Arup
Design Yearbook 2006

Building genius

Libraries have always been places where people go to learn, but the National Library Board of Singapore has added a completely new dimension to this traditional function, with a building that rivals its contents in intelligence.

Words: Will Hersey

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Above: design of the reference library spaces has focused on imaginative co-ordination with technology to provide an exciting learning environment. A good example of this is the triple-height space featuring a book wall that provides continuous visual impact over three floors to engage visitors' attention and encourage use of the library.

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Above: this PDA is showing an actual NLB information portal designed to assist and guide the library's users.

In brief

When the National Library Board of Singapore announced its intention to redefine the library concept for the 21st century, the challenge was to design an intelligent building that could be leading-edge in the present, but could also adapt to future change.

Traditionally the intelligent building has remained more associated with sci-fi movies than city libraries. But if an intelligent building is one that can respond in various ways to the demands of its users and environment, then the technology infrastructure within the new flagship building of the National Library Board of Singapore is evidence that such thinking is now firmly rooted in reality.

To put the scale of the Singapore Government's vision for their national reference library into perspective, large-scale libraries the world over had been analysed and observed – and nothing could be found to match what they were trying to achieve. As a business, they wanted a facility that would increase visitor numbers, expand the status of learning, and provide the most effective and conducive learning environment possible; but as a building they wanted a structure that would set a benchmark for its use of technology and, simply speaking, make the rest of the world sit up and take note.

For a project several years in development, the most immediate problem was the absence of a crystal ball to predict the future. Just how do you decide which technologies will be most relevant to library users in 2006 and beyond? And for a building with a lifespan of at least 50 years, how do you then install these leading-edge technologies while also implementing a design that will respond to inevitable technological change – in other words, that won't need to have its insides ripped out because of technical advances it cannot support? It's a challenge that fell to the Arup team, whose traditional field of deciding how technology fits into the building design process has now expanded to analysing how this can be aligned with business objectives.

An exhaustive review of how technology could integrate with the library's practical, day-to-day functions as well as its wider ambitions led to several technology 'wow' factors being drawn up, factors that would provide a strong and immediate impact. For the longer term, a more holistic view was taken. All parties understood that there would be a huge turnover of technology, but what would be the backbone to these trends? Wireless technology, which is how the intelligent environment took shape.

"From the word 'go', Arup showed great enthusiasm and commitment to this project. Although the project went through many challenges, including the change of the main contractor's project manager, turnover of other specialty consultants and the difficulties faced in dealing with subcontractors for not implementing our specifications, they stayed the course throughout."
Lau Kai Cheong, Director, Infocomm National Library Board

Client
National Library Board of Singapore
Technology systems providers
Hewlett-Packard Singapore Pte Ltd
SCS Networks Pte Ltd
Architect
Ken Yeang of Llewelyn Davies Yeang

In the library today, which also incorporates a café, an auditorium and exhibition space, multi-use hand-held PDAs allow librarians to stay in contact with colleagues and provide relevant information to the public as they move around the facility. The library's 1.5M books all have radio frequency ID tags to increase operating efficiency and improve security. In the future this may allow staff and visitors to track down the exact location of books with a hand-held device, wherever they might have been left. Other applications include online research facilities and roadmaps, virtual tours and souvenir kiosks for personalised interaction – all have been designed with the philosophy of engaging its 32M users at every step of their library experience.

During the 1990s, a downturn in the Asian economy meant the budget did not allow all the intended technologies to be installed in Phase One, but the infrastructure and space have been built in to allow such additions as large interactive video information screens. The building is also fully equipped to support the installation of additional green technologies in the future. In fact, the technology now available to library visitors is so advanced that this seemingly traditional institution is now one of the most cutting-edge places for anyone to spend their time.

Wireless LAN

Having decided on the projected importance of wireless working, Arup had to be sure wireless devices would work in every public space and most back-of-house areas. "Radio propagation is something of a black art," explains Jim Read, associate director, Arup. "Wireless LAN is very high frequency and very low power, which means the signal can travel a maximum of 50m inside a building.
It's also very hard to determine how far signals will travel round corners and through certain materials and fittings. Predicting coverage was a challenge, as it is impossible to conduct a survey for a building that doesn't exist – so some creative thinking was required."
A thorough knowledge of how radio waves react to all types of building materials – partitions, blinds, glass and steel – was essential. Once the system had been installed and the building completed, the software from the wireless LAN system was used in conjunction with the building plans, to optimise the final solution.

© Ken Yeang

The schedule so far…

December 2004
Line 1 (linking Lo Wu on the Hong Kong border with the Window on the World theme park) and four Line 4 stations open for business.

July 2005
Line 4 contracts awarded to Arup.

Feb 2006
Completed specifications and design delivered to MTR.

End 2009
Line 4 extensions open for business.

The birth of a boomtown

From fishing village to commercial hub, Shenzhen has been the focus of massive infrastructure development for 20 years. A six-line underground system is set to complete the picture in 2012.

Words: Tim Edwards

Line 4 links Shenzhen's central business district to the Hong Kong Special Administrative Region via Huanggang, a border checkpoint to the south. It will also link north to an interchange with a new high-speed train station, Lunghua.

Shenzhen Line 4
Shenzhen, China

Back in the 1970s, the residents of economic powerhouse Hong Kong could have been forgiven for being unaware of Shenzhen, a Chinese fishing village 35km north of Hong Kong. But in 1980 all that was set to change, as the late Chinese leader, Deng Xiaoping, designated Shenzhen one of four Special Economic Zones (SEZs).

