emorut,
Stuart Perry, Lotte Reimer,
John Scullion, Fred Smith,
Rob Spooner, Wayne Waterworth

Building contractors:
FMI Costain
CABCo

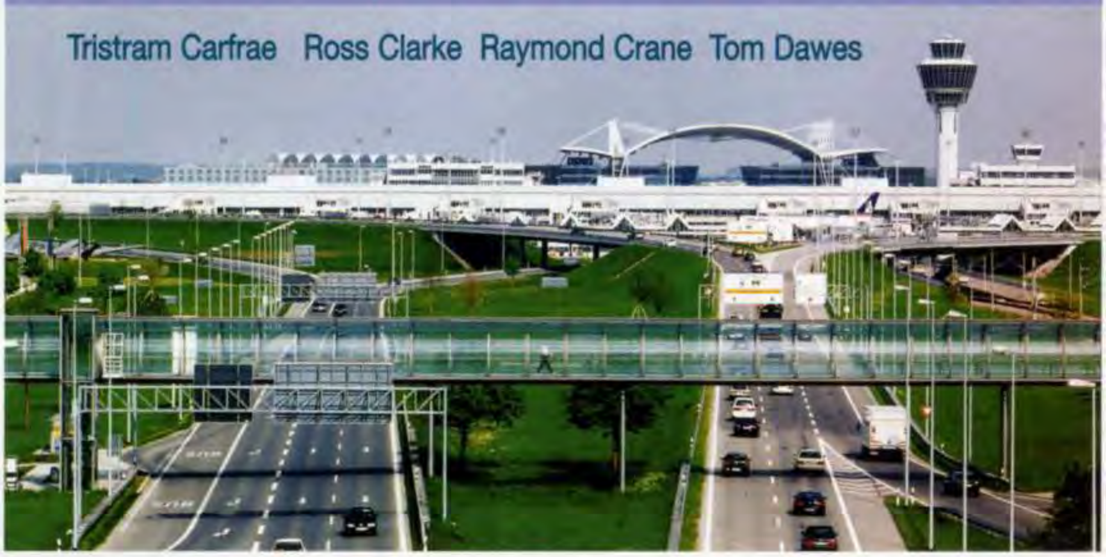
Roads contractor:
Bitumen Construction
Services

Water and sewerage
contractors:
R Davis & Company

Illustrations:
2: Fleet Utria Architects
1, 3-6: David Brazier,
Wide Angle

Munich Airport Centre Forum Roof

Tristram Carfrae Ross Clarke Raymond Crane Tom Dawes



1 top: The Forum roof in the context of Munich Airport.

Some history

Think of Munich, and more than likely it will be of beer halls, enormous sausages, and the Alps not far away. All this is true, which helps to make Munich a great place to visit. Locals and tourists from around the world know it, and as a result the number of passengers passing through the airport has been growing steadily.

The old Munich Airport (Munich-Riem) was close to the centre, but in the early 1960s the local government decided that the time had come to relocate it away from the densely populated and growing city, and the search was on for a remoter location. In the 1980s a 1500ha site about 30km away to the north-east was decided on and construction began. Airport Franz Josef Straus was opened in May 1992, comprising a terminal and two parallel runways.

In the years since, passenger numbers continued to rise, from 12M in 1992 to 21.3M in 1999. This ranks Munich Airport as the second busiest in Germany in both aircraft movements and passengers, behind only Frankfurt with its 45.8M passengers in 1999. Development of the site has continued since the opening, with shopping, restaurants, hotels, and office buildings being created in the surrounding area. Amongst these facilities is the Munich Airport Centre (MAC), a six-level 49 400m^2 development comprising approximately 30 500m^2 of office space on four of its levels, plus 10 000m^2 of service facilities, showrooms, shops, and restaurants.

Munich Airport Centre design competition

MAC was designed to be a service and communications centre at the heart of the airport, acting as an international meeting point with direct, nonstop connections to over 200 destinations.

Early in 1990, Murphy/Jahn Architects of Chicago invited Arup in New York to enter the international design competition set up by the airport operator, Flüghafen München GmbH (Munich Airport Authority) to choose a design for the complex.

In 1991 the team learned that it had been successful, and was chosen to take the design of the centre through to construction. This was the signal for Arup to draw on its worldwide resources to ensure delivery of the project.

Early design

Arup's New York office acted as project manager to deliver the firm's design and documentation, co-ordinating with the architects in Chicago and the client in Munich. Arup Sydney provided advice, in collaboration with New York, to the architects in Chicago on the structural scheme for the long-span Forum roof over the top of the office development, with further support provided by Arup's German offices in Düsseldorf and Berlin. Wind tunnel testing of the roof was carried out by RWDI (Rowan Williams Davies Irwin) in Canada.

It was a truly global collaboration.

The design process accelerated in early 1995, and a team was assembled in the New York office to complete the structural design and manage calculations submission and review by the German proof engineer (see below). Full structural engineering services were provided for the Forum roof, in addition to various elevator tower and stair elements, in accordance with all relevant German DIN standards.

German contracts are subdivided into several distinct stages under the HOAI (*Honorar Ordnung für Architekten und Ingenieure*) (terms of agreement for architects and engineers in Germany), with responsibilities and submission requirements strictly defined. These stages correspond approximately to the following for a structural steelwork project:

Stage 1: concept design

Stage 2: schematic design

Stage 3: design development

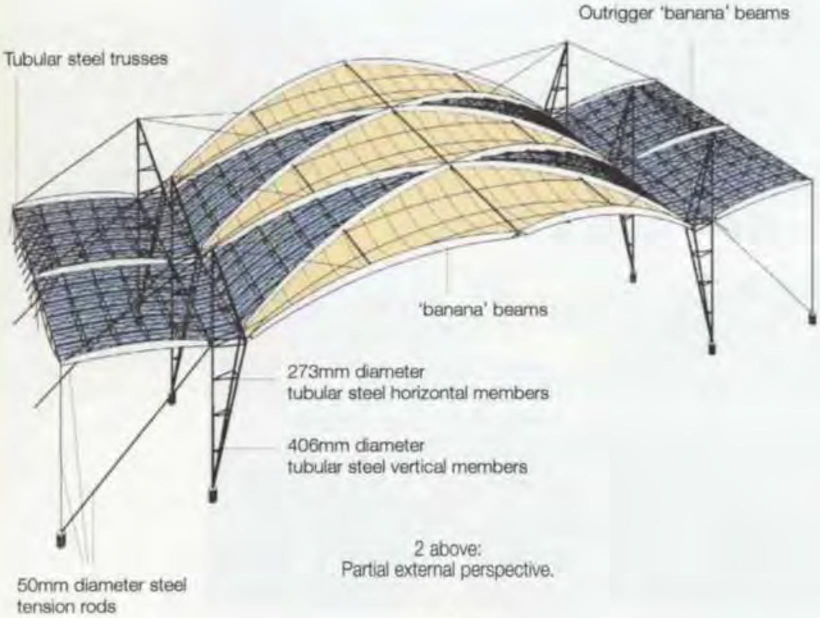
Stage 4: submission of AFC
(Approved for Construction)
calculations to proof engineer

Stage 5: submission of AFC
contract drawings to proof engineer

Stage 6: review of shop drawings

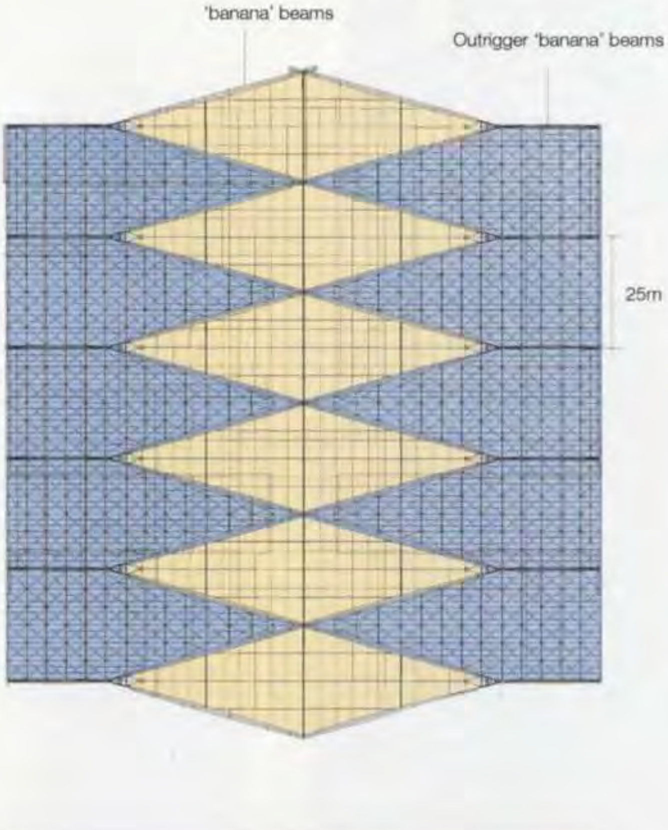
Stage 7: site inspection.

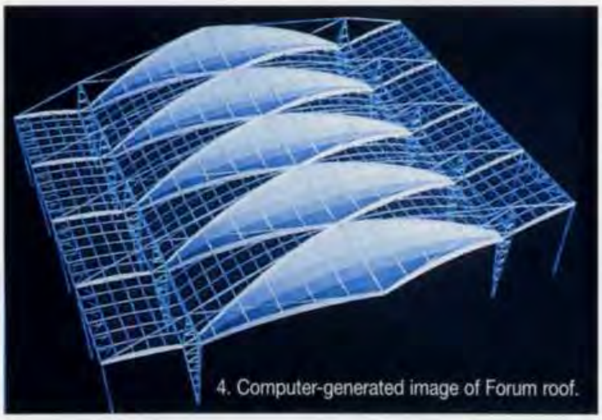
Arup's full structural engineering services covered Stages 1-6 inclusive. In addition, Arup in New York reported to the client on office environmental factors such as daylight, occupant comfort, and wind environment.



2 above:
Partial external perspective.

3 below:
Plan of glazed and fabric areas.





4. Computer-generated image of Forum roof.

The Forum roof

The most striking part of the development is the 19 000m^2 Forum roof, which encloses the common space between the office buildings around the perimeter of the site. The roof spans approximately 90m across the Forum space between steel tubular masts, to a maximum height of 45m. 22m back spans spring from the root of each support mast back towards the perimeter office buildings. Alternating glass and fabric panels cover the space below, supported by arching 'banana beams' criss-crossing the roof.

Arup's responsibility embraced the structural design of the Forum roof itself and provision of reaction loads at the base of the support masts and the ends of the tension rods. The engineer for the office buildings then considered these loads in the design of the foundations and base buildings.

Structural system

The primary support system via the banana beams for vertical downloads from snow and wind depends on a suspension rod system. Vertical rods spring from ground level up to the outer edge of the cantilever beams, thence up to the mast tops, down through and below the main roof span, and then mirror the same line on the opposite side of the roof. Wind uplifts are carried by the roof via the inverted arch formed by the main banana beams, being resisted at the connection to the root of the mast by inclined tension rods anchored into the side of the office buildings.

The completed roof structure does not appear to the casual observer to contain any obvious lateral load-carrying mechanism for imposed longitudinal loads parallel to the main axis of the roof. In fact the roof is anchored to the roofs of the office buildings below via a series of inclined high tensile 50mm diameter steel rods. These rods serve the dual purpose of tying down the ends of the outrigger banana beams, and restraining longitudinally the whole roof structure. Lateral wind loads are carried by the cross-braced diaphragm in each glass roof panel back to the roof edge via cantilever action, and finally to the roofs of the office buildings below.

Primary support frame

The whole Forum roof structure is a repeating 'kit of parts', including the steel banana beams, the tubular steel masts, the glass roof trusses, the fabric roof diamonds, and the tension rods.

Primary support is from the triangular cross-section, tapering banana beams, fabricated from varying thicknesses of flat plate. The main span beams have 20mm thick plates at the corners of the cross-section, with 8mm plates on the sides or webs of the section. Full-strength butt welds were used to connect adjacent plates. The outrigger banana beams have 25mm thick plates at the bottom corners and 32mm plates at the top corners of the cross-section, with 8mm web plates on the sides.

Loads are transferred into the support masts via a 120mm diameter steel pin connection at the lower end of the main span beams. Various roof elements, including the glass roof support trusses and the fabric roof struts, interconnect with the banana beams at points along their length.

The tubular steel support masts for the roof are located at 25.2m centres along its length. These elements were fabricated from typically 406mm diameter tube sections (verticals) and 273mm diameter horizontal tubes. The roof connects to the root of these masts 28m above ground, whilst their upper parts continue to a total height of 44m.

All node connections were designed to carry the imposed forces calculated from the roof structural analysis (see below) in accordance with the requirements of the German code DIN188001, which was based on the CIDECT (*Comité International pour le Developpement et l'Etude de la Construction Tubulaire*) guide for tube intersections[2]. Loads are transferred to concrete pedestals at the base of the masts via 190mm diameter structural steel pins.

5. Truss node detail in the glass roof zone.

The glass roof zones

Over 12 000m^2 of glass roof - or rather 12 individual 1000m^2 glass roofs - are suspended between the main and outrigger banana beams at a height of between 30m and 40m. Tubular steel trusses span up to 25m between outriggers, with 193mm diameter horizontal top chords, 139mm diameter curved bottom chords, and 114mm diameter vertical webs typically.

120mm x 60mm rectangular hollow section mullions at 1.35m centres carry the glass panes. Small diameter rods run between each of the adjacent glass roof trusses, forming a cross-braced diaphragm within the plane of the glass roof panels to resist longitudinal lateral roof loads.

Bottom chord stability under uplift loads is achieved via restraint provided by the vertical legs of the truss acting together with the horizontal tubes at roof level. These two elements form a series of inverted frames with moment continuity at tube connection node points.

The fabric roof zones

In the diamond-shaped zones between the masts and the main span banana beams, the fabric roof segments of the roof total about 7000m^2 in seven panels. Curvature in two directions provides load-carrying capability, enhanced for wind uplift cases by stainless steel spiral strand tension cables laid on the curving top surface of the fabric. The fabric panels are connected onto the edge of the banana beams via continuous powder-coated aluminium clamp plates. A nominal prestress of 5kN/m was introduced into the fabric before achieving the final geometry.

Sloping side walls

Running along the length of the roof is a sloped glass wall between the roof of the office buildings below and the outer edge of the Forum roof. Slotted hole connections at the tops of the sloping walls' mullion elements allow the Forum roof to move under load, independently of the office buildings.

6. Backstay connection to building.

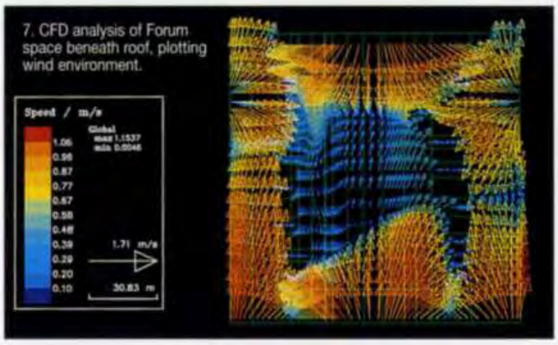
Structural analysis

Structural analysis models were produced in the GSA program for two bay-width segments of the Forum roof structure, including all steel elements. In addition, analysis models for the diamond-shaped fabric roof segments were produced in the FABLON program to determine the non-linear response of the material under imposed wind and snow loads.

Wind loads were estimated from the results of the wind tunnel testing, while snow loads (uniform and drifting) were based on the requirements of *DIN1055: Part 4*[3]. The maximum tensile stresses in the fabric were then compared with fabric strengths to ensure adequate factors of safety against fabric failure. Reaction loads from the FABLON analyses applied to the supporting roof structure (ie the banana beams) for each loadcase combination in the corresponding GSA analysis of the remainder of the roof structure.