Shenzhen is one of two SEZs located in the Pearl River Delta. This location gave the city an advantage in developing private enterprise, manufacturing capabilities and foreign trade. Additionally, Shenzhen has been quick to make the most of its proximity to Hong Kong, becoming the manufacturing powerhouse of China. While Shenzhen offers a competitive market for companies to source or manufacture goods, Hong Kong, the source of approximately 70% of cumulative foreign direct investment in the region since 1979, provides logistic, financial, legal, design and marketing services that allow companies to export their products to rest of the world.

Today, the city of Shenzhen has a population of 10M and is home to mainland China's second stock exchange (the other is in Shanghai). In 2005 it was the world's fourth largest port (measured by container traffic).

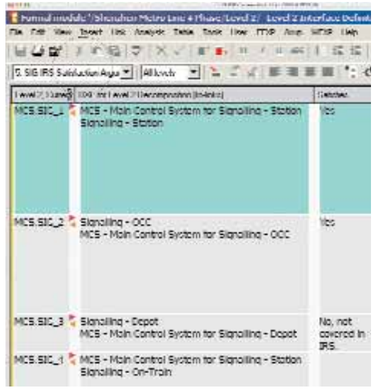
To serve this boomtown, extensive infrastructure development is under way, including plans for an underground metro system with six lines fully operational by 2012. When completed, the 21km-long project will have 14 stations and run between the Huanggang border checkpoint and Longhua.

The scale of the task on the metro system alone is massive and for Arup, the designated engineers, the task has required considerable resources. The concessionaires, MTR Corporation, divided the design into four contracts: underground stations and tunnels; design of the elevated section; depot design; and systems design. Arup is delivering the elevated section, depot and systems design amongst the communications systems for the Shenzhen Line 4 project, including the operational networks, radio, CCTV and office automation.

In large projects involving many different contractors, effective control is an issue. It is common for contractors to turn up on site without some piece of essential hardware, thinking that another contractor was supposed to bring it. To avoid this on Line 4, the team is using a management system called DOORS, a powerful tool which allows all concerned not only to predict the future, but also change it if they need to. It gives client and contractor complete control.

What is DOORS?

DOORS (Dynamic Object Oriented Requirements System) is widely used, particularly in the avionics industry. It's a requirements tool that can be adapted for individual projects. Think of it like a database. It's not the system itself that's exceptional, but how Arup uses it.



So how does Arup use it?

For this project, DOORS works like a very clearly identified management tree. In any given circumstance the system will cross-reference inputted data to come up with a solution. This kind of planning means that later, when it's time to work with contractors on the ground, the system identifies who's doing what.

What are the benefits?

DOORS removes risk from the project. It smoothes delivery and the impact of changes ensures cross-requirement compatibility. Clients benefit from seeing a visible audit trail throughout the design phase and are able to determine the cost or time implications of changes immediately.

A new retail generation

The opening of two experimental Wal-Mart stores in the US is set to make a major impact on the environment, potentially changing the way the whole retail industry does business for the better.

Words: Will Hersey

Above: dimming lights during daytime hours reduces energy consumption.

Conserving water using the xeriscape method, which involves using low-maintenance plants and trees to create a sustainable yet attractive landscape, also requires proper use of mulches. After planting, a thick layer of mulch is applied to protect the plant roots from harsh weather conditions. Several mulch types are being used on this site, including rubber mulch from recycled tyres, which is being tested in selected areas.

Solar power: four different types of photovoltaic arrays generate enough electricity in one year to power 1726 homes for a day.

Native species of plant have been used in large open spaces, reducing the need for irgrigation, chemical fertiliser and maintenance crews.

The trees selected for this project were chosen for their superior performance in urban environments.

Since it first emerged on the scene in the 1960s, 'big-box' construction has traditionally sat its considerable bulk at the more rudimentary end of the design scale. When considering the cutting-edge of environmentally-conscious construction, supermarkets aren't necessarily the first buildings that spring to mind. Yet Wal-Mart has developed two experimental stores in McKinney, Texas, and Aurora, Colorado, to serve as test grounds for technologies and products that save energy, conserve natural resources, reduce pollution and enhance their customers' shopping experience. They call them 'living laboratories'.

Specifically, the experiments had to result in a store design that improves the comfort of Wal-Mart associates and the ability to serve the store's customers, and reduces Wal-Mart's use of natural resources. Cynics might see a mere two-store venture as a token publicity project to tick corporate responsibility boxes. For Wal-Mart, a company that builds around 300 new stores every year in the US alone, it's the starting block in a programme to reduce the company's global energy footprint and greenhouse gas emissions.

For Arup, the challenge was to take experience on sustainable energy projects into a new arena – moving away from the existing green building process, which tests technologies one building at a time – and assess the impact on a far larger scale instead.

Wal-Mart's decision to appoint the engineers as prime consultants and leaders of the design effort was deliberate. They wanted the mechanical and electrical services to drive the design, as opposed to the aesthetics and architectural elements.

"With all the education efforts that are present in the stores, we have a chance to influence a huge number of buildings as well as a huge number of people," says Alisdair McGregor, Arup's project director.

It was clear that effective collaboration was going to be crucial to the project's success. On one side, Arup's San Francisco office had a relatively fresh perspective on the supermarket merchandising experience, which allowed for free thinking. On the other, Wal-Mart's long experience in big-box retail construction provided some fairly immediate feedback on viability.