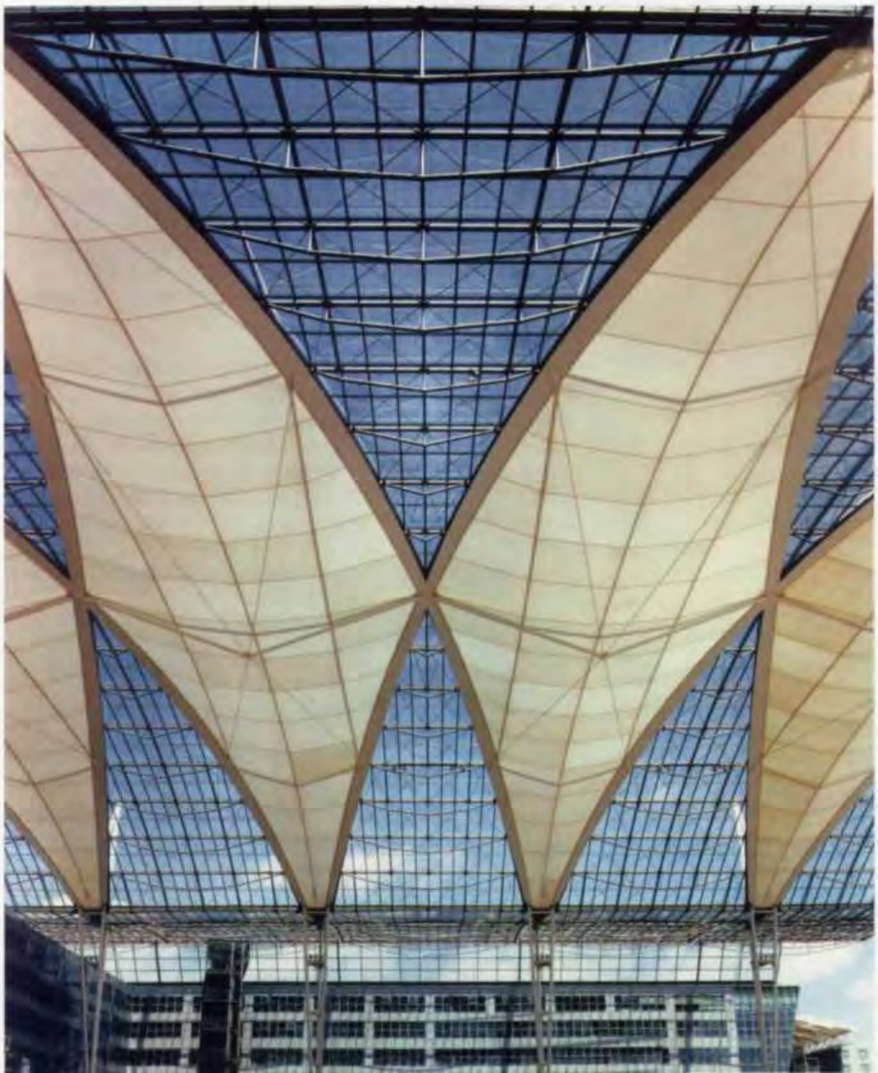
GSA models were used to analyse the remainder of the roof structure. One second order effect that needed to be monitored was the possibility of tension rods going slack under various loadcase combinations. In cases where this occurred, the slack rods were simply removed from the analysis model.

Reaction loads at support points were tabulated and provided to the design engineer for the base buildings so that they could be considered in the design of those elements.



7. CFD analysis of Forum space beneath roof, plotting wind environment.

8. Underside of Forum roof, showing tension cables below fabric roof zones.



9.
The roof seen from the Forum space along the central axis; the main entry platform is at the far end.

Involving the architects Murphy/Jahn in Chicago, Arup in New York / Sydney / Düsseldorf / Berlin and RWDI in Canada, the MAC project was a truly global collaboration.

Additional items

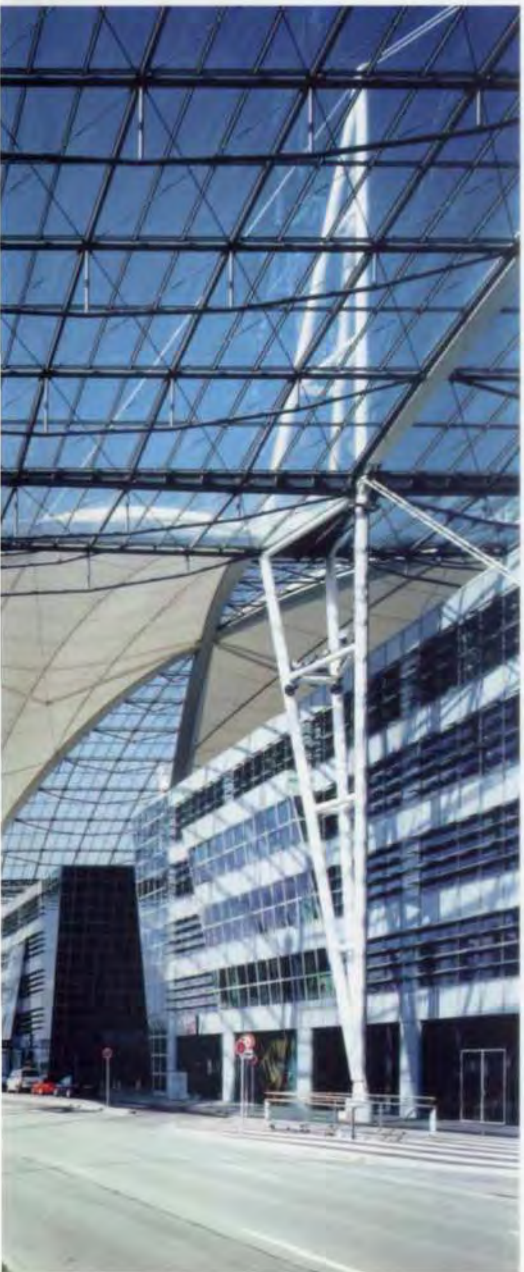
As well as the spectacular long-span Forum roof, Arup designed several smaller but no less interesting elements. Glass and steel elevator towers attached to the sides of the office wings provide access between the lower Forum floor area and the upper parts of the office buildings. These comprise slender steel skeletal frames attached to glass and steel access floors at each level. Cross-bracing in these floors provides restraint to the elevator towers, the glass floors of which are supported by cantilevering steel floor beams.

A large entry structure combines a grand glass and steel staircase with elevator access between entry level and the lower Forum level. Careful review of vibration performance of this element was necessary, as the architect required minimal dimensions for the structural support elements, as well as long spans. Two glass and steel 'scissor' stairs complete the access elements between these two main levels.

Proof engineering

As with all development projects in Germany, an exhaustive proof engineering process is followed, whereby the local authority appoints an independent engineer to review and report on the design of the client's engineer. The approval of the proof engineer is a necessary requisite for the authority to grant building approval.

Aside from submitting a full copy of all calculations and drawings in German to the proof engineer according to a predetermined schedule, it was necessary to meet face-to-face several times to explain the Arup approach and critical assumptions, in order to be signed off. Proof engineer queries were treated with the utmost urgency and were always fully responded to. The review process took nearly six months before full agreement was reached and construction could begin.



Construction

After the shells of the office buildings were constructed, erection of the main Forum roof could begin.

Shop drawings of the roof steelwork were reviewed in New York, with a number of German / English / German translations required during the process. The first signs of the roof on site were the concrete abutments at the bases of the slender tubular-framed steel support masts.

With the arrival of the prefabricated steel elements on site, construction of the roof proper followed. After erection of the main support masts, segments of the banana beams were transported to site, where they were assembled on the ground and lifted to their final positions. Of interest was the requirement to construct a full coverage scaffold up underneath the Forum roof structure during construction.

Opening

In 1999 the MAC Forum roof was completed, together with its access stairways and elevator towers. The first major tenant for the complex was the car manufacturer Audi, attracted to the modern image of the development in no small part because of the spectacular roof.

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10 top:
The Forum roof spanning over the office buildings.

11 left:
End bay of Forum roof above roadway,
showing backstay anchor points at ground level on left in picture.

Credits

Client:
Flughafen GmbH
(Munich Airport Authority)

Project manager:
Alba GmbH, Munich,
Germany

Architect:
Murphy/Jahn Inc, Chicago

Joint venture partners:
Grebner GmbH,

Structural, daylighting, and fire consultants:
Arup Paul Anderson,
Tristram Carfrae, Ross Clarke,
Raymond Crane, Tom Dawes,
Dieter Feurich, Peter MacDonald,
Alexander Schmidt-Narishkin,
Alan Shuttleworth

Prüfingenieur:
Professor Grimme,
Munich, Germany

Illustrations:
1, 8-11: Sellin/Engelhardt /
Murphy/Jahn Inc
2-4, 7: Arup
5, 6: Tom Dawes

'The world's largest self-supporting enclosure'

Michele Janner

Rüdiger Lutz

Pieter Moerland

Tristan Simmonds

1. top
The 363m long, 107m high elevation of the CargoLifter airship hangar. Its total covered area of 66 000m² would accommodate eight football pitches.

The CargoLifter hangar in Brand, Germany

Introduction

After 50 years airships are once again being developed in Germany. A firm named CargoLifter AG will use them to lift and transport goods of up to 160 tonnes over long distances. For this they have built a hangar to produce and maintain the first two of this new generation of CL160 helium-filled airships or 'blimps' - so called because they will have no rigid skeleton. No internal structure means less self-weight to lift, so they will be able to carry far more than the approximately 60 tonnes of the largest pre-War Zeppelins.

The site is a former Soviet airfield in Brand, some 50km south of Berlin, and the whole project comprises the hangar itself, several other buildings for component production, plus a visitors' centre. The architects for the hangar were SIAT Architektur + Technik, Munich, who also developed the masterplan and co-ordinated the planning. For the hangar they were supported from an early stage by Arup as structural engineer. Though it is an 'industrial building', the architecture of the CargoLifter hangar is of considerable importance both functionally and visually, due to its size and impact (Fig 1).

Planning

Based on production planning requirements for the CL160, a building envelope was developed which:

- minimised the building volume
- minimised the building surface
- will accommodate two CL160s next to each other
- relates in shape and choice of material to the airship 'theme'
- relates to and clearly develops technically in construction terms from past airship hangars
- guarantees an economic, functionally efficient, and aesthetically pleasing building, in which risk factors were minimised within the available timescale[1].

All this led to a building 363m long and 225m wide, its most notable feature being the large semi-circles at each end. Their 100m radius makes the central part of the building 'only' 160m long, which in section also forms a semi-circle with a height of 107m (Fig 2). This shape will snugly enclose the airships, but with ample tolerance. The segmented 'clamshell' doors at both ends of the building each comprises two fixed and six moving elements, and enclose the larger part of the hall. The additional cost of the doors' structure was compensated by the reduced central part of the hangar and minimised floor slab area - both resulting from the chosen door structure.

2.
Height / scale comparisons.

Also the aerodynamic outline, closely matching the clearance shape for two airships, minimised wind load on the structure. The hangar covers an area of 66 000m² - completely free of internal support - and encloses a volume of about 5.2Mm³.

The cylindrical central part divides into four bays covered with a translucent fabric and supported by five steel arches at 35m centres, springing off concrete plinths which also act as covered entrances. These arches have a clear glass roof between their top chords to allow daylight into the building, and through these 'arches of light' people can be directed straight to the nearest exit in a case of emergency.

Two-storey high concrete 'buttresses' along both sides of the production floor house facilities for 250 employees, with laboratories, and offices for a further 75. The hangar is heated from underfloor sources plus radiant panels hanging from the steel arches in the side areas.

Early on, IFI institute from Aachen carried out wind tunnel tests for the membrane and door structures. Before detailed design began, the analysis methods and principles were discussed and agreed with the *Prüfingenieur*. Eight months later, the detailed structural design was finalised and in 1998, before tender, the complete detailed design was checked and approved. Generally, all the concept ideas, solutions, design methods, and analyses developed by the design team were confirmed by contractors, the *Prüfingenieur*, and the wind tunnel test very early in the process.

4\.
The clam shell doors slide underneath each other, opening the hangar to the outside world. Inside, small versions of the CargoLifter are visible.

5\.
One of the building's two main parts: the steel arch-supported, fabric-covered bays. The arches spring from concrete plinths which also act as covered entrances giving protection against snow avalanches.

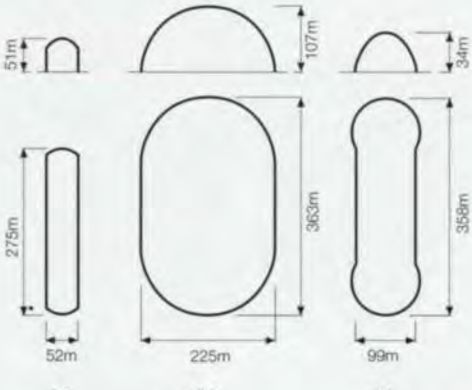
Historical background

Like railway stations, bridges, industrial buildings, exhibition halls, and towers, airship hangars are outstanding and fascinating examples of structural engineering. However, more than these other types of structure, in the past they have been designed purely with economics and function in mind, often ignoring aesthetics[2]. In Germany airship hangars were only built from 1898 to 1938 and none survive, nor any personal recall of them. Documentation is very scarce.

Nevertheless, the CargoLifter hangar is in a clear lineage of traditional German airship hangar technology, incorporating developments in design, detailing, and construction of large span structures from the intervening 60 years. Research on hangars and structural membranes at the Institute for Lightweight Structures (IL) at Stuttgart University by Frei Otto and Berthold Burkhardt during the 1970s and 1980s was repeatedly referred to during the design. Biaxial tests at the IL as part of the SFB64 research programme led on from earlier testing for Zeppelin skins, and are the present-day basis for the structural use of membranes[3].

Burkhardt and Osswald[2] surveyed and identified various structural systems used in airship hangar design. From this survey it became clear, that the fully moment stiff arch-structure resembles in shape, size, and structural system most closely the early reinforced concrete halls. A semicircle without hinges was a new structural shape. Structures with hinges came to be used because they were simpler to design and easier to build, but now the CargoLifter hangar in turn has reverted to a rigid hinge-less arch-structure because that requires less steel.

The CL160s, being blimps, will be rounder and more compact than Zeppelins, so the hangar is correspondingly wider and higher, but not much longer, than the largest earlier hangars (Fig 3).



3\.
Airship hangar comparisons
(a) In Frankfurt, Saarbrücken by Seibert (1936)
(b) CargoLifter hangar, Brand (1999-2000)
(c) Goodyear Airdock, Akron, USA (1929) - thought to be hitherto the world's largest airship hangar.

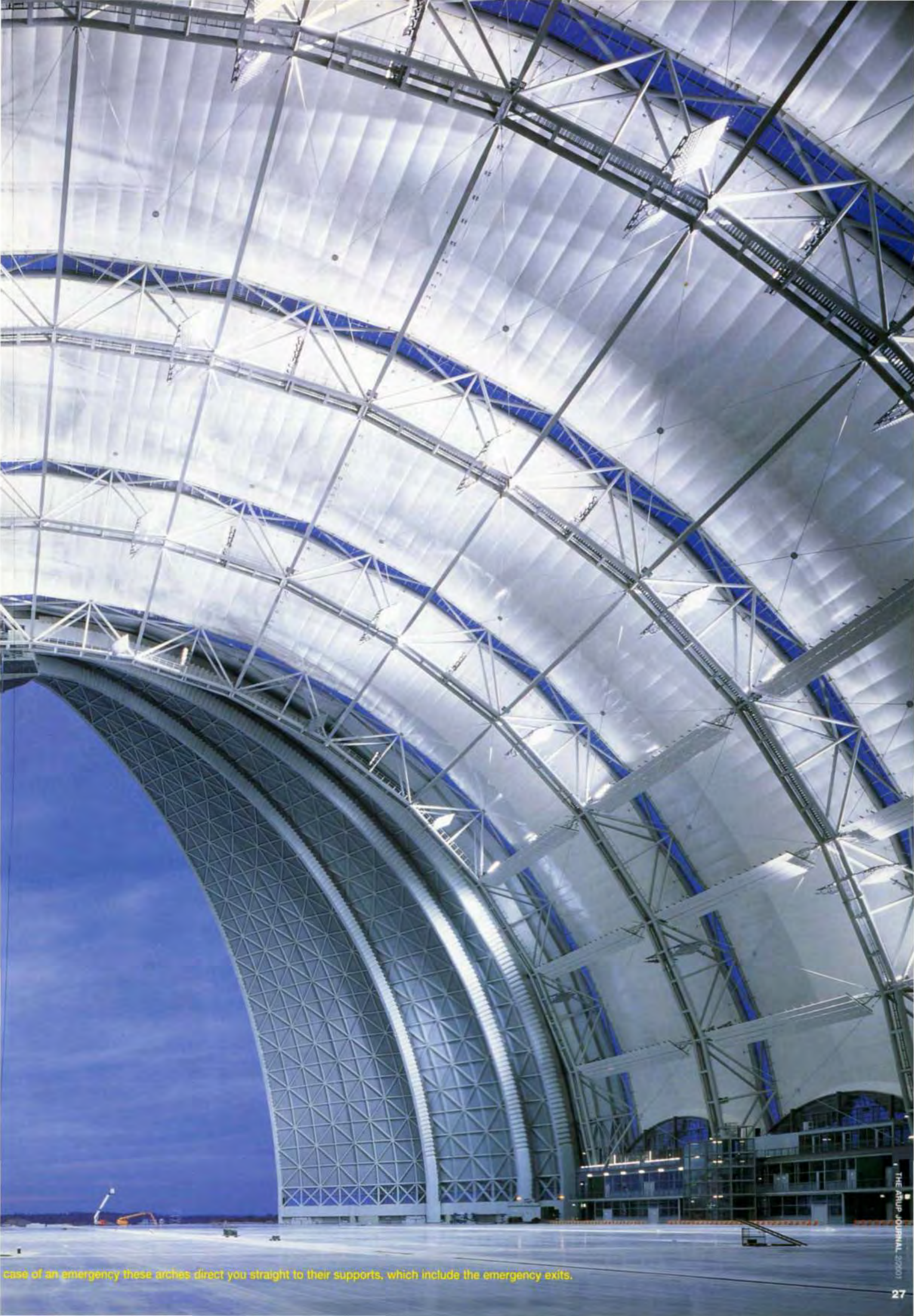
It also needed a new innovative solution to the design of its doors. In the past, various types were developed and built - sliding, swivelling and rotating, and also foldable and sliding doors - but those for the CargoLifter hangar, which are Z-shaped, are absolutely new in concept. It is worth noting that at, the same time, Arup was developing a retractable roof for the Miller Park Stadium in Milwaukee, USA, which is also segmented in single Z-shaped elements rotating around a single central point[4].