A switch to lower energy LED lighting in all food cabinets, for example – producing less heat so refrigeration becomes significantly more efficient – is already a likely candidate for the wider market. A displacement ventilation system that moves air out at low velocity so only air in the immediate surroundings is chilled, replaces the traditional high-level system that conditions the entire space, which is just over 6m high. One proposal for sliding doors on mid-temperature refrigerated products such as bacon and cheese has resulted in significant energy savings.

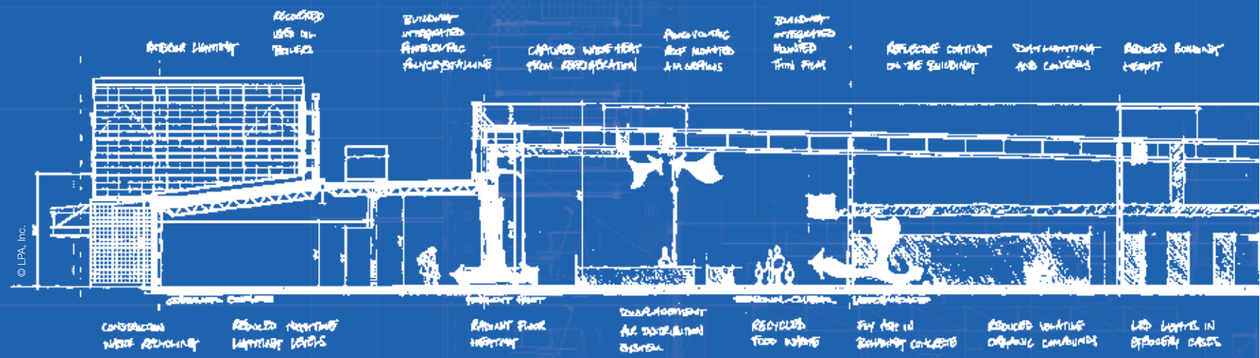
Anecdotal customer feedback that 'it makes the food feel fresher' suggests that rare commodity, a happy union of customers, associates, commercial and environmental concerns.

"Our intent was to implement leading-edge technologies, not bleeding-edge ones," says Shaun Landman, project manager. "The integration of so many new and different systems and products into one big-box store is unprecedented."

Ultimately, it's the numbers that matter, but there are also more intangible objectives that will be harder to measure. Part of the mission statement for the Wal-Mart experimental stores is sharing the process as well as the results of the experiments with others in the industry, the general public, and government agencies. For Wal-Mart, effectively educating and including its customers in the process will certainly have an impact on future developments.

"Here we have a chance to influence a huge number of buildings and also a huge number of people with all the education efforts that are happening through the stores themselves."

Alisdair McGregor
project director, Arup



A fast track for sports fans

Redesigning Wembley Park Underground station in half the planned timeframe and half the budget called for Arup's serious creative thinking skills.

Words: Tim Edwards

Arup and architects Pascall & Watson (P&W) had developed a design for the total reconstruction of Wembley Park Station, to create a London Underground (LU) station on a par with the best of the existing Jubilee Line extension stations. Wembley Park Station is the primary gateway to Wembley Stadium and one of the busiest cross-platform interchanges on the network, with six LU platforms and adjacent network rail tracks. The complex project was planned to take four years at a total cost of £90M, including major signalling and track works, but was stopped by early uncertainties about whether the stadium redevelopment would proceed along with the mooted plans for a Public Private Partnership for maintaining the underground system.

Three years on, with the stadium construction on site and set to finish in September 2005, LU returned to Arup and the architects to continue with the station redevelopment. The budget had fallen to £42M and just two years remained before the stadium was due to reopen.

The team knew this would be a stiff challenge and immediately set about generating options for what could be done. "Our intimate knowledge of all the site's complexities allowed us to plan out the most expensive and time-consuming elements of the previous construction programme," recalls Tim Snelson, Arup's project manager. "So we were able to achieve the required increase in predicted passenger levels despite the time pressure."

Renewing building services without disruption

Position a new plant room in the car park, away from the existing plant rooms, under the new concourse allowed new cabling to be routed from the opposite end of the station. Old cabling was peeled back as work progressed. This meant cabling work could begin before the new concourse was finished and avoided a need for costly temporary station systems, saving approximately £2M.

Arup proposed a neat solution to retain and extend the area of the existing station concourse by moving the stairs down the platform away from the ticket hall, building a new overbridge in their place. Lifts for mobility-impaired passengers would go into the old stairwells in a deliberately efficient and functional response to strict railway engineering constraints.

Work on railways is often frustrated by restrictive engineering times dictated by the need to keep trains running. The new overbridge was designed to be built piecemeal using bolted steel and precast concrete components that could be hoisted into place by tower cranes at night and during weekend possessions (closures). It's a logic that would apply to any work over operational train tracks. Indeed, Arup is currently using the philosophy for a bridge design over the tracks at Harrow-on-the-Hill.

Work was also accelerated by introducing three work fronts. These were separate building areas within the station where work could continue simultaneously and independently. This meant that when Tube Line Ltd (TLL) asked Arup to modernise the sagging platforms halfway through construction, the contractors were able to continue work on the concourse and event-day ticket hall while a solution was designed.

The result of all that intricate planning? A station designed to meet the most exacting standards and the strictest limitations, delivered on time and within budget.

Maximising passenger throughput

Double size of station concourse; widen entrance stairs. Remove obstructive columns in new event-day ticket hall by erecting a mast that could support the lightweight ethylene tetrafluoroethylene (ETFE) roof from above.

Correcting sagging platforms

Close three of the six platforms at a time, allowing the station to remain open. Avoid time-consuming cable diversions and track closures by retaining platform edge walls and constructing a new platform behind.

© Pascal & Watson Architects

Timesavers

Avoiding unnecessarily complicated works, such as signal and drainage diversions. Keeping demolition to a minimum. Retaining as much of the existing buildings as possible, especially the area of the existing ticket hall above a Network Rail track (permission for work here may have taken months to obtain). Creating three work fronts, minimise station closures by using precast overbridge components over tracks. Replacing existing canopies by producing a 3-D computer model in the same package used by the manufacturer, using the same specifications, to reduce lead times.

Client
Tube Lines Ltd
Project Sponsor
London Underground
Architect
Pascall & Watson Architects Ltd
Management contractor
Taylor Woodrow Construction
Cost consultant
Franklin & Andrews

Bill Prentice

Working for a greener government

In a highly contentious debate, the Welsh Assembly is gaining ground in its plans for renewable energy at a staggering rate.

Words: Lisa Clifford

The consultation work called for a regional approach to landscape and visibility analysis for wind farms. Using geographic information system technology, the team developed its own techniques to ascertain the relative visual performance of different parts of the seven strategic search areas (typically 100-200km²). These needed to model what the team thought were the most important visual and landscape facets of wind farm development in Wales.

There's policy, and then there's the necessary politics required to implement that policy – that's how one of the most sensitive projects of this decade in Wales began for Arup and the Welsh Assembly Government.

It all started with a seemingly modest brief. UK Government policy dictates that renewable resources must produce 10% of the country's electricity by 2010. Meeting these steep targets requires a massive amount of planning and until 2002, Wales had yet to decide how it would meet its obligations. After an initial consultation, Arup submitted the first radical proposals to introduce up to 500 wind turbines in seven sites across the country. Their impending construction will bring about the biggest change to the landscape in living memory.

At around 130m high, the wind turbines soon to be dotting the Welsh countryside will be anything but inconspicuous. Though Wales already has 300 turbines, most are in relatively unpopulated areas and are a more modest 50–70m in height. Under the new plan, the turbines will be concentrated in seven strategic areas, and these will be broadly distributed across the country, with the majority in the more densely developed parts of South Wales.

At the heart of this vast onshore wind scheme lie the proposals from a team of Arup planners and researchers. Using research produced by the Arup team, the Assembly produced a planning document that was to act as the vehicle for the implementation of the new policy.

"We spent a lot of time working with the Assembly to define what their energy policy was," says Simon Power, environmental scientist. "When our final results were published in June 2004, the public's reaction was considerable, and was fully explored by a long debate in the national press."

The response shocked the Assembly, which promptly re-employed Arup to deal with the consultation responses. Power accompanied government officials to visit local planning authorities in the seven key areas, acting as an advocate on behalf of his clients.

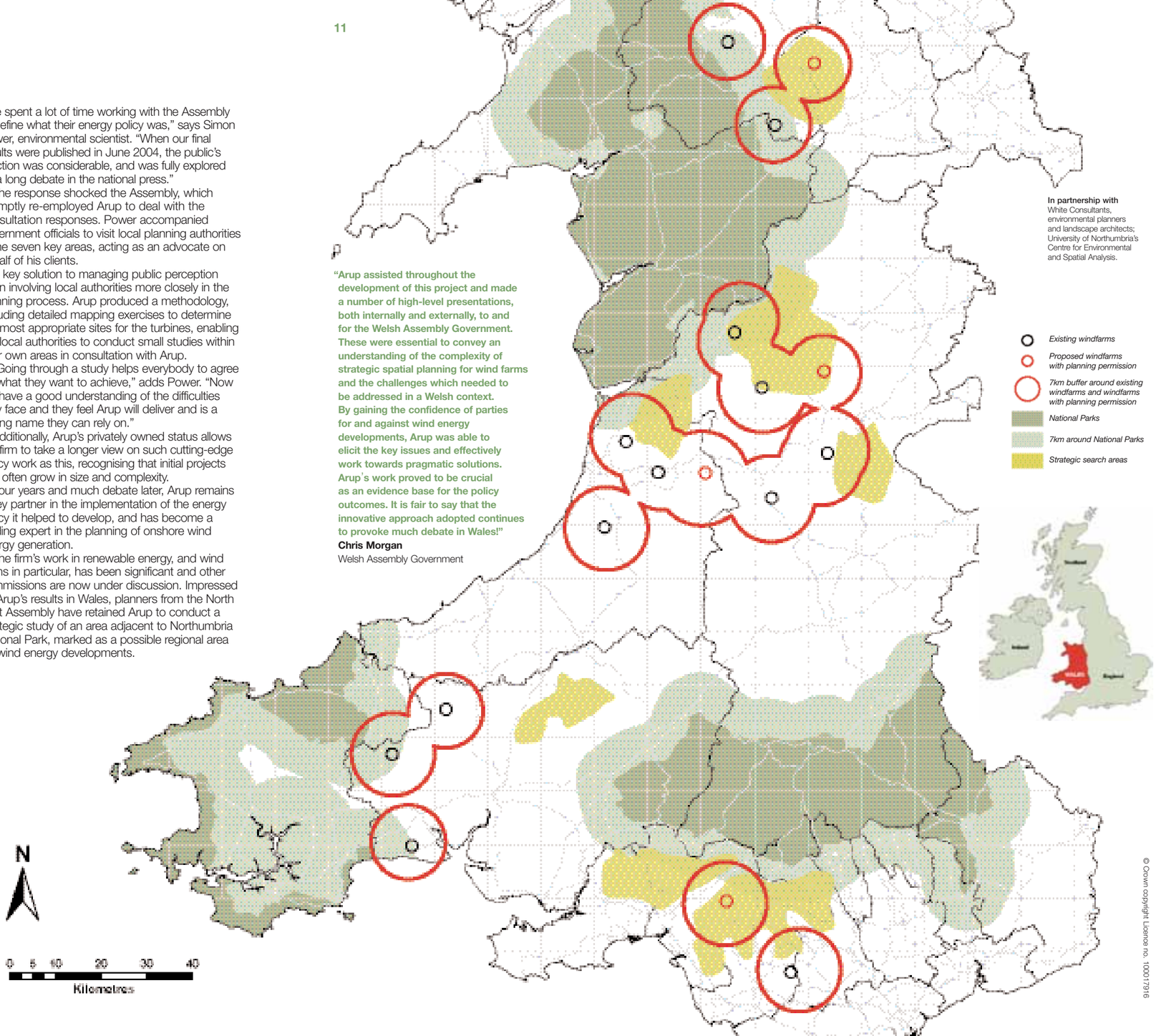
A key solution to managing public perception lay in involving local authorities more closely in the planning process. Arup produced a methodology, including detailed mapping exercises to determine the most appropriate sites for the turbines, enabling the local authorities to conduct small studies within their own areas in consultation with Arup.