Structural concept

As already noted, the building has two main parts - the cylindrical centre of steel arch-supported, fabric-covered bays, and the sliding doors at both ends. The arches spring from concrete plinths, which also act as covered entrances to protect against snow-avalanches from the 107m high fabric roof (Fig 5). These bases are founded on large concrete pad footings designed to limit settlement to 30mm, and to avoid sliding due to horizontal wind loads and thrusts from the arches. There are no additional tension members tying the bases.

The steel arches have cross-bracing between them internally and props on the outside to avoid overall torsional buckling. They therefore provide a very stiff framework against horizontal thrust from the sliding doors. Both doors form a semi-circle in plan and a quarter-segment of a sphere in three dimensions. In each half of them, three moving elements slide under one fixed element. Each shell-shaped element is fixed to a hinge at the top of the end arch and guided horizontally by rails, both tangentially and radially, at the bottom. Each sliding door element has two motor drives at both ends at ground level (Fig 4). The floor was built as a concrete slab using road construction techniques, whilst the two-storey side buildings are simple flat-slab-on-column concrete structures on an 8.1m x 5.6m grid.

6. The trusses of the central part, being covered with clear glass, form arches of daylight spanning 225m. In the



case of an emergency these arches direct you straight to their supports, which include the emergency exits.

Loading assumptions

Initially, all the known and assumed loading data were assembled into one document, which was sent to and checked by the entire project team. After receiving approval for all the loading, this 'Loading Assumptions Report' formed a very important basis for the whole engineering team carrying out the calculations.

The snow load considered is based on the German standard *DIN1055: Part 5*, using a base value of 0.75kN/m^2, which can be reduced depending on the slope of the surface. The IFI Institute of the *Fachhochschule Aachen* carried out a wind tunnel test to determine the wind loading, though for the closed-door case only because the hangar doors will only be opened at wind velocities up to 10m/s. Hand calculations were sufficient to show that the open door case would not be a design load case.

As for special loads, a ±45°C temperature variation was applied to the external steelwork and ±10°C to the internal steelwork, whilst an additional load from ice up to 30mm thick (0.21kN/m^2) was applied to the external steel. The influence of foundation settlement (50mm) was analysed, but as expected the effects of foundation settlements on a structure this size were negligible.

The cylindrical part of the building

The five arches have a structural height of 8m and span 225m, with top chords at 3.441m centres and bottom chords at 2.0m centres. The chords are brace-connected to each other, with the exception of the two bottom chords; only straight members, forming a Vierendeel system, connect these (Fig 7).

Although the arches are always referred to as forming the 'cylindrical part' of the building, in fact they are not perfectly circular but polygonal: each consists of 17 straight segments about 18m long. The wind bracing is connected to the bottom chords at each intersection of two arch-segments. At the same intersection between the top chords, external props restrain any torsion in the arches induced by the eccentrically connected membrane (Fig 8). At their ridge the arches are longitudinally connected by a four-chord, 8m deep truss, similar in structure to the arches. This ridge beam enables the membrane and the valley cable at the top to be connected, and takes up the large compression force between the two end arches generated by the doors (Fig 9).

The CargoLifter hangar shows an awesome realisation of the original concept in the massive scale of the building envelope...

7.
'Charlie', a small version of the future CargoLifter.

8.
Between the top chords, external props restrain any torsion in the arches induced by the eccentrically connected membrane.

9.
At their ridge the arches are connected by an 8m deep truss, enabling the connection of the membrane and the valley cable at the top, and taking up the large compression force between the two end arches generated by the doors.

The arch elements are of tubular hollow sections because of their high torsional resistance and good buckling performance. The chords are 559mm outside diameter, the diagonals and bottom straight 355mm, and the side and top straights 273mm.

An iterative analysis optimised the use of steel over the whole structure. The cylindrical part was designed using the Arup non-linear structural program FABLON, plus the buckling option of GSA to determine the mode shapes.

Fabric roof

Textile membrane-covered timber halls were developed in the 1960s and 1970s, notably by C Stromeyer & Co, Konstanz. However, because of the availability of other, more durable, structural materials, these halls - for uses unconnected with airships - were all designed for ease of transportation and / or a short lifespan only.

For the CargoLifter hangar, PVC-coated membrane was chosen as the roof covering for three reasons: its light weight, the expected 20 years' lifetime, and the experience of over 30 years in using it for other types of construction. The stressed membranes span 31m clear between the trussed tubular arches in the warp direction and between the ridge truss and the edge cable attached to the arch bases in the fill direction (Fig 8).

Due to the large radius of the arches and their relatively small spacing, could enough curvature be generated in the membrane to limit stresses and deflections? Analysis based on a form found surface with equal prestress in warp and fill directions verified that it couldn't. Also, membrane deflection under wind uplift had to be limited to avoid contact with the main structure's external bracing. Both issues were solved by placing a valley cable over the membrane midway between arches and prestressing it against the membrane and edge cable at eaves level (Fig 10).

The doors

The enormous size of each door segment (arch length 168m, bottom width 42m) inevitably meant that they would be extremely heavy, and door weight strongly influenced costs. The upper supports of the doors load the ridge points (Fig 11), which in turn apply concentrated loads to the end arches and therefore influence their section dimensions. The lower support reactions of the doors also dictate the costs of the driving mechanism and the foundations of the doors themselves. To minimise the tonnage of steel was thus the main goal of the door design.

10.
Connection of the edge cable with the valley cable, the inclusion of which was of benefit when environmental reasons required a second internal membrane. By adjusting the prestress levels in the valley cables during form finding, it was possible to develop surfaces that did not clash when loaded.

11.
The doors rotate around a 450mm solid steel pin, held horizontally by horizontal plates between each door segment. This cantilevering connection is about 8m high and weighs 100+ tonnes.

The lightest structure was achieved by adopting the shell principle (Fig 12). The inner part of each door segment comprises a spherical grid of identical horizontal, vertical, and diagonal elements (DIN HE240A-sections), rigidly jointed. The corrugated metal sheet cladding spans across this grid between the upward-curving side beams, which are 3m x 800mm on plan. The shell is eccentrically connected to the side beams: at one side to the top flange and at the other side to the lower flange, so that a horizontal section through each door segment shows an approximate Z-shape (Fig 13). This allows each segment to slide under the next. At the foot, each door segment is terminated by a lower beam, 2.3m deep and 800mm wide, the four of which on each side of each door nest concentrically inside each other when the doors are opened (Fig 14 & 15).

Due to the hangar plan symmetry, wind tunnel investigations could be restricted to only one quarter of the building with four door segments (including the fixed segment). This produced for eight wind directions eight different wind profiles for each of the four segments. Adding the dead weight of the steel frame and cladding, snow loading, temperature loading, and movement of the ridge points generated several hundred load combinations. Arup's linear structural calculation program GSA gave a first impression of governing load combinations, and two distinct load cases, producing typical deformation shapes of an arch, were made. The appropriate loading factors were determined from these shapes, one 'gravity-dominated', the other 'wind pressure dominated'. In the latter, the loadings acting approximately in the gravity direction are multiplied by a factor of 0.9.

The German steel design code *(DIN18800: Part 2)* stipulates non-linear analysis for structures with critical loading factors λcr less than 10, as linear analyses do not produce realistic section forces for such structures. The procedure is to superimpose scaled buckling shape deflections on the original geometry and perform the non-linear analysis on the imperfect structure thus obtained.

14.
On opening, the door segments nest inside each other.

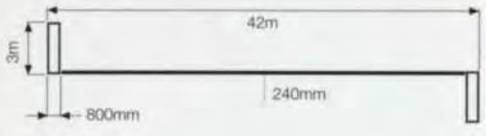
12.
Adopting the shell principle achieved the lightest structure for the doors.

Arup's non-linear program FABLON was used for this. FABLON recognises eventual instability of the structure (development of the collapsing mechanism can be monitored on the screen), so that the derived stresses in a 'survived structure' can be directly compared with allowable steel stresses (without slenderness limitations).

Additionally, however, a lateral torsion buckling check for the individual elements in the structure was required, as FABLON does not account for this instability phenomenon.

The deformations of the lower part of the shell relative to the edge beams were around 300mm, but they did not generate snap-through, even though the horizontal elements are very flat: an initial arch height of about 2m over 42m arch length.

Throughout, the cost aim of saving steel tonnage was not lost, and ultimately the combined effect of the wide-spanning lightweight stressed membrane, the thin, light shell structures, and 60 years' development in design, detailing, and construction led to an impressive weight comparison between two famous predecessors and the new hangar (Table 1).



13.
Horizontal section through a moveable door segment, taken at its base.

Table 1:
Compared to Cardington, the CargoLifter hangar spans more than 3.5 times as much with only 79% of its steel weight per m^2.

Location	*Year of erection*	*Width*	*Height*	*Weight*	*Weight / span*
Cardington (UK)	1924/26	55.4m	47.8m	~270kg/m^2	4.87kg/m^2 / m
Akron (USA)	1929	99.1m	54.8m	~230kg/m^2	2.32kg/m^2 / m
Brand (Germany)	1999/2000	203m	101.5m	~212kg/m^2	1.04kg/m^2 / m

15.
Near the ridge the perfect match of the z-shaped doors is clear.

Concrete elements

As well as the large amount of steel, about 20 000m^3 of concrete was also used in the hangar, mostly in the foundations to the arches, doors, and in the floor slab. Also, between the concrete bases of the arches is the two-storey office building (Fig 16).

The fairly good soil conditions did not require complicated foundations. A maximum allowable soil pressure of 500kN/m^2, with the assumption of a maximum settlement of 40mm, was used to calculate the door foundations. The groundwater level at -15m was unimportant for the structural design, so sliding, stability, occurrence of tension, and maximum soil pressures were used as design criteria.

Strip foundations - a 1m thick reinforced concrete slab with a 2m high upstanding block - were used for the sliding doors.

The foundation geometry was mainly governed by the required rail pattern for moving the doors. The slab width varies from 6m to 10m (from the centre towards the fixed door segment, and the large total length of the strips necessitated a doweled temperature/shrinkage joint in the centre of each segment (covering one door segment).

Single slab foundations support the arches of the central 'cylindrical' part, the bottom level of the 2m thick slab being founded at -5m. Two different sized slabs were needed, depending on position in the 'cylinder'. The end arches carrying the large door loads required 12m x 26m foundations, but those supporting the inner arches could be limited to 9m x 16m. The arches are based at level +8.85m and connect to the foundation slabs at -3m via 800mm thick concrete walls, which also form the short side of the office zone.

To minimise foundation moment about the hangar's longitudinal axis, each slab is placed eccentrically under its arch. The horizontal arch forces act outwardly, so putting the slab perimeter outside the hangar counteracts moments from horizontal and vertical arch forces.

The 300mm thick floor slabs of the office span between the concrete bases of the arches over three rows of columns, with a maximum clear span of 8.5m. These slabs act as diaphragms between the concrete bases, restraining the façade against horizontal loading. The slabs are only connected to one base, an expansion joint connection to the other base allowing for temperature movement.

Conclusion

The CargoLifter hangar was designed in 1997/98 and completed in 2000. A prototype airship should fly in 2003, with commercial operations beginning in 2005. The use of the building, its size, and the high architectural standards required by the client and delivered by SIAT prompted an outstanding structural design response - an arched steel construction carrying 2400m^2 high performance fabric segments over a total of 66 000m^2, at 203m clear span and 101.5m clear height, enclosed by the colossal segmented doors at both ends which open to the full height and width of the building in only 15 minutes.

The hangar marks the rebirth of the almost forgotten technological history of airship hangars in Germany, as indeed the advantages of the airships themselves for heavy long-distance transport - as they enter service during the next few years - will comparably come into their own within the 21st century's changing patterns of use, need for sustainability, and environmental sensitivity. Already the building is receiving high acclaim in the construction and architectural world, with its winning the Institution of Structural Engineers' Structural Achievement Award for 2001, and also the European Steel Award 2001 as an outstanding steel structure.

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Credits

Client:
CargoLifter AG, Wiesbaden

Planner and architect:
SIAT Architektur + Technik, München

Building services:
Klöffel, Bruchköbel

Client's representative:
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Structural design:
Arup Andrew Allsop, Cordula Cherubim, Pat Dallard, Thomas Dossenberger, Brian Forster, Volker Hass, Eva Hinkers, Michele Janner, Rüdiger Lutz, Pieter Moerland, Torsten Schröter, Tristan Simmonds

Road and landscape design:
Cordes + Partner, München

Fire engineering:
Halfkann & Kirchner, Erkelenz

Wind tunnel tests:
IFI, Institut für Industrieaerodynamik, FH Aachen

Illustrations:
1, 5-10, 12, 14-16: Palladium Photodesign
2: Sean McDermott
3, 13: Tom Graham
4, 11: CargoLifter AG

16.
The two-storey office building between the concrete bases of the hangar's arches.

International Tennis Centre, Olympic Park, Sydney

Graeme Bardsley-Smith

Geoff Herman

Daryl McClure

Robert Pugh

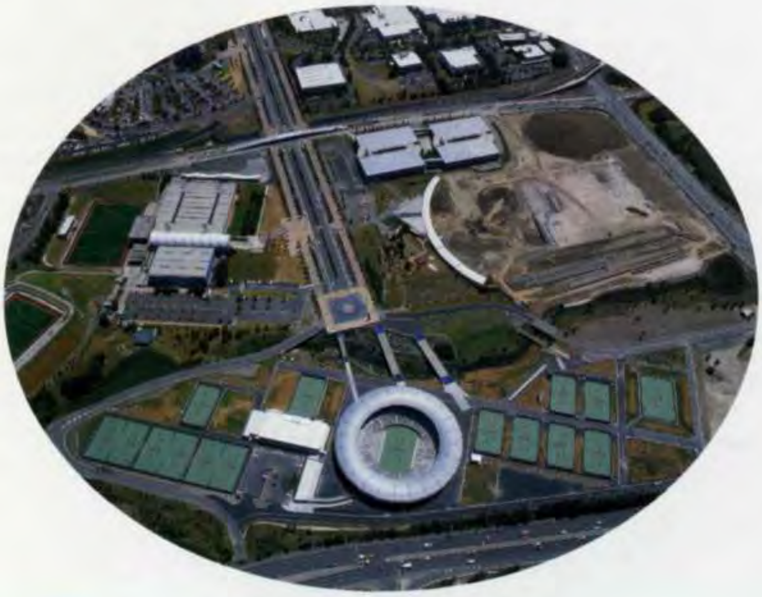
1 above:
External view of Centre Court Stadium in landscape setting.

2 below:
Aerial view of Tennis Centre site at the southern end of the main Olympic Boulevard, Homebush Bay.