"Going through a study helps everybody to agree on what they want to achieve," adds Power. "Now we have a good understanding of the difficulties they face and they feel Arup will deliver and is a strong name they can rely on."

Additionally, Arup's privately owned status allows the firm to take a longer view on such cutting-edge policy work as this, recognising that initial projects can often grow in size and complexity.

Four years and much debate later, Arup remains a key partner in the implementation of the energy policy it helped to develop, and has become a leading expert in the planning of onshore wind energy generation.

The firm's work in renewable energy, and wind farms in particular, has been significant and other commissions are now under discussion. Impressed by Arup's results in Wales, planners from the North East Assembly have retained Arup to conduct a strategic study of an area adjacent to Northumbria National Park, marked as a possible regional area for wind energy developments.



"Arup assisted throughout the development of this project and made a number of high-level presentations, both internally and externally, to and for the Welsh Assembly Government. These were essential to convey an understanding of the complexity of strategic spatial planning for wind farms and the challenges which needed to be addressed in a Welsh context. By gaining the confidence of parties for and against wind energy developments, Arup was able to elicit the key issues and effectively work towards pragmatic solutions. Arup's work proved to be crucial as an evidence base for the policy outcomes. It is fair to say that the innovative approach adopted continues to provoke much debate in Wales!"

Chris Morgan
Welsh Assembly Government

In partnership with
White Consultants, environmental planners and landscape architects; University of Northumbria's Centre for Environmental and Spatial Analysis.

Making a stand

The recently redeveloped Khalifa Stadium is poised to become one of the star players at the 2006 Asian Games, helping host country Qatar to make its mark as a tourist destination.

Words: Mary Penny

© Arup

© GHD

The lighting arch uses gravity to create tension in stay cables that hold the arch up and control lateral buckling.

Khalifa Stadium
Doha, Qatar

OVERVIEW
August 2003 – February 2005
All services and finishes upgraded.
August 2003 – February 2005
All precast seating platforms replaced.
October 2003 – July 2004
New steel and precast concrete seating structure and VIP area installed.
January 2004 – February 2005
New 15 000m² Polytetrafluoroethylene (PTFE) coated glass membrane fabric roof, supported by elegant steel arches and stressed cables.
June 2004 – February 2005
Over-cladding of the old concrete structure complete.
July 2004 – February 2005
New 265m free-spanning cable-stiffened arch to support competition lights and speakers installed.
January 2005 – February 2005
New running track and playing field complete.

A successful 2006 Asian Games for Doha, the capital of the Gulf state of Qatar and winning bidder for this year's event, could help to significantly improve Qatar's appeal as a tourist destination. The economic gains that accompany staging a successful sports tournament are clear – sponsorship and broad-casting brought in an estimated US$100M for the last Asian Games and that figure is projected to rise for this year.

Add to that the cachet that comes with being the first Arab city to stage the event, and the pressure to provide first-class sporting facilities could not be greater.

Khalifa Stadium, the venue where the opening and closing ceremonies will take place, is the centrepiece for Doha's $720M Khalifa Sports City development project. Its crowning glories, a floating roof over the western side and a lighting arch over the eastern side, were structurally designed by a team of Arup's engineers based at the firm's offices in Australia.

Working alongside Arup's team were suppliers and contractors in the US, Canada, Europe, Asia and Qatar. Aware of the margin for error that such a disparate team might present, Arup contributed to the development and control of the entire installation processes for the roof and lighting arch. Every stage was modelled using Arup's own software. The approach worked so well that despite the project's complexity, everything fitted perfectly when it arrived on site.

"By drafting the entire roof and lighting arch in 3-D we were able to reduce design and drafting time, making the process much quicker and cheaper for the client," comments Peter MacDonald, Arup's project leader. "It was also much quicker to communicate with the client in 3-D models, given the various time zones that we needed to work across."

First-class facilities are essential for this project, as the venue is also part of a larger plan to increase tourism in the region. Arup's sporting venue experience includes total multidisciplinary design of sports arenas and stadia and specific consultancy advice, making the firm an ideal partner for project architects Cox/PTW/GHD.

But that doesn't mean that the project was easy for the teams. Extreme desert weather conditions made it essential for all of the roof's steel and cables to withstand temperatures ranging from 5ºC to 85ºC. The surrounding flat terrain required in-depth analysis in a wind tunnel, measuring wind loads to ensure that the roof, lighting arch and individual cables do not vibrate alarmingly as the regular trade winds blow.

The brief from the architects for the iconic lighting arch was to create a dramatic and delicate structure with no visible means of support. Careful design, based on British and American codes and guidelines, was called for. After formulating the specifications and co-ordinating the prototype testing, Arup developed non-linear analysis models to predict the behaviour of the arch at all stages of the installation process.

The resulting leading-edge tensile structure has set new standards in sporting venue design and given the client a head start for one of this year's most important sporting events in the region.

Client:
International House General Trading, in association with Midmac Contracting and Sixconstruct, on behalf of Khalifa Sports City Development Committee.
Architect:
Cox/PTW in association with GHD Qatar
Project manager:
GHD

© Arup

The lightweight flexible roof covering consists only of stressed cables and PTFE-coated glassfibre membrane. The whole roof is in tension, which gives the canopy the appearance of floating in mid-air.

© Arup

"Designed as a landmark, this stadium features two main arches that result from pure function and demonstrate a sporting concept in a powerful and energetic way. The construction methodology and the detailed design were solved in a short period, thanks to the proactive approach of all parties concerned. Arup's 3-D design enabled accurate fabrication and construction of this unique steel/cabling structure. Arup also engineered the erection sequence in co-ordination with Eversendai/Pfeifer so that site assembly proceeded smoothly."
Didier Bosredon, project director on behalf of Midmac-Sixconstruct JV

Successful partnerships are always key to the success of vital infrastructure projects that cross borders. And for the particularly environmentally sensitive Hong Kong-Shenzhen Western Corridor carriageway, Arup proved that developments like these can be completed, in record time, without the need for unsatisfactory compromises.

Words: Tania Coates

Partnering on public consultation

© Michelle and Peter Wong

Feast and flight: a cleaner, richer feeding ground has given migratory birds such as the spoonbill reason to nest in Deep Bay once more.

© Arup

The 210m main span was constructed over an existing navigation channel in the Hong Kong waters of Deep Bay. With a single central inclined tower the cable stays converged at the anchor piers, with a back span of 99m and two side spans each of 74.585m. The cable-stayed bridge is one of the world's widest bridges with a single central cable plane.

In brief

The Hong Kong-Shenzhen Western Corridor is a 5.5km dual three-lane carriageway, built in record time, to ease the congestion on three neighbouring boundary crossings and strengthen the position of Hong Kong as the hub of the Pearl River Delta region. It is the fourth road to mainland China from Hong Kong.

In the wake of China's admission to the World Trade Organization in 2001, the Hong Kong-Shenzhen Western Corridor (HKSWC) is providing the transport infrastructure to fuel the economic boom occurring within the Pearl River Delta region further. Arup was commissioned by Hong Kong Special Administrative Region to undertake the HKSWC investigation and planning consultancy. Usually a project of this size and complexity would take over seven years from feasibility study to completion. This project has taken just four years and four months to complete, with design and construction beginning just seven months after Arup's appointment.

The three existing vehicular crossings to Hong Kong were nearly at saturation point, so building a fourth bridge to link Hong Kong and Shenzhen removed potential bottlenecks to trade and traffic. The HKSWC has also brought the opportunity to develop Hong Kong's container port, further opening up the potential for foreign investment in the region.

Arup's project team selected four alignment options for detailed evaluation. Following this, an S-curve bridge alignment option was adopted, as it has less impact on the region's air and water quality, ecology, waste and cultural heritage.

For the bridge scheme, the project team adopted a cable-stayed bridge with a steel orthotropic deck and a single, inclined, concrete tower. As a result of close negotiation between Hong Kong and mainland China, construction began in 2003 – one month earlier than anticipated.

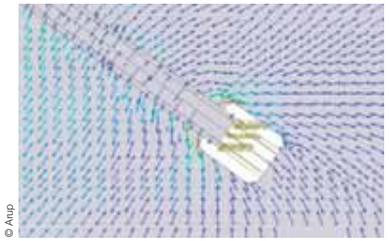
Despite the efficient negotiation between partners Arup faced several logistical challenges on this project, including designing around the ecologically sensitive Deep Bay, a vast territory of mudflats and mangroves. Mai Po, an area 6km northeast of the project site in Inner Deep Bay and best known as a haven for migratory birds, was designated a Wetland of International Importance in 1995.

Following public consultation, the World Wildlife Fund in Hong Kong raised fears that the bridge would result in raised levels of sedimentation and a subsequent reduction in the exchange of tidal water between Deep Bay and the Mai Po shrimp ponds. Conservation of the natural habitat was a top priority for the project team. The proposed solution meant convincing the Shenzhen and Hong Kong team to increase the typical span length of the HKSWC bridge from 50m to 75m, reducing the number of piers from 106 to 70 pairs.

The creative partnership between Arup and the contractor resulted in part of the steel deck segment erection weld being taken off the critical path for completion at a later stage. This allowed segments of the cable-stayed bridge deck to be erected within five-day cycles.

© Arup

Below: arrows show the principal stresses acting at a typical stay-cable anchorage inside the bridge's deck.