Introduction

The Sydney 2000 Olympics were acclaimed as the most successful Games ever. Many factors contributed: beautiful locations, the Australian enthusiasm for sport, the professional organisation, and not least, the quality of the facilities. Most of these were brand new, state-of-the-art, and developed not only for the Olympic and Paralympic events, but also to provide an important post-Games legacy. The International Tennis Centre (Fig 1), designed by Lawrence Nield and Partners with Arup's Sydney office as consulting engineer, was completed in December 1999. Of all the Olympic facilities, it had special recognition by being awarded the 2000 Royal Australian Institute of Architects Sir John Sulman Award for Excellence in Public Buildings.

This article describes the engineering design.



Background

Most of the new Olympic facilities were in the geographical heart of Sydney at Homebush Bay, a brownfield site with a legacy of industrial waste and contamination from former brickworks and abattoirs closed in 1996. The remediation adopted a sustainable design approach, incorporating wetlands, parklands, waste and pollution control, and water and energy conservation. This approach informed the successful bid for the 'Green Games'[1], and was maintained for each individual development.

The Olympic Co-ordination Authority (OCA), formed in 1996, was the government vehicle for procuring the Olympic facilities, funded by combinations of grants, private enterprise, and contributions from sporting bodies depending on the particulars of the individual venues. The Tennis Centre client body derived from Tennis New South Wales (TNSW), as a secondary stakeholder to the OCA, since they intended to sell their existing White City Stadium and adopt the new Olympic facility post-Games as their future HQ.

Since the Olympics were seen as a once-in-a-lifetime capacity event, most venues, including the Tennis Centre, were set with a project brief and budget for the post-Olympic 'legacy' condition. A separate budget accommodated the temporary Olympic 'overlay' - increased capacity, television lighting, and broadcasting, catering, and ticketing facilities, etc. This 'overlay' budget, and the specific organisational aspects of the Games themselves, were administered by the Sydney Organising Committee for the Olympic Games (SOCOG). To ensure smooth operation, all venues had to be completed in time to stage a significant 'test event' before the Games.

The Homebush masterplan organised the main facilities either side of a broad, pedestrian, roughly north-south, 'Boulevard' spine, with the main transport node, the railway station link to the City, near its centre. The Tennis Centre site (Fig 2) anchors the Boulevard's southern end by the second major transport node, the connection to the interstate highway network. This prime site set the design challenge.

> **'...This is a significant and intelligent solution resolving urban issues as well as planning constructional and environmental concerns in a simple and direct manner...'**
>
> (From the citation for Australia's highest architectural award, the RAIA's Sir John Sulman Award, to the International Tennis Centre, Olympic Park, Sydney.)

Competition

The design team for the Tennis Centre, like most of the venues, was selected by open competition via a shortlist with corporate credentials, fee bid, and design approach as key criteria. The architect, Lawrence Nield, who had earlier led the masterplan of the whole Olympic site for OCA, had a particular affinity for tennis and assembled a very strong team including John Newcombe, the former No 1 player and Australian Davis Cup coach as tennis consultant, Building Design Partnership UK (who had recently completed the new Court No 1 at Wimbledon), as co-concept architect, and Arup in Sydney as structural, civil, geotechnical, electrical, mechanical, hydraulics, fire services, transport and acoustic engineers. The team was successfully appointed in December 1997.

Development brief

Initially, the complex was to provide a 7000 seat-capacity open centre court stadium, a players' facilities and administration building, two show courts (1 and 2), seven other match courts and six practice courts; and allow for three separate operational modes: Legacy, Olympic Overlay, and Long-Term. It was to be constructed to 'legacy mode', reflecting what TNSW would inherit post-Olympics as its new HQ: an international-standard venue (hosting the annual Sydney Open, the traditional warm-up event to the Australian Open at Melbourne Park, and thus incorporating the same 'Rebound Ace' artificial rubber playing surface) plus the national training academy, and also a day-to-day members' club and community facility.

'Olympic overlay mode' added 3000 temporary seats around the Centre Court to boost the capacity to 10 000, and provided for temporary sports lighting to broadcast TV standard, and other SOCOG facilities. Long-term, TNSW wanted to extend the stadium to a permanent 10 000 capacity, incorporating a shade roof.

OCA/TNSW's budget was for 'legacy mode' construction, with design provision only for 'Olympic overlay' mode (to be separately installed under a SOCOG budget), and for the long term (subject to future TNSW funding).

The skill of the design team led, however, to a design concept for the Centre Court which met the long-term objectives of a 10 000 permanent seat stadium within the combined budgets of the 'legacy' and 'Olympic overlay' modes, in such a way that the client could also provide the necessary additional funding for the roof. All three mode aspirations were thus satisfied at once by a singular design solution.

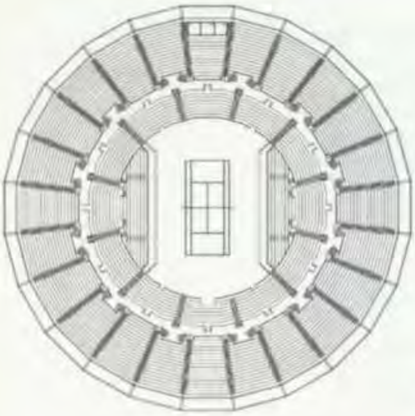
Masterplan

Apart from the obvious constraints of function and operation, the principal influences on the masterplan layout (Fig 3), were the site's context, orientation, and features. It is long and relatively narrow, running south-west to north-east and bounded to the north by a natural creek, liable to flooding, and south by an elevated busy main highway. Initially, therefore, major earthworks were envisaged to raise the site level for flood protection and also to provide some berm landscaping against noise.

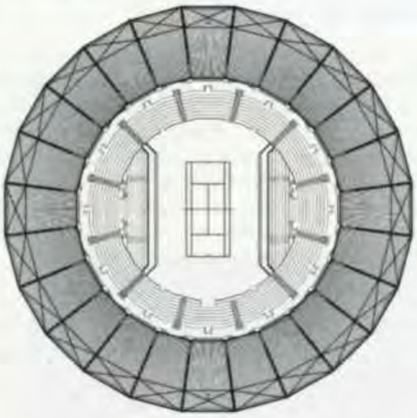
Tennis courts should be oriented north-south to avoid player distraction from low east and west sun glare. To fit all the courts onto the narrow site, they had to be arranged each side of an east-west axis - necessarily in two arms because of the site shape. The location of the Centre Court is the key to the masterplan. It anchors the Olympic Boulevard southern end, where the axis bisects the site, and its circular shape acts as a pivot which links the two arms of the east-west court layout. Match Courts 1 and 2 then form the ends of each arm, to spread spectator interest as well as dissipate congestion. The northern boundary, attractively landscaped towards the creek, and linking across to the main Boulevard circulation, then became the public front-of-house.

The southern boundary, adjacent to the highway and with a service access road, correspondingly became the private back-of-house and secure player entrance.Raising the site level had other advantages. It actually facilitated recessing the Centre Court to reduce its bulk, and enabled mid-level spectator access to speed entry and exit.

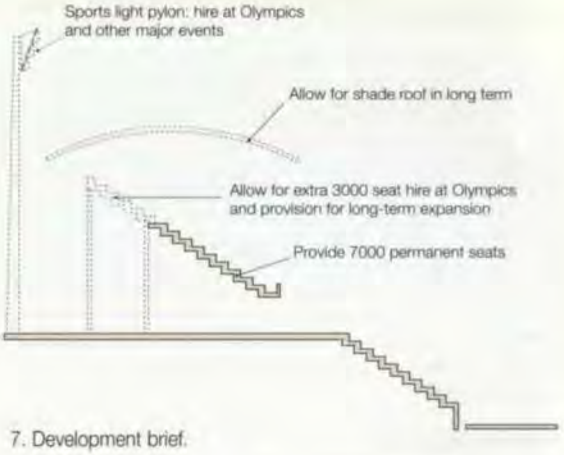
3.
Site masterplan.



4. Floor plan.

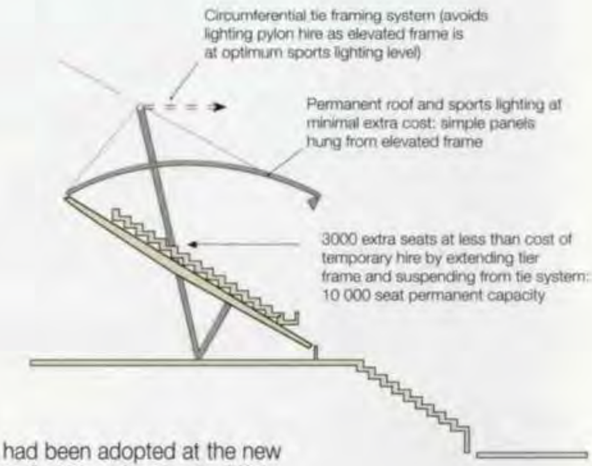


5. Roof plan.



7. Development brief.

8. Design added value: Arup solution.



6. Elevation.

Centre Court design

Concept

The team decided early to separate players' facilities and administration accommodation, normally bundled around the main stadium, into a separate free-standing building, thus liberating the stadium to be more simply designed in its pure functional form. The key design drivers - plan shape, raking geometry, and structural form - were ultimately combined together with each exploiting the others efficiently, and enabling a singular solution for the three operating modes.

Plan shape

For tennis, end-of-court viewing is preferred, but adequate capacity within acceptable viewing distances was only achievable with side seating as well. Also, enclosing all sides of a court with seating relates the audience more closely and satisfyingly to the tennis.

The human eye has difficulty perceiving anything clearly that subtends an angle of less than 0.4°, so for a 75mm diameter tennis ball the maximum viewing distance from the court centre is generally considered to be 41m (optimum: 30m). As this distance is relatively short, the most compact and efficient stadium shape is circular or approximately so, eg octagonal. By contrast, the efficient shape for other sports like football or athletics is rectangular or elliptical.

For 10 000-seat capacity, a circular plan with upper and lower tier sections of graded sight angles yielded an overall diameter (c100m) just above the maximum recommended viewing distance. Some perimeter seating falls outside the ideal distance, so some spectators may lose some perception of the ball - but not the drama of the play, so it was considered satisfactory.

Though a pure circular form is ideal, curved elements are expensive. A faceted approximation with equal segments, however, maintains the principle with a more efficient repetition of standardised straight elements.

A duodecimal form (12 sides) had been adopted at the new Wimbledon No. 1 Court, but for Sydney the team decided to adopt a 24-sided shape (Figs 4-6), offering ideal span dimensions for the floor units of each segment. It also helped to plan the alternate bays with vomitory access connecting to an intermediate circulation aisle linking the upper and lower tiers.

Raking geometry

The raking angle of tiered seating had to provide adequate spectator sightlines. A steeper angle generally gives clearer sightlines and taller seating risers (increasing available depth of spanning floor units), but it also raises overall height and overshadowing potential (a constraint for daylight tournament tennis). The most efficient approach is to increase rake proportionally with distance from the focal point, though for practical reasons this is usually done by incremental tiers. Four increments - roughly 15° to 30° - were provided in the Centre Court: courtside, lower tier, and two increments of the upper tier.

Structural form

A circular plan shape together with raking geometry creates a bowl - a stable form when circumferential tie forces are used, ie one side effectively balanced by its opposite. Taking account of this, an efficient structure free of conventional columns was developed, with a perimeter tie ring supporting raking tier beams and their seating units.

As already noted, the brief was for a 7000-seat bowl, with allowance for temporary and long-term expansion. This demanded extra perimeter seating - a larger diameter bowl (Fig 7) - and it soon became clearly more cost-effective to extend the same system of permanent seating than to pay for hiring tall temporary seating and falsework for the Games. Also, just as a necked vase is stiffer than an open bowl, the perimeter ring was arranged to create a rim, where a 'couple' could be developed between outer and upper rings so that the form would remain stable under asymmetric loading. The upper ring was propped on a raked mast which also gave additional support to the raking beam to minimise its section.

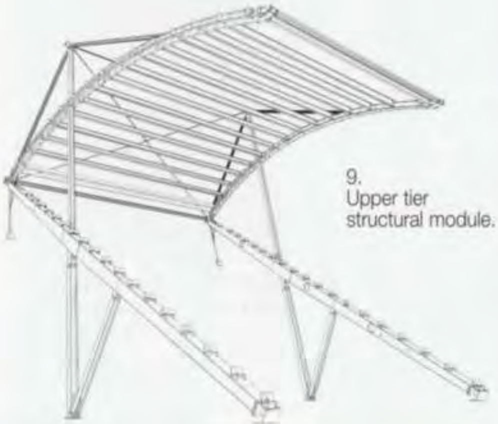
The upper ring was positioned at a level on the ideal angle for the temporary sports lighting, thus saving the cost of temporary lighting pylon hire for the Games, and making permanent sports lighting affordable (Fig 8).

A budget transfer from the SOCOG 'overlay' allowance was made to the 'legacy' budget so that a permanent 10 000-seat stadium with sports lighting could be built. However, since an elevated frame was included at no additional cost to the normal support of the seating, it made the provision of a suspended panel roof simple. TNSW were impressed by the value of this and found the extra money so that the roof (previously envisaged only in the long term), could also be built.

The design team believes this to be an excellent example of 'design added value', where the design solution took the client beyond his immediate ambition to achieve long-term goals at once.

Structure

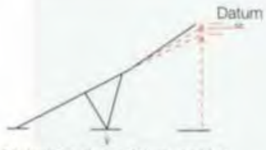
Levels for the semi-recessed Centre Court were determined by sitting the court level below soft soil on a firm founding shale, with fill built up as necessary (above flood level), to the concourse. In principle, the entire lower seating tier and concourse could thus be simple ground-bearing structure, but, since covered circulation was to be provided for secure court access for players, and banked earth sloping was preferred to avoid retaining structures, some suspended structure was in the end required. In situ reinforced concrete footings, ground slabs, and framing were provided for the lower tier, plus precast concrete seating plats to the same 24-segment system, as the upper tier.



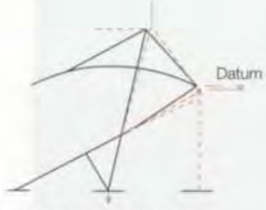
9.
Upper tier structural module.

10.
Erection sequence (a) - (d).

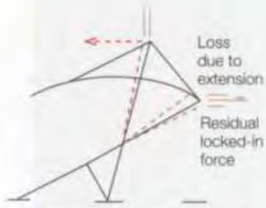
(a) Prefabricated downward precamber



(b) Jacking above datum position by temporary prop



(c) Complete roof and tie ring



(d) Remove prop - prestress induced in tie ring

11.
Roof panel prefabrication.

This upper tier comprises 24 fabricated steel, galvanised, tapered, box-section radial raking frames (Fig 9), supporting precast, prestressed concrete L-shaped seating, all carried on pile foundations through the soft fill to the shale. The outer ends of the tier frames are supported by a perimeter tubular tie, coupled and cross-braced with tie-rods to the upper tie ring supported on the mast. Since the masts are on radial stair lines, spectator viewing is not impeded.

The cross-braced couple forms a bending stiff ring on plan, to distribute out-of-balance loading on the overall stadium bowl. The upper tie ring was prestressed (Fig 10) by jacking the outer edges of the tier beams during construction to enable a visually slender tie rod element (otherwise a tube would have been required due to load reversal under certain conditions).

The panel roof has 24 segments, each 18m long by 12m wide. Each segment is made of a pair of simple radial channel sections, supporting purlins, with metal decking and a sound-insulated metal lining. The channels arch from the outer edge of the tier frame to the panel leading edge, which is supported by a raking tie from the mast. An inner tie ring completes the system. The 10 tonne panels were prefabricated on site (Fig 11) and lifted into place.

At concourse level, the toilet blocks are tucked under the bowl between tier frames, alternating with the vomitory access openings. The apparently 'cantilevering' superstructure effectively provides a shade covering and free spectator circulation around to the concourse level of the stadium, offering both efficient access and respite from the powerful Australian sun (and rain).

12.
The Centre Court at dusk.

Ventilation

The Centre Court was designed as naturally ventilated, with outside air flowing into the seating area through grilles mounted on acoustically treated plenums. Air is introduced to the plenums by intake louvres at concourse level. At court level, acoustically treated fans mounted in shafts supply air mechanically. Outside air passes through air shafts from the concourse level louvres into and through the tunnel, and into the court.