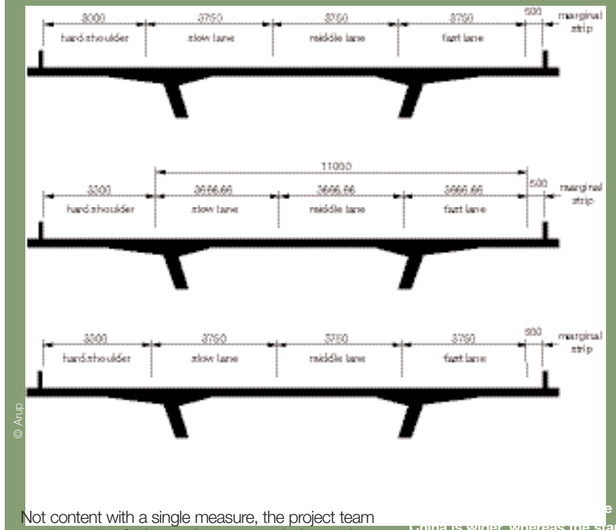
© Arup

In addition, the pile caps were installed below the seabed to maintain tidal flow. "We recommended dredging one existing inlet channel linking Inner Deep Bay to some of the shrimp ponds inside Mai Po," explains Alex Kong, Arup's project director for the HKSWC project. "The dredging made the inlet wider and deeper, so that water could circulate more often than just at high tide, bringing in additional supplies of shrimps and fish from Deep Bay into the shrimp ponds. It meant that the ponds could once more function as a core feeding ground for birds."

Oyster beds, providers of a delicacy and staple food, carpet the mudflats. Coastal fisheries and commercial oyster cultivation is a mainstay of the Deep Bay economy. Unable to avoid the extensive oyster beds in the mudflats, Arup's partnership with oyster farmers and the rural community ensured that oysters could continue to be harvested during construction. The solution was a temporary access bridge to accommodate the construction plant and protect the mudflats. The temporary bridge also acted as a platform to the deeper waters, easing marine-based logistics.

© Arup

Stay-cables for the 210m span of the cable-stayed bridge. Subject to different forces, each cable comprises between 52 and 88 numbers of galvanised high tensile seven-wire strands with individual extruded coatings of grease and HDPE, all contained inside an external HDPE stay pipe with helical surface fillet.



© Arup

Not content with a single measure, the project team went one step further and recommended removing exotic mangroves and marsh weeds from Inner Deep Bay, so restoring the mudflats and further improving water exchange into the fish ponds.

Other innovative methods to improve water quality include a Y-shaped funnel mounted over piling casing to intercept spillage of wastewater and spoil material during bored pile construction.

As well as overcoming the limitations of the environmentally sensitive Deep Bay and making full use of the joint implementation of two governments to complete the project in record time, the bridge is a statement in itself. Aesthetically pleasing, the central plane of cables allows breathtaking views across Deep Bay and the S-curve elevates the driving experience. Once that congestion has been reduced, drivers will be more inclined to appreciate its unique design, too.

e in mainland China is wider, whereas the standard hard shoulder in Hong Kong is wider. However, in this joint project, both sides have agreed to adopt the higher standard, and the wider carriageway width (3.75m) and the wider hard-shoulder width (3.3m) have been adopted along the whole length of the HKSWC.

Client
Major Works Project Management Office,
Highways Department,
The Government of the Hong Kong
Special Administrative Region

NO
17
Kongs notes

PROJECT
Proyecto Eduardo Chillida - Montaña Tindaya
Fuerteventura, Spain

ARUP

"Many years ago I had an intuition which I really thought was utopian. To create a space inside a mountain that would offer men and women of all races and colours a great sculpture dedicated to tolerance… The giant space carved out of the mountain wouldn't be visible from the outside. But anyone who penetrated her heart would be able to see sunlight and moonlight inside a mountain that overlooks the sea, the horizon, a mountain that is unreachable, necessary, non-existent…"

Taken from a statement made by Eduardo Chillida to local press in July 1996

Two of the technical difficulties overcome by Arup included:

① Working on top of a mountain with steel and other strong electrical conductors meant that the team needed to be extra careful of lightning strikes. They set up a special lightning detector with a warning system to detect charge ions in the air should an electrical storm approach. When the warning system goes off, it's time to down tools – fast.

② The team has not been permitted to create even a cloud of dust during their work. To avoid any environmental impact on the mountain, all drilling sites were isolated from the rock using geotextile blankets beneath the drilling platforms and sealed water pipelines. Allowing water to escape would have prompted lots of plants to grow where they have never grown before, disrupting the natural landscape.

Magnum opus

This is how the celebrated Spanish abstract artist Eduardo Chillida defined his idea for his project in July 1996. Despite his death in 2002, this project is the culmination of the artist's work and every effort is being made to realise his last ambition.

The central chamber will be an approximately cubic cavity with few straight angles. The horizontal access passage is northwest-oriented, facing the sea and measuring approximately 13m high, 12m wide and some 70m long. The vertical 'sun and moon' shafts will be around 50m long from the roof of the cavern to the mountain surface, very close to its peak. Arup is part of the design team engaged by the architects, L Fernández-Ordóñez and D Diaz Font (Estudio Guadiana), to help bring this project to life. The work presents some unprecedented technical challenges as a result of the cavity's shape and considerable dimensions – and the need to immaculately preserve the surrounding environment. Detailed work in three phases is being carried out to determine the project's feasibility and Arup has been involved at every stage.