The design takes advantage of the thermal mass of the tunnel walls for passive cooling. In summer, the outside air drawn in is cooled by the walls of the tunnel through convection. This slightly cooler air is then discharged to the court. The daytime heat absorbed by the tunnel walls and bowl seating is removed by night cooling. With the fans switched off, the tunnel and air shafts form a thermal chimney. Cool night air is drawn into the tunnel from the court by natural buoyancy. It draws heat from the tunnel walls, and then rises naturally through the air shafts to be discharged to the atmosphere. In summer the fans can be switched on at night to assist this process. Their speed can be reduced in mid seasons and winter, when court cooling is not required. The toilets at concourse level are naturally ventilated by high level louvres.

13.
Detail of Centre Court at night, with Facilities Building in the background.

Lighting

Very high levels of illuminance and uniformity to camera were required for the Olympic TV coverage - and achieved. The lights were distributed in groups to the four '45°' corner angles, and attached along the leading edge of the roof, conveniently located over the concourse level cross-over aisle, so that they could be easily accessed for maintenance by mobile 'cherry-picker'. The Centre Court bowl was externally floodlit (Fig 13) from suspended fittings, and the spectator area illuminated by a combination of direct and indirect lighting.

Services integration

Principal services distribution is by a ring main system accessible from the circulation undercroft. This conveniently feeds the lower tier and court via the undercroft, the concourse toilets direct, and the upper tier by incorporation into the box tier frames above, which in turn feeds the roof at high level via the mast. Such careful integration of all elements was crucial to the final appearance in such an expressed structure.

Players' facilities and administration building

Concept

The aim was to bring together all the brief requirements for players' facilities and administration into a single stand-alone building, separate from the Centre Court - a focus for 'club' activity. Economic constraints dictated a simple, compact rectangular block (Fig 13), with a secure player connection to the Centre Court and the other match courts. It was sited to give a terrace grandstand view over Match Court 2, a main entrance off the private service road, and a cut-and-cover tunnel link to the Centre Court undercroft. Arranged on two floors, the building essentially comprises a lower ground closed box housing changing facilities and linking to the tunnel, and an upper, more open level, containing the club facilities and linking to the adjacent Centre Court concourse.

Structure

The lower storey is an in situ reinforced concrete flat slab-and-wall box on pad foundations; the upper storey a braced steel frame with a lightweight roof. In keeping with the simple design, both concrete box and steel frame were finished visually exposed, which of course necessitated careful detailing.

Ventilation

The building is fully air-conditioned, by an air-cooled R134a chiller and fan coil unit arrangement. The main function rooms, however, have openable glass louvres at either end to enable the air-conditioning to be switched off when conditions are favourable.

Match courts and practice courts

Concept

Following the Masterplan, all the other courts were arranged either side of east-west arms pivoting on the Centre Court. Major civil works were needed to raise the site level, provide drainage and other infrastructure services, and road and pavement access. Each element was integrated into the landscape using the hierarchy of the Masterplan axes.

Earthworks

The site had been remediated, and reportedly contained clean, well-compacted fill. Initial pavement and court designs were based on this assumption, but were modified during construction as the fill proved to be unsuitable. It was removed to the entrance to the Homebush site, forming a 'mound' feature which also serves as a noise barrier.

Settlement was critical in designing the court pavements, being limited to <3mm long-term. Due to removal of the unsuitable sub-grade, the average depth of court pavement was increased from the 700mm design thickness to well over 1m. Surface levels were increased in public areas to ensure they were above the 100-year flood level of Boundary Creek on the site's northern edge, and care was also taken to ensure all areas were wheelchair accessible. Over 90 000m^2 of fill was used - mainly crushed sandstone excavated from other concurrent local developments.

Drainage and flooding

Being below the 100-year flood level, the Centre Court playing surface needed a suitable detention and pump system, with fail-safe measures against flooding. The roof drains separately through syphons to surrounding drainage lines. A key feature of the complex is the subsoil drainage system, which is unconnected to the stormwater drainage to ensure no subsoil back-charging occurs during heavy storms. The aim was to minimise potential moisture changes in sub-grades under courts, thus avoiding unacceptable surface movement.

All stormwater lines lead to gross pollutant traps before entering Boundary Creek, which has been highly successful in stopping pollution entering the natural waterway.
The piped system was designed for 20-year return storm events, and overland flow paths were created to ensure none of the courts or buildings would be inundated during 100-year storms.

These being the 'Green Games', PVC and environmentally unacceptable materials were avoided wherever possible.

Site infrastructure

A comprehensive integrated voice and data network was provided, including outlets at all match courts. This had to integrate with the Olympic overlay and with future operations, and external campus distributors were provided with multi-mode fibre links back to the main distributor. To integrate as required with the scoring and ticketing systems, the system is set up with switches and hubs for tournaments, but is not normally used in the facility's day-to-day operation.

All courts have sports lighting, which in the Centre Court and match courts 1 and 2 is to broadcast standard. Area lighting is via fully cut-off pole-mounted fittings, and lighting generally is controlled to minimise spill to the surrounding area. Metal halide lamps are used externally throughout.

Electrical supply is from an on-site supply authority substation. With a significant distributed load external to the Centre Court and players' building, separate external distribution centres were established at each end of the site, supplying power for concessions, general area lighting, and court lighting. Water and sewer mains were available near to the site, as were telecommunications.

Roads and pavement

A new service road was built along the southern perimeter for heavy vehicles and for media and tennis club patrons and officials. Internal pavements were limited by budgetary constraints, and were eventually constructed as asphalt with concrete strip inlays, designed to carry occasional heavy vehicles, temporary stands, and concessions.

Programme and completion

The complex was completed in time for the January 2000 Sydney Open (Adidas International), the official test event prior to the Games, and it has been universally appreciated by players, spectators, and administrators alike.

The out-turn project cost was approximately A$34M. All the additions to the original brief were incorporated by the design team into the tight design-and-build timescale. The 2000 Olympics and Paralympics are of course now history but the client, design and construction team for the Sydney International Tennis Centre are proud that they played a part in the Games' success. Apart from the 2000 RAIA Sir John Sulman Award, the complex also received the Sir Zelman Cohen Award Commendation for Outstanding Work in Public Buildings, the BHP Colourbond Awards for Innovation in Steel Design and for the Most Outstanding Work of Architecture in Australia using Steel, and the Galvanising Institute Sorel Award for Industry Achievement.

Reference

(1) CLARK, B, HENSON, C, and HULSE, A. Transportation for the Sydney Olympics. *The Arup Journal, 36*(1), pp3-8, 1/2001.

Credits

Client:
Olympic
Co-ordination Authority
Tennis New South Wales

Project manager:
NSW Department of
Public Works and Services

Architect:
Lawrence Nield and
Partners

Consulting engineer:
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Henk Buys, Tristam Carfrae,
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Colin Henson, Geoff Herman,
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Daryl McClure, Robert Pugh,
Paul Raddatz, Jordi Skelton,
Vince Urbano, John Webster,
Pavel Zielinski

Quantity surveyor:
WT Partnership

Main contractor:
Abi Group

Steelwork contractor:
Pacific Steel

Illustrations:
1, 12, 13: John Gollings;
courtesy Lawrence Nield
and Partners
2: Bob Peters;
courtesy Lawrence Nield
and Partners
3-6, 9: Lawrence Nield and
Partners
7, 8, 10: David Grose
11: Robert Pugh
14: Bob Peters;
courtesy of Sydney
Olympic Park Authority

14
Olympic Doubles final

Ibhayi Brewery, Port Elizabeth, South Africa

Roger Hayim Ric Snowden Barrie Williams

Introduction

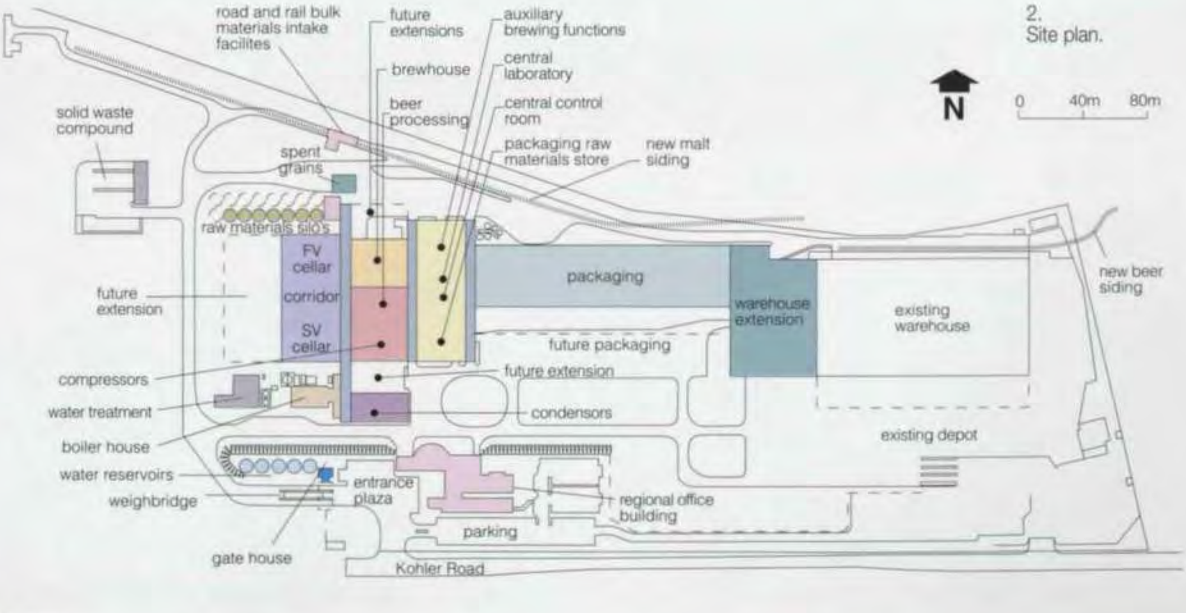
South African Breweries plc (SAB) is currently the world's fifth largest brewer, with 79 breweries in 21 countries and over 34 000 employees. Over the last 40 years Arup has successfully carried out projects in South Africa for SAB, and in 1993 and 1996 respectively, the firm prepared scheme designs for new breweries in the Eastern Cape at Port Elizabeth and East London. For various reasons neither of these was built, but more recent lack of capacity in the Western Cape, and market growth in the George/Knysna area, convinced SAB that the Eastern Cape was now the right place for a new brewery. Located by their existing depot in the Perseverance industrial area, 19km north of Port Elizabeth, the new brewery produces 750ml (quart) bottles for five of SAB's more popular brands. The total annual production of 2.4M hectolitres (50 000hl/week) is bottled through a single filling machine operating at 50 000 quarts an hour.

Arup's role

SAB's management wanted to build this brewery to international standards at better than world norms in terms of design and construction time, and cost. They were especially interested in improving on internationally accepted norms of dollars per hectolitre installed.

Arup, following its work on the earlier Eastern Cape designs, was asked to bid for the civil and building engineering design package. On appointment, a joint venture was formed with Davis Langdon Farrow Laing (DLFL), quantity surveyors, to provide civil and structural engineering, quantity surveying, architectural, and mechanical, electrical, and public health (MEP) services. Arup's South African practice provided the civil and structural engineering from Johannesburg, with the Zimbabwean practice handling the MEP services in consortium with Port Elizabeth-based firm Clinkscales Maughan-Brown.

1 Top :
SAB Ibhayi Brewery from the north-east.



2.
Site plan.

The architects were Winterbach Pretorius Letele from Johannesburg, together with Robertson Baker and Lochner from Port Elizabeth. Other services were provided by Port Elizabeth-based consultants and previously disadvantaged consulting firms. Contractually, standard FIDIC joint venture and sub-consultancy agreements were used.

Such a multi-faceted team required additional project management to establish skills requirements and availability. Arup was design and administrative leader within the joint venture, and with the design team embracing 14 different firms located in three cities and two countries, this leadership and technical co-ordination role was critical to the project's success. Process design was excluded, except for certain piped utility services and the refrigeration of the cellar storage buildings. Danbrew of Denmark were the process concept design engineers, and senior Arup personnel worked with them and SAB's project personnel to establish the site layout.

The scope of services provided by or under the direction of the Arup/DLFL joint venture was:

- principal agent for all civil and building work
- site selection and planning, including comparison of possible sites at the Coega Industrial Development Zone, Struandale, and Perseverance
- geotechnical engineering
- site services and infrastructure
- utilities and piped services (separate appointment)
- civil and structural engineering
- architecture
- quantity surveying and cost control
- mechanical engineering including natural ventilation, specialist refrigeration services and fire protection
- electrical engineering
- public health
- rail siding engineering
- access control and security
- full-time construction monitoring.

3 above:
Cellar building.

4 below:
View from south.

Shortly after finalising the basic layout, the client appointed project managers to assist their own project team in co-ordinating the process design, project implementation, cost and time management. A project office was established in Arup's Johannesburg office, which facilitated good communication between the various players.

The site

Arup looked at five possible locations around East London and Port Elizabeth, at one of which, Perseverance, an SAB depot already existed. The possibility of integrating this into the new scheme, plus the good road and rail access and municipal services, and the general attractiveness of the location, were the main factors in its choice. Some 17.9ha were already owned by the client. Conceptual planning began, to integrate the following facilities to achieve an efficient and economic layout:

- bulk malt road and rail intake facility, including road and rail weighbridges
- work tower for milling malt
- silos for 3000 tonnes malt storage
- brewhouse and beer process area
- compressor house
- Fermentation vessel (FV) and storage vessel (SV) cellars
- Ancillary brewing products and packaging store areas
- Control rooms and central services offices with laboratory
- service corridors and pipe spines
- packaging hall
- warehouse extension
- miscellaneous service buildings and external facilities including:
  - *water treatment building and reservoirs*
  - *truck wash bay*
  - *boilerhouse*
  - *waste compound*
  - *effluent balancing tank*
  - *rail dispatch facility*
  - *regional offices (scheme design only).*

The site is in the Swartkops River valley some 8km from the sea, and thus not unexpectedly its geology contains fairly substantial layers of hillwash and transported clayey sandy material with gravel layers and small boulders. Below this are layered siltstones and shales varying from very soft to soft rock.

Strip or pad foundations were founded on a stiff, coarse, alluvium layer at bearing pressures not exceeding 300kPa, whilst pre-drilled driven cast in situ piles were used under the main process buildings and heavy equipment foundations. A perched water table was present some 4m below ground level, and the aggressive groundwater required the pile and pilecap concrete to have an increased cement content of 425kg/m^3. To resist excessive chlorides and sulphates, a 50/50 mix of ordinary Portland cement and Slagment was used.

Piling was used to support all the buildings, whose total floor area is around 28 000m^2, except for the east end of the packaging hall and warehouse extension.

The 40 SV/FV tanks in the cellars, 480 tonnes each, were also supported on piles. The cellar floor slabs were stiffened with ground beams along the routes taken by the empty tanks during installation, whilst all other process equipment, including the heavy fuel oil boilers, is on ground slabs with or without thickenings.

5.
SAB Ibhayi Brewery from the north-west.

Site planning

The final layout centres around a common axis, which accommodates the product flow lines and links all the principal process areas. This layout will enable contiguous future expansion of all the main process areas, access between which is provided by service corridors/pipe spines. Central control rooms provide immediate pedestrian access to all key process areas, whilst locating the packaging hall to the north of the axis means that an additional hall can be constructed with minimum interference to existing operations.

Incorporating two site access points permits the existing busy depot entrance for distribution vehicles to be kept, and separates this traffic from the process-oriented raw materials bulk delivery vehicles, all of which pass over a weighbridge.

6.
Cellar building at completion of tank installation.

7.
Cellar structure's insulated paneling partially completed.

Environmental considerations

The main issues were the external impact of large industrial buildings, particularly on the adjacent housing estate, the internal environment, and industrial emissions.

External environment

Positioned as they are against a large, run down, fibre cement-clad building, the brewery buildings could only improve the look of the industrial area. However, the cellars are insulated with white painted panels and as it is standard practice in South Africa's cold storage industry to use these as external cladding, the visual impact of a bland white box some 80m x 40m x 25m high was of great concern. The possibility of cladding the cellars was considered, but this was only of slight additional insulation benefit, as well as raising similar concerns about large cladded areas, not to mention extra cost. Fortunately, the preference for an uninterrupted internal space of minimum volume suggested that the structure be external, and its filigree of exposed, hot dip galvanised steelwork has created visual interest.

Care was taken that the external site lighting had minimal impact on the adjacent residential area, and the whole site has been landscaped with many indigenous trees and has been fully enclosed with precast walling and an electrified fence for security.

Internal environment

The brewery is highly automated, with very few workstations in the process areas themselves and most of the production staff working in part of the central services area.

This houses fully air-conditioned areas such as the brewing and packaging central control rooms and laboratory at ground floor level. Also at ground floor level are workshops, raw material stores, refrigerated hop store, a label store with a controlled temperature and relative humidity, and 'process programmable logic controller' / server rooms. The production managers' offices are on the first floor.

Internally, in the process areas, 'light and airy' is the norm. Plenty of illumination is essential and good natural light has been provided by the generous spacing of the roof monitors, which incorporate ridge ventilators above, and translucent polycarbonate sheeting. Also, the light-coloured finishes give a clinically clean appearance.

Good ventilation is vital in brewery process areas, where heat and/or water vapour are always present and together make conditions ideal for mould growth. As much of the ventilation as possible is natural, but the building's depth necessitated mechanical injection of fresh air from high level ducting into the beer process area.

Industrial emissions

SAB intend to meet *ISO 9001* and *ISO 14 000* in the near future, but apart from effluent and providing the necessary infrastructure for certain of the waste streams, Arup was not directly involved in negotiating with local authorities on the treatment and handling of these.

SAB decided to contract a private supplier of steam who uses an electrode boiler with heavy fuel-fired (HFO) standby boilers for use when the power supply authority is under pressure, and when there are power failures. These standby boilers are kept at 80% of normal operating temperature for rapid start-up. This use of 'non-firm' electrical power (the local power supply company may discontinue supply to the boilers at their discretion at very short notice) is proving very effective, and avoids the smoke and general ground-level pollution from the normally more economical coal-fired boilers. Tall stacks are provided for the two HFO boilers.

As for effluent, provision has been made to install future treatment facilities; currently 200m^3 of it is stored for dilution in an underground balancing tank. Some of the packaging hall wastewater is recycled. Effluent and domestic sewage are reticulated separately for metering purposes.

'The Ibhayi Brewery project, for its size, has set new world standards for programme and cost.'

The compressor house is another area that received careful treatment. Its inherent noise levels and the rare possibility of ammonia escape necessitated it being totally sealed off from the other process areas, and a gas alarm connected to a mechanical extract ventilation system has also been installed. Its fire rating required the fire doors to be installed, as well as fire louvres over the windows, and there is also permanent extraction to the fork lift battery charging area.

Very unlikely, but nonetheless significant emissions, are those from the dust explosions that are possible in the work tower and silos. These have been fitted with low resistance blast release panels to minimise potential damage.

Design requirements

The client's required useful life for the brewery is 45 years, and this enabled lifecycle costing to be applied in selecting several of the major construction elements:

- pile concrete mix to resist aggressive ground water
- corrosion protection of exposed structural steelwork
- unpainted, imported *Zincalume* profiled metal cladding materials from BHP, Australia
- the finishes in general, including porcelain tiling and self-levelling epoxy screeds
- the insulation beneath the roof sheeting
- natural ventilation (low level louvres or dado wall openings with high level ventilators) instead of normal mechanical ventilation in the brewhouse, packaging hall, compressor room, boilerhouse, water treatment building and warehouse extension, thus conserving energy
- box type cellars over the tank farm areas to minimise ongoing maintenance of the tank insulation and energy costs.

Throughout, the key objectives were to construct the complete brewery economically and to the right quality, with a design and construction programme that bettered world norms for a brewery of this capacity. The client affirms that this was achieved, and senior SAB staff have expressed their delight with the completed brewery.

Building form

The main architectural design objectives were to create a unified family of buildings with a consistent architectural theme, using simple forms and efficiently engineered structures - all to support a harmonious and easily maintained working environment.

This has been economically achieved by using common components, colours, materials, and profiles, with carefully designed rooflines and building elevations.

Externally the principal materials are a maize-coloured facebrick and unpainted *Zincalume* profiled metal cladding, giving an interesting high-tech metallic appearance. In the end it was agreed not to clad externally the cellar walls but instead rely on the exposed, hot dip galvanised structure to provide visual relief against the stark white insulation panelling.

The cellar buildings have a full structural steel frame whilst other process areas and warehouse use cantilever concrete columns with a tubular steel roof structure. Torsionally stiff, triangular main trusses were used over the brewhouse and packaging hall areas, providing convenient locations for natural lighting, roof ventilators, and walkways for servicing artificial lighting in places inaccessible from below due to large items of process equipment or bottling conveyors. Tubes were selected because of their structural efficiency, looks, and dust collection advantage compared with angles.

Because of the delayed tank delivery programme, the cellars had to be designed for significant internal wind effects due to the west gable end remaining open until the tanks arrived. This allowed the bulk of the structure, insulation, and roof cladding to be completed before tank installation started - a solution that worked extremely well.

The silos were slipformed at a rate of 300mm per hour, the same slipform equipment being used to construct the water reservoirs.

9.
Interior of beer processing and brewhouse.

8.
The light and airy packhall.

Mechanical services

The scope included the following:

- heating, ventilation, and air-conditioning
- natural ventilation
- smoke ventilation
- hazardous zone classification
- fire detection
- fire protection including sprinklers to the warehouse extension and CO_2 gas protection to the PLC/server areas
- public health and other utility piped services
- cellar refrigeration plant and insulation design.

Cellar buildings

Process parameters are different for the two cellar buildings. The storage cellar is required to maintain temperatures between 0°C and 2°C with no specific internal humidity requirement, but the fermentation cellar is maintained at 14°C and a dew point of -6°C. Structural stability of the insulation panels was an important factor to allow the vapour barriers associated with the insulated envelope to perform satisfactorily.

Packaging hall

To facilitate using natural ventilation in the packaging hall, Arup carried out thermal dynamic studies which indicated that 40mm thickness of roof insulation would be adequate. It was also found that a slightly thicker polyisocyanate would span between purlins without additional secondary supports and without significantly affecting the thermal performance of the natural ventilation. Used with a coated fibreglass lower surface, this would provide an impervious washable surface - an essential maintenance requirement in high humidity areas. The studies determined the required opening sizes at low and high level, to provide about six air changes per hour and keep the 5% weather temperature below 30°C. Similar studies were carried out for all the other naturally ventilated areas.

10.
'Spaghetti junction'

Electrical services

The total electrical demand, excluding the feeds to the non-firm supply (by others) to the steam plant, is 3MVA. The site has a dual 11kV supply, which is reticulated to the enclosed transformer banks near to the boiler house and packaging hall. Power factor correction is incorporated in the system.

Artificial lighting levels were set at 500lux in the control rooms, laboratories, process areas, and offices, with 280lux in the warehouse and general areas.

Also included were:

- small power reticulation
- access control and electrified perimeter fence
- lightning protection
- surveillance and PA system.

Construction stage

The design and construction programme was extremely tight, with approximately 18 months from SAB Board approval (and start of design) in April 1999 to the first brew in September 2000. This placed great pressure on the design team and the contractors, but nonetheless the original target date was met.

An innovative solution was proposed by Arup which defined the various building envelopes prior to finalisation of internal process layouts, process loads, and even drainage requirements, all of which were later designed and installed within completed building shells. This two-stage design approach proved very successful, and allowed most of the structures to be built whilst the process design and design of the internals was being carried out.

Conclusion

The tight programme and the fact that briefing and design were often only a fax or e-mail ahead of construction set many challenges for everyone on the team from client to sub-contractor. However, the end result is what matters. Happily the excellent co-operation by all concerned has led to a successful project that, for its size, has set new world standards for programme and cost.

Special commemorative labels were printed for the first brew and this Limited Edition beer was presented to the guests who attended the official opening of the brewery in March 2001 by the Minister of Trade and Industry, Alec Erwin. In July the project received the SA Institution of Civil Engineering Witwatersrand Branch Award for Technical Excellence, and was shortlisted for the National Award.

11.
Cellar building detail at column.

12.
Brewing the modern way.

Credits

Client:
The South African
Breweries Ltd.

Implementation manager:
EMS (Pty) Ltd

Design team leader, and civil, structural and building services engineer:
Arup Tammi Abey, Mark Bester, Mark Boswell, Colin Chauraya, Greg Davies, Errol Davison, Eugene de Souza, Newman De Souza, Lukas Edwards, Clive Fick, Neil Glen, John Goddard, Geoff Green, Martin Grieve, Stuart Hall, Roger Hayim, John Heddon, Andy Howard, Dave Jackson, Dennis Jacoby, Jack Jaza, Roy Jones, Senzele Khosana, Elaine Lawrie, Melissa LeBattie, Carlos Lopes, Dezray Lopes, Denise Mall, Leonard Maramba, Brenda Maritz, Antun Medic, Roy Morris, Fortune Ngombe, Ofentse Nthutang, Mark Phillips, Johannes Ramapela, Gordon Read, Ronelle Roux, Denise Sanderson, Howard Scott, Ben Sehole, Richard Shedlock, Greg Skeen, Nic Smith, Ric Snowden, Faizel Solomon, Paula Sturgeon, Elvira Tessa, Paul Trewartha, Cathy Tuck, Barrie Williams

Civil and structural sub-consultants:
Ivo Huisman and Associates, Port Elizabeth
PD Naidoo and Associates, Johannesburg
Sibanye Consulting Engineers, Johannesburg

Building services engineering joint venture partners:
Clinkscales Maughan-Brown, Port Elizabeth
Worthington-Smith and Brouwer

Quantity surveying and cost control:
Davis Langdon Farrow Laing

Architectural sub-consultants:
Winterbach Pretorius Letele, Johannesburg
Impendulo Design Inc, Port Elizabeth
Robertson Baker and Lochner, Port Elizabeth

Rail engineer:
Robertson and Hitchins

Geotechnical engineers:
Geotechnics Africa

Main contractor:
Wilson Bayly Holmes / LTA Joint Venture

Illustrations:
1. Emine Tolga
2-12. That's Me Photography, Port Elizabeth

1 top:
Interior of London Heathrow datacentre.

European datacentres for IX Europe

Ed Russell

Introduction

Neutral colocation datacentres are large computer rooms, covering thousands of square metres, where many different companies house their computer equipment in a controlled and managed environment. The buildings provide a high level of M&E systems with the necessary resilience to support the '24/7' operational computer facility. 'Neutral' means that it is not owned or controlled by an individual telecom carrier company, and can thus supply its customers with a choice of carriers - between which they can swap with minimum disruption. Individual clients are also encouraged to trade between themselves in a mini-market within the datacentre, with the host company offering managed services that can include some of their client's products.

IX Europe (IXE) is one such company, formed in 1998 to set up a pan-European network of 24 individual datacentres in 10 different European countries by the end of 2002. In May 2000 IXE asked Arup to undertake a design review of their second datacentre site at Heathrow. Following this, the firm was asked to quote both for producing a standard reference design and for carrying out the project management of the roll-out. IXE accepted both of these, and by the end of May 2000 design and project management teams were in place. By April 2001 eight datacentres were already established in five countries - two in London, Paris, Antibes, Zürich, Frankfurt, Düsseldorf, and Milan.

Two further sites were being developed - in Barcelona and at a second location in Zürich.

2 left:
European locations for IX Europe datacentre roll-out.

Project management

Arup initially proposed to IXE that a project management team be set up comprising a senior project manager based at IXE's London headquarters, and individual project managers on each site for the duration of the works. IXE accepted this as the best route to delivery, and the senior project manager joined them at the end of May 2000. The first site project manager was appointed soon after for the Paris project, and the team continued to grow as individual sites were selected until Arup had nine project managers based in six different countries in Europe. This project management team was both multi-national and multi-lingual.

Project stages

The project management services provided to IXE can be divided as follows:

1 Locate suitable buildings / sites, undertake due diligence surveys
2 Negotiate building lease / purchase and organise local utility supplies
3 Assemble the consultant design team and manage
4 Negotiate with landlords and local building permitting authorities
5 Manage the tender process and appointment of contractors
6 Manage construction to quality and time
7 Manage completion of the project.

Suitable buildings

IXE had a clear rollout strategy of 24 cities to have datacentres by the end of 2002. The cities were also prioritised, so Arup knew which were likely to be first. IXE had also engaged Colliers as their real estate agent to carry out a pan-European search for suitable sites in these cities. Once Colliers had identified a possible site, Arup and IXE surveyed it for suitability. The basic requirements are listed below; some easily checkable with a site visit, others necessitating further investigation:

- minimum clear height of 8m for installing a mezzanine
- floor slab strong enough for a mezzanine
- clear span areas with minimum 6m column spacings
- external area for electrical and mechanical plant
- availability of local carriers and utilities
- access into the building - office and reception space.

By April 2001 IX Europe had established eight datacentres in five countries...

IX Europe is one of the best funded companies presently in the European business...

Negotiate building leases / purchase

Once a building was located and passed the initial survey, negotiation and detailed surveys began. Before the lease / purchase agreement was signed, the Arup team worked with IXE staff to investigate a building's suitability, including:

- site investigation
- structural survey (from visual to complete surveys)
- asbestos investigation
- project suitability with local authorities (change of use, additional areas, etc)
- availability of electrical power to the site and delivery of this power within the required project timescale.

As well as all this, it was sensible to include a break clause in the lease contract should planning consent and utility connections not be approved. A description of the proposed works was prepared, discussed, and agreed with the landlord, and then included in the lease contract. This mitigated problems over landlords disagreeing with works once construction had begun.

Electricity

None of the buildings found had the required power supply, and with around 1000W/m2 needed for the datacentre space, the total supplies had to be 4-10Mva per site. The buildings chosen were normally industrial warehouses, connected to only a small existing supply, so delivery of the new supply was not only critical to the programme, but also essential for the facility's operation. Arup made early approaches to local electrical companies to ascertain what supplies were available and on what timescales. In some cities, electrical supplies proved the main factor in choosing the correct site, the two most critical being Amsterdam (this datacentre never proceeded to completion) and Barcelona. Provision of supplies there could cost up to 10% of the total capital cost of the project, and the timescales could be many months.

Carriers

The other operational must for a datacentre is availability of local telecom carriers. They had to be consulted as to the location's suitability so that IXE knew whether they could connect to the facility. Generally, carriers keep information about their networks secret and so had to be asked direct questions about specific sites. One good approach was to arrange a carrier function where they were asked to attend; after this they could be followed up individually as to their availability.

All sites had two diverse ducts installed into the building from the public highway. Each contained 24 individual ducts, and as a carrier would normally take two ducts on each leg, this allowed a total of 12 different carriers for each site. The exact locations of the building entry points would be set after the initial responses from carriers as to which streets their networks were located.

Negotiation with landlords and local building control

The planned programme to design and construct each datacentre was around six months, the hardest obstacle to this being to get the correct approvals to carry out the works. Most sites were leased, and so landlord's approval was required for the works and also for some planning applications.

Approval from the building control / local permitting office was most important, and this had to be carried out in conjunction with production of the design. Time and procedures vary across Europe, and local advice had to be sought at the outset. One particular success was in Düsseldorf. German regulations were known to be stringent and work couldn't start without a construction permit, but IXE managed to speed the process up by approaching the Mayor and explaining what was needed. He was very keen to attract this type of business and loaned an assistant to guide the team through the permissions.

This not only helped with technicalities but also showed the planners that there was a certain political pressure to give the project the approval.

In some countries work can commence immediately (at client risk), but in others full permission must be granted beforehand. In France, for example, Bureau Veritas was employed as technical approver for all the works, starting work immediately on site knowing that the facility could not be opened unless it complied with local regulations. This saved some six weeks on the programme.

Procurement routes

From the start, design-and-build was the preferred procurement route. The project needed a fast-track strategy that was flexible, to incorporate differing local requirements. With D&B, local contractors with the necessary local contacts could be engaged.

The Arup-produced detailed reference design (see facing page) was used in tandem with laser survey drawings of the buildings to tender for the works.

Prequalification list

All those contractors known to be working in the field were contacted, and a pre-qualification list compiled of ones known to be D&B-capable and who were either based or had experience in the required locations.

For some countries it is more efficient to import the workforce from the UK, but in others better to employ locals. Some countries, like France, enforce a stringent 35-hour working week, so importing labour from the UK was more productive, but in Italy and Spain local contractors were the better option.

3.
External plant at Düsseldorf datacentre.

4.
Cut-through of typical datacentre

Supply chain management

When looking at the procurement it was beneficial to take the process one stage further. Initially Arup identified the plant items critical to the project programme, and then had to ensure that these were available. Manufacturers were contacted directly and agreements negotiated with them, but the main contractors were also asked to investigate what agreements they could negotiate. Even with the numerous items the rollout project required, the main contractors could often obtain better prices and conditions.

The contracts could be set up in different ways. Ideally the client wanted guaranteed delivery in a reasonable period at the best possible price. There was no advantage in reducing the delivery period below what the project needed, so for example 12 weeks for the generators and eight weeks for the uninterrupted power supplies (UPSs) and air-conditioning units (ACUs) was deemed acceptable.

Arup's preferred contractual set-up was for the manufacturers to guarantee delivery to a chosen contractor, with IXE only taking liability for the units being manufactured at the time. The route of purchasing equipment and free issuing to contractors was avoided because:

- Any delay in delivery can be used by contractors as an excuse to delay the overall project programme.
- If there are any faults in the equipment, again the contractor can blame the client.
- Procuring and managing the commissioning needs to be clarified.

Managing the construction works

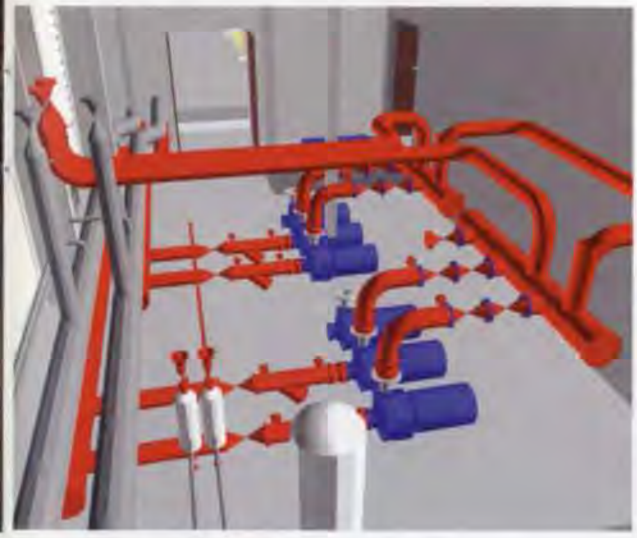
The full-time site-based project managers were IXE's eyes and ears, as well as monitoring and reporting progress of the works and design for the site. Weekly progress meetings were held and minuted, and these minutes issued to IXE as progress reports. The works were also checked on site to ensure that they complied with the reference design; any deviation from it had to be agreed with the contractors. The quality of the installation and the contractors' health and safety activities were also monitored.

Construction sequence

When allowed, works could start immediately as there was always stripping out and demolition to be done. When a site included a mezzanine, its installation was the next stage. A lightweight steel structure was chosen, with 38mm chipboarding that also incorporated a class O foil on its underside. This mezzanine was manufactured off site, delivery starting within three weeks of ordering, and took about three weeks to erect for a 3700m^2 site.

Once part of the mezzanine was complete, the main pipework for the glycol system would commence underneath, and would then continue across the main floor towards the plant area.

5.
3D model of pumproom pipework.



At the same time a jumbo stud plasterboard lining would be erected around the building perimeter, covering all the windows and giving both thermal and security benefits.

When pipework was complete, the next installation item would be the heavy grade raised floor - again commencing at the furthest point from the power room - including the floor frames for the ACUs and power distribution units (PDUs). Once the floor was in place, the high level *Hi-Fog* mist extinguishing system pipework and aspiration pipework would be installed and the suspended ceiling and lighting begun, an *Electrack* type plug-in lighting system being used for flexibility. The main cabling would be run on the slab at this point and left under the floor. Only when most of this work was completed were the ACUs and PDUs installed.

As work in the datacentre progressed, the plant areas were being completed ready for installation of the main electrical and mechanical plant - the dry coolers, generators, electrical panels and UPSs to be delivered later. In tandem with these works, the two carrier ducts were installed between the public road and the centre - normally let as a separate contract, and co-ordinated with the main works.

Works to the office, reception, control room, etc, were all programmed to finish in time for the opening, as well as for particular site's office requirements.

Security system

Good security is vital for the operation of such centres: all sites had 24-hour manned security from the day the building was obtained, and a secure four-stage entrance procedure was established as soon as the new reception areas were completed. Turnstiles, bandit glass and palm scanners were specified. Fixed CCTV systems were installed internally and externally, and a proximity card access system installed for the whole facility.

Handover

This differed from comparable handovers like an internal bank computer room, mainly because a full IT fit-out doesn't commence on the day of handover from the construction team. Usually one area is taken early, for the sales team to sell to an anchor tenant, and the main datacentre then handed over in one phase from the contractor to IXE when the works are completed.

Arup set up an internal system for IXE for the handover between the roll-out group and the operations group. This was in three stages, including checking that training and documentation was complete. Stage 1 was initial acceptance of the building and stages 2 and 3, completion of outstanding items. This helped because most of the operating staff were new to the datacentre world and could not be expected to operate all the equipment from day one.

The reference design

The Arup reference design was completed in June 2000, including a performance specification and set of schematic drawings and layouts. This design allowed IXE to procure construction as a D&B package. The design was in 3D - typical for most mission critical projects; this not only gives the design a better presentation, it also allows the layouts to be used in client marketing.

Electrical power requirements are the most important single issue with the design. Over the last year or so power requirements have risen significantly for such facilities, mainly because computers get ever smaller and more powerful, so more servers can be fitted in the same sized cabinet. The average power level required was approximately 1000W/m^2.

Electrical services

The design called for all sites to be supplied from medium voltage supplies, which supply dedicated parallel high voltage transformers owned by IXE. External low voltage generators were included in acoustic enclosures, each generator being provided with an integral fuel tank and additional fuel storage for 36 hours' continuous running of all generators.

The UPS units were sized to support the internet service provider load (ie not the telecom installation) with N+1 redundancy, for a duration of seven minutes at full load.

Arup produced a detailed reference design which allowed IX Europe to procure the works on a design-and-build basis...

Concluded: ▶

These *Chloride EDP90* range units were to be installed in parallel; from the main UPS electrical panel the supply was to be taken to moulded case circuit-breaker boards. Once a customer suite was sold, Arup would then install the final electrical system to their requirements, including the PDUs and the electrical runouts to slab-fixed sockets. Distribution boards were also included in the datacentre to feed telecom 48V DC systems.

All power cabling within the datacentre area was to be armoured LSF cabling laid on the slab, which allowed the maximum space within the raised floor for data cabling. Each cabinet would be fed from two sockets on the slab beneath the cabinets, on different circuits coming from two different PDUs. No cabling was installed at high level.

The lighting was to be Category 2 diffused, providing 500lux at floor level. An *Electrack* type plug-in system was used for flexibility.

Fire safety systems

The datacentres were equipped with both point detection and a highly sensitive aspiration system. The aspiration pipework was installed at low and high level, and was used to activate the *Hi-Fog* water mist fire suppression system - chosen by IXE for all the datacentres in preference to a gas system. This allowed great flexibility in construction as areas do not need to be sealed; also, *Hi-Fog* is safe for humans and computer equipment.

Mechanical services

Close control of the environment is vital for operating a datacentre. The rooms were to be cooled using close control ACUs connected to a glycol-free cooling system. The temperature chosen was 22°C ±2°C and the humidity levels within the space controlled to 48% ±15%.
The system was designed with 133% over-capacity.

Building management system

A specialist BMS was installed, a fully integrated modular *Cylon* system with a layered architecture that can be expanded and upgraded to keep in line with industrial developments.

Architectural works

A 600mm deep heavy grade raised floor with 600mm x 600mm antistatic laminate floor tiles was specified.

The perimeter of the datacentre was to be lined with jumbo stud lining and painted the standard IXE colour to *BS 22B15*. An open cell suspended ceiling was specified for the required 'look'; this also allowed for the easy construction of individual suites using demountable partitions.

As well as the datacentre area, all sites needed the construction / refurbishment of a new reception, control room, offices, toilets, etc. We also constructed specialist meeting facilities for the larger sites. These ancillary areas allowed us some architectural freedom to brand the facilities with a quality IXE feel and the design was completed on a site-by-site basis.

Conclusion

Since the IX Europe roll-out was announced, the whole internet and telecom market has become changed beyond recognition, and demand for datacentres has been reduced. 2001 has seen several companies go into receivership or pull out of the market, but for those that survive there is a good future. IX Europe has reduced its roll-out programme in response to the market changes and, working with Arup, has been very successful at keeping its capital expenditure under control. It is also one of the best-funded companies presently in the European business.

There is likely to be further industry consolidation over the next 12-18 months before the final structure for European datacentre companies becomes clear.

Credits
Client:
IX Europe
(www.ixeurope.com)
Designer and project manager:
Arup Alberto Bounous, Darren Briggs, Andy Brooks, Clive Cooke, Meik Graeve, Mark Grynberg, Jo Kennedy, Chris Marshall, Jimme Moller, Francisco Parrilla, Toby Reid, Jane Roberts, Ed Russell, Peter Samain, Tom Smith, Mark Togher, Michael Underhay, Owen Webber, Gordon Wills
Design-and-build contractors:
IT Environments
Asta Spa
GTM Spain
Illustrations:
1, 3, 6: Ed Russell
2: Nigel Whale
4, 5: Arup

Corporation Street Footbridge, Manchester

Stuart Clarke Andy Foster
Rick Houghton

Introduction

Corporation Street's new footbridge is an important milestone in the rebuilding of Manchester City Centre, the original bridge having been severely damaged during the terrorist bomb blast of June 1996. The replacement structure forms an enclosed link between Marks & Spencer's new flagship store and the much enhanced Arndale Centre, and is the result of a design competition devised by Manchester City Council. The bridge has set new standards of structural and façade engineering in urban footbridge design. Innovative techniques used in its realisation range from employing prestressed steel to form the hyperbolic paraboloid primary structure, to incorporating state-of-the-art glazing materials to ensure public safety in the event of glass panel failure. The result is a powerful symbol of regeneration.

Geometry

One of the biggest design challenges set by the brief was to conceive a form that could accommodate a sloping pedestrian route and address the street sympathetically at the same time. Further geometrical complexity was added by the fact that the openings in the two buildings were not quite opposite each other and that their façades are not quite parallel.
The structural form of the bridge, together with the fully glazed cladding solution, provides an elegant and apparently symmetrical intervention in the streetscape. The glazed section is in fact symmetrical, the adjustments for the variations in geometry being accommodated at the end collars.

Structure

Nine straight 114mm diameter tubes arranged around a horizontal axis give a sleeve of constantly varying diameter. Alternating with the tubes are an equal number of 28mm diameter rods, pretensioned so that no combination of loading results in stress reversal and slackening of the rods. Analysis checks focused on the sensitivity of the structure to frame buckling and parameters were adjusted to give the optimum solution.

1.
Assembly of structural 'sleeve'.

2.
The bridge at night.

3.
Interior towards Marks & Spencer

4.
Tubular sleeve and alternating rods in place.

5.
Interior towards Arndale Centre.

End collars

At both ends of the bridge's central section, asymmetrically braced collars transfer loads to the supporting buildings. These collars also act as anchorages for the tension rods. The collars were site-bolted to the central section to facilitate erection without the need for costly in situ welding. Due to programme constraints the collars had to be erected several months in advance of the middle section.

Walkway

The structure of the internal walkway deck consists of steel joists spanning longitudinally onto slender steel crossbeams coincident with hoop frames at alternate node points of the primary structure. The level of this walkway deck varies by some 1200mm along the length of the bridge.

Cladding

The architectural intent required the bridge to be fully enclosed to protect shoppers from the Manchester weather. This was achieved by cladding the end collars with decorative perforated ribbed aluminium grilles enclosing weathertight inner membranes that in turn clad the openings used for natural ventilation. The solution for the glazed section was to use a series of 10 different-sized triangular, laminated, heat-treated glass panels, positioned to create the three-dimensional curvature. These panels are fixed by cast stainless steel nodes that clamp the corners of each panel to the steelwork. The issue of safely supporting maintenance staff on the glass was solved by using polyester PET interlayers extending beyond the corners of each glass panel in the form of rectangular tabs mechanically restrained within the stainless steel nodes. Even if both layers of glass are broken, the interlayer is sufficiently strong to support the weight of a person safely for an extended duration. To confirm the viability of this proposal, a rigorous testing regime was specified and implemented by the contractor.

Credits

Client:
Manchester Millennium Ltd

Owner:
Prudential Portfolio Managers Ltd

Lead designer:
Arup Stuart Clarke, Graham Dodd, Andy Foster, Rick Houghton, Andy Sedgwick, Richard Summers

Architect:
Hodder Associates

Illustrations:
1, 4: Rick Houghton
2, 3, 5: Inside Out Photography

IT for the new Bank of China Headquarters, Beijing

1 top:
Exterior of new
Bank of China HQ, Beijing.

Michael Tomordy

Introduction

The People's Republic of China (PRC) has been in a period of rapid economic growth as it has opened up to the outside world. Currently, its foreign direct investment amounts to US$48bn, double that of the rest of South East Asia, and it is widely predicted that by 2005 the PRC's foreign trade will amount to over US$600bn.

This has resulted in a building, economic, and population boom, particularly in Beijing and the eastern seaboard cities like Shanghai. Perhaps more importantly, however, the PRC joining the World Trade Organisation (WTO) has opened the trade flood gates and created enormous global opportunities for the country's developing businesses as it inevitably moves towards a market-driven economy. Equally, this is likely to result in increased competition from more advanced market economies and better-run companies offering a wider range of often higher-quality products and services.

This in turn has led many mainland Chinese organisations to re-evaluate their business plans to maximise the expanding local and international marketplace, increase their competitive advantage, and defend against increased overseas competition in the local market. A fundamental requirement for competing both in the large Chinese market and globally is to invest in an adequate information technology (IT) and communications infrastructure.

Increasingly, organisations in the PRC are starting to implement more sophisticated customer service models that utilise IT and communications, eg call centres and Internet banking, since consumers are now expecting improved levels of service.

A little history

The Bank of China (BoC) is no exception in this drive to invest in new IT and communications. Historically, its predecessor was the Bank of Great Qing in the Qing dynasty (1644-1911), which in January 1912 reorganised itself and became the Bank of China. With the establishment of the PRC in 1949, the BoC was taken over by the new government and, since 1950, has been under the leadership of the People's Bank of China. Today the BoC has become the state-owned bank specialising in foreign exchange and foreign trade, and is thus more outward-looking towards global markets than other Chinese banks.

> Whilst Arup's was not the lowest cost bid, the firm was chosen because of: directly relevant international experience, understanding of integrating technology within building projects, total independence, value for money.

Arup's role

The BoC has built a prestigious new headquarters in Beijing, and this prompted it to re-evaluate the way it does business, its working environment, and - of necessity - its IT and communications infrastructure. Over the last two years Arup Communications has been responsible for many aspects of the IT and communications infrastructure for the new HQ, which houses over 5000 of the Bank's staff. Specifically, Arup provided the following services:

- IT concept designs
- detailed tender specifications
- managed tendering process
- project management during implementation phase.

Winning the project

Despite there being no Arup office in Beijing and the firm having no track record then of IT work in the PRC, the BoC appointed Arup Communications (the only Arup group working on the HQ building) against stiff, entrenched, locally-based competition in the form primarily of major US system integrator and consultancy firms already working with the Bank's IT department. Winning the appointment took over six months - partly due to the various stakeholders in the BoC's hierarchy needing to buy in to Arup's appointment, and also because in the PRC the market for consultancy services is neither well understood nor developed.

The traditional, familiar route is to use local design institutes, manufacturers, or the design-and-build contractor approach.

The project team

This embraced both local and international designers, contractors, and suppliers. The architect was the celebrated IM Pei and his firm Pei Partnership of New York, which teamed up with a Taipei-based interior designer. Pei, now in his 80s, has a long-standing family relationship with the BoC where his father worked in the 1930s; more recently his firm designed the landmark BoC Tower in Hong Kong, with its striking geometry.

For major Chinese state construction and infrastructure projects, a limited number of big, state-owned design-and-build contracting firms usually undertake all tasks necessary for a project's completion, and for the BoC project the main contractor and project management roles were undertaken by one of these, China State Construction and Engineering Corporation (CSCEC).

So far as the IT contractors were concerned, Arup worked with major US technology manufacturers, and appointed local Beijing firms to undertake the implementation works.

Undertaking the project

The design work was largely done remotely from Arup's Hong Kong office. Co-ordination meetings were held in Beijing with the client and other members of the design team as and when required. This proved both efficient and cost-effective, particularly with the absence of an Arup office in Beijing.

The importance of achieving and exceeding international standards was of paramount importance to the BoC and hence Arup was subsequently appointed to manage the project during implementation. Within the BoC, Arup was chosen and championed by the IT department although the building construction budget (including, unusually, the IT) was controlled by CSCEC. Thus, whilst Arup had lines of communication with both the client's IT and construction teams, the firm was appointed by and effectively reported to the latter.

This sometimes created differences of opinion between the IT department, who wanted world-class technology (at a price), and the construction team who controlled the budget and schedule. Equally, since the objective was to provide a world-class IT infrastructure, most of the design concepts were new to the client team, and their implications for the design of the building space and facilities required careful explanation from the outset.

Communications were mainly in Mandarin and English via translators, and to guarantee accuracy and effectiveness, official government interpreters from the Ministry of Communications were used. This reassured the client, helped to reduce concerns about using an overseas consultancy firm, and mitigated the communications gap. In fact, the same interpreters represent Chinese heads of state on high level inter-governmental discussions at home and abroad - so the Arup team was in good hands!

The building

The new HQ is close to the Forbidden City and Tiananmen Square. This meant that it could not be more than 45m high – a maximum of 16 storeys - and its designers were thus faced with the challenge of creating a high-density commercial building within this constraint. The total site, however, covers 13 100m^2. The HQ is distributed around a central atrium and has four below-grade storeys for parking, as well as an auditorium. Two sides of the structure afford clear passage into the atrium; no columns support the structure above.

The irregularly-shaped frame is reinforced concrete with continuous floor diaphragms at each level. Steel trusses support the free-span façade and auditorium roof.

The giant excavated atrium with its indoor garden is intended to be friendly open public space and thus forms an ideal meeting place. It also solved the problem of light penetration for a building with 100m long perimeter walls. Natural illumination enters from eight sides, not four, and internally the building seems light in contrast to its opaque neighbours.

It has both tenant and BoC open-plan office spaces, executive floors, audio-visually equipped meeting rooms and auditoria, computer rooms, the trading floor, a global network operations centre, and public spaces. Arup designed an integrated technology for all these spaces.

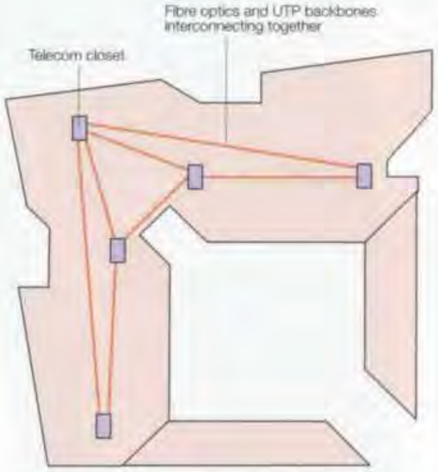
The solution

The ideal situation with such a project is to be able to influence / educate the decision-making process early on, through good, early intelligence. However, for the BoC project Arup was appointed relatively late; it had been under design and construction for 10 years and was already near completion.

This meant that most of the IT-related infrastructure, such as equipment rooms, telecommunications risers, and distribution routes for cabling, had already been determined and was under construction. This in turn meant that the Arup design team had to innovatively design its services within what was available, which in some cases was less than ideal.

Due to the large size of the floor plate, five sub-equipment rooms (SERs) are provided on each of the 16 floors. Dedicated telecommunications risers are within each SER, located vertically contiguously. Resilience and redundancy of both physical infrastructure and networking services is important.

A mesh architecture was employed for the backbone cabling, which consists of both optical fibre and Unshielded Twisted Pair (UTP) draft Category 6 copper cabling - over 2000km of which was ultimately installed. A structured cabling system was used, thus providing flexibility in terms of the distribution of voice, data, and video signals over a common type of cabling to any communications outlet within the building and subsequent ease of management. The use of a common type of cabling and communications outlets, coupled with a simple patching system in the various computer rooms, enables IT services to be delivered quickly and cost-effectively to any part of the building, without the need for re-working any part of the installation. This generates significant long-term cost savings. All equipment rooms on a particular floor are fully inter-connected, so if a particular equipment room, section of riser, or backbone cabling fails, networking services can be rapidly re-routed through a simple patching arrangement. This minimises risk and ensures business continuity to BoC.



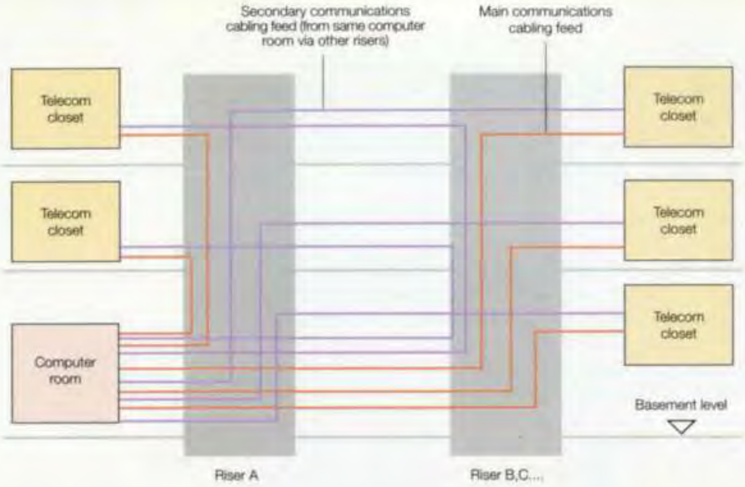
2.
Floor connectivity diagram for structured cabling system: a full mesh architecture is provided for resilience and redundancy to minimise risks and maintain services.

Though there is some tenanted space, the building was being constructed for occupation primarily by the BoC, so the IT requirements were significant and major in terms of the sheer size, capital value, and services required.

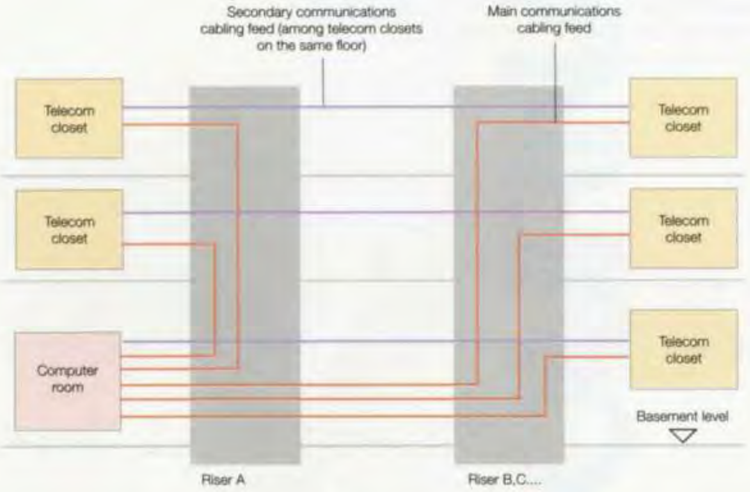
The networking infrastructure core equipment was also designed according to a distributed architecture and a resilient approach. This was based around duplication of certain key components in different locations but linked with high-speed optical fibre.

The need to meet and exceed international implementation quality standards was paramount, so - as already noted - Arup also took the project management role, working alongside the contractors and other members of the multi-national team.

Site conditions were often challenging. For the structured cabling, the very uneven slab provided a clear raised floor depth of only 40mm (the normal recommendation is for a clear void of at least 150mm). There were also various difficult environmental challenges, particularly the rodents! Suffice it to say that the standards of health and safety and working conditions were perhaps less than ideal, with a number of dust-borne illnesses prevalent on site.



3 Above: & 4 below: Telecom riser diagrams.



The BoC has offices across the PRC and globally, and the guarantee of a secure telecommunications link to headquarters is increasingly important as retail banking grows in popularity across the PRC. The system was designed for use both by BoC staff and their customers and members of the public - as, it is predicted, will be increasingly the case. Telephone banking is relatively new in the PRC, and the PBX was designed to accommodate this facility through provision of a call centre.

As the density and penetration rates of telephones increases, the volume of traffic will also expand, hence the need for a robust solution. Increasingly the trend in the IT industry is towards convergence of voice and data networks.

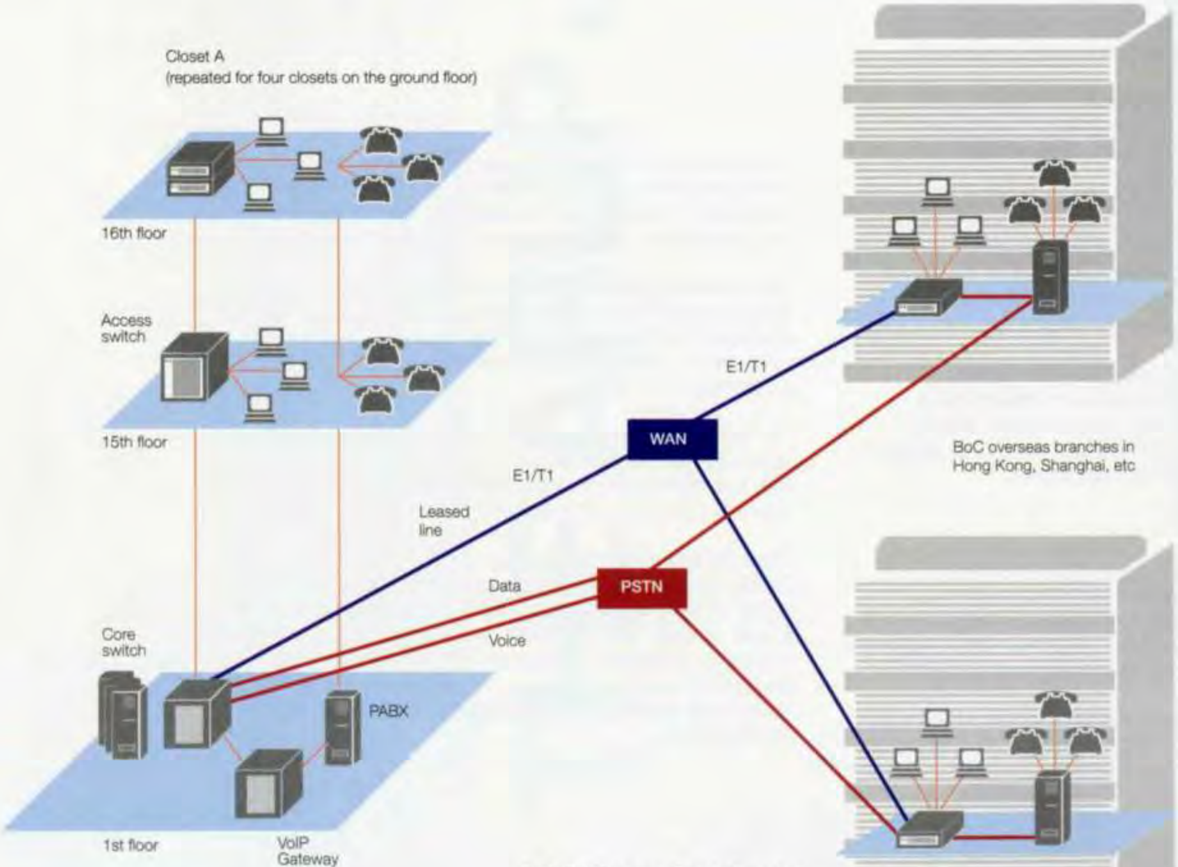
Whilst these technologies were not available at the time of implementation, the system was designed with an upgrade path to enable Voice Over Internet Protocol (VOIP) solutions to be implemented, thus 'future-proofing' the solution.

Due to the size of the building, the need for mobility of services is of paramount importance, and a private wireless-based telephony system is also employed. Walkie-talkie and radio paging is also provided, allowing staff to use the system and be contacted whilst they are in the new HQ, and also use the same handsets from other major offices in Beijing, thus increasing flexibility and productivity.

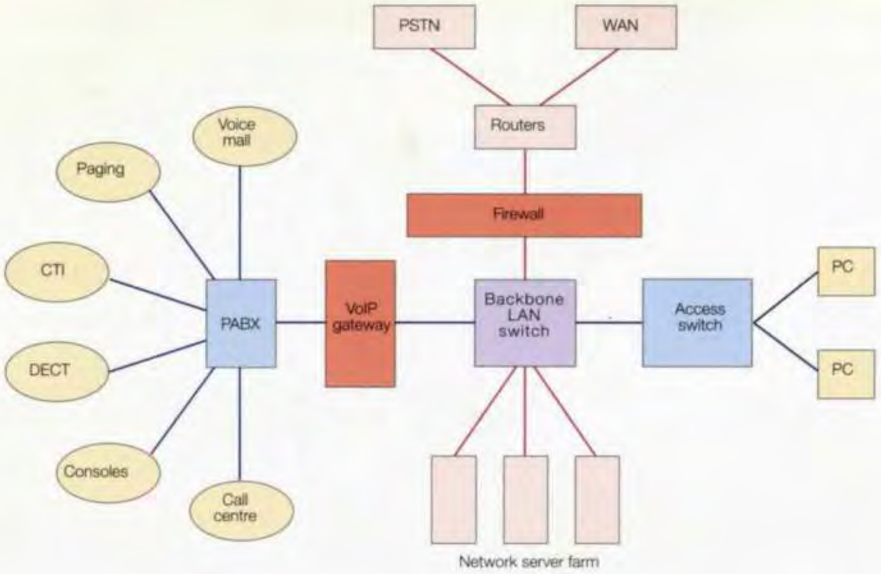
As well as the high-speed cabling infrastructure, a complementary wireless overlay network is also installed for both voice and data services (up to 10Mbps), to enable services to be accessed from almost anywhere within the HQ. This required over 40 radio base stations.

Though each has a nominal spherical coverage of around 40m, the number required is determined from the amount of wireless users, and the permeability of the building structure to radio waves, which is established with a site survey.

This wireless network supplies services to parts of the building that cabling cannot reach; the network speed and market penetration of wireless data networks is steadily increasing and becoming comparable to traditional, fixed data networking infrastructures.



5. BoC HQ connections to branches.



6. Internal communications links.

Credits

Client:
The Bank of China

Architect:
The Pei Partnership

Structural engineer:
Weidlinger Associates

Main contractor and project manager:
China State Construction and Engineering Corporation

IT and communications designer and project manager:
Arup Jimmy Chan, Simon Chung, Patrick Leung, Michael Tomordy

Illustrations:
1. Martin Saunders / Arup
2-6. Jimmy Chan / Jonothan Carver
7. Courtesy Weidlinger Associates

The wider context

Inevitably, technologies are being introduced at widely varying rates from country to country, but the same products, manufacturers, and design principles cover the globe, and so apply as much to the PRC as to Europe, the USA, or anywhere else. Nonetheless, this rapidly developing new market has many different local cultures, design practices, and ways of doing business, and so the challenges are as numerous as are the opportunities.

Piracy and counterfeit products are major concerns for many overseas manufacturers supplying the PRC, and this equally applies to the IT and networking products being introduced by US vendors. Also, more and more mainland firms are developing similar (in some cases improved) networking products for the home market at significantly lower costs than those of their overseas counterparts.

During the implementation phase of the BoC project, the checking of products being installed and collaboration with the manufacturers was critical, as this is where the largest margins are generated, as opposed to labour costs.

Conclusion

The new Bank of China headquarters has one of the largest and most advanced structured cabling, voice and data networking infrastructures currently installed in the PRC; indeed it would be a major installation in any part of the world. Arup's project management aimed to ensure that the installation was world-class, matching the high standards demanded by other leading international financial institutions. This was partially achieved by working closely with (indeed, to some extent educating) the contractors during implementation.

On the project as a whole, the technology design, procurement, and implementation issues were not the greatest challenges, but rather the 'soft' issues. The latter included the procurement process, the high-profile nature and importance of the project, the hierarchical nature of the organisation leading to slow decision-making, considerable cultural issues (both national and organisational), and inter-personal relationships with the client, the design team, and the contractors. Understanding the client's brief, as anywhere else in the world, was fundamental to the success of the project.

It should never be forgotten by anyone undertaking a project in the PRC that assuming a Western approach is not likely to be widely understood or appreciated.

> 'Understanding the client's brief is fundamental to success. Do not assume that in the PRC a Western approach to a project is likely to be understood or appreciated.'

7. Internal atrium.

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