The first phase included a series of studies that were carried out to establish that the project was possible and that the mountain would not be affected if the project finally goes ahead. Next, intrusive geotechnical investigations were carried out to familiarise the team with the rock's unique characteristics. Studies of each one of the 14 boreholes revealed the rock's inner structure in detail. Despite its being made up of igneous rock, the mountain carries rare liesegang banding which more often occurs in porous rock such as sandstone. Stone with this banding is often highly prized for building façades and the Tindaya stone has been used locally for the last 300 years, more recently at the new Fuerteventura Airport.

The Arup team is currently working on Phase III, including the design of the cavern support requirements and site access and facilities. The final phase, the planning and execution of the sculpture itself, is expected to take place in 2007.

© Daniel Diaz Font

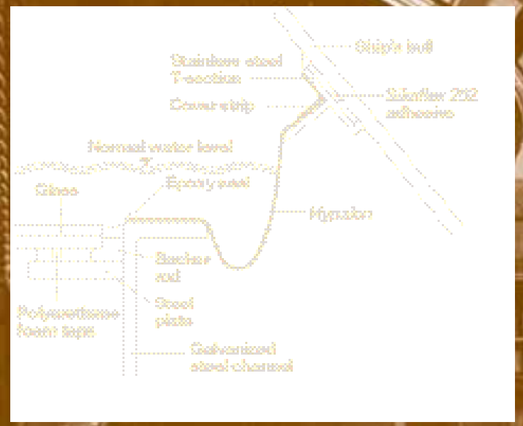
Client
Estudio Guadiana

Ship to shore

No matter what the weather, you will never see the ssGreat Britain move an inch. But this isn't a new wonder of the modern world, the first great ocean liner is surrounded by a sea of glass.

Designed by Isambard Kingdom Brunel, the ship carried the first English cricket team to visit Australia and transported troops during the Crimean War and the Indian Mutiny. After decades of decay, work began on the glass sea in 2004. It was the final stage in the restoration of this historically significant ship.

Thanks to the painstaking conservation and restoration process, visitors to Bristol's dry dock can view the ship that was the largest in the world when she was first launched in 1843. Saving her crumbling and corroding iron hull is where the Arup team came in, designing a glass sheet that stretches across the dry dock at water line level. Covered by a thin layer of water from bow to stern, this glass sea gives the impression the ship is floating and forms an airtight chamber around the lower hull, which is dehumidified, to prevent further corrosion. Visitors can also descend beneath the glass into the dock to see her great curved flanks and mighty propeller.



The 1000mm glass plate supports 50T of water in a layer 50mm thick.

Arup's solution comprises about 170 individual laminated hard strengthened plates 21mm thick, supported by laminated glass beams 450mm deep.

Client
SS Great Britain Trust
Architect
Alec French Partnership

Six things you should know about the Chartist Bridge

1. It is part of the Sirhowy Enterprise Way regeneration project in South Wales, a bridge and road scheme linking the former coalmining towns of Blackwood and Oakdale. The most striking feature is the Arup-designed Chartist cable-stayed bridge – 230m long and supported 30m above the valley floor by a single 90m high A-frame pylon.

2. It opened to traffic in December 2005 – four months ahead of schedule.

3. The bridge gets its name from the area's historical links with the Chartist Uprising of the 19th century. Many of the protesters involved in a march to Newport to demand electoral reforms started their journey from Blackwood and the surrounding communities.

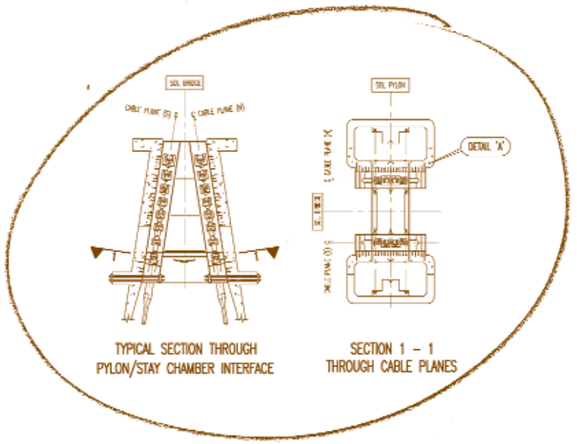
4. Costain and Laing were awarded the Sirhowy project, which operates as a Design, Build, Finance and Operate (DBFO) contract. With little room in the budget for architectural extravagance, Arup, as Costain's designer, produced a bridge that was minimalist yet iconic in design, a simple and natural shape built within the value demands of a Design and Build agreement.

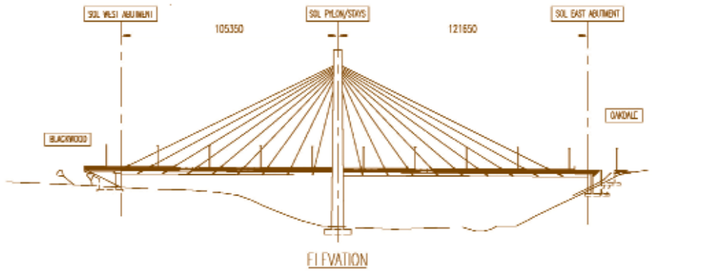
5. Mining-related subsidence is common in the region, with the ground continuing to sink in some places. Arup designer Kelvin Moneypenny says the bridge is designed to breathe if further settlement occurs and can be adjusted to compensate for any significant ground movements.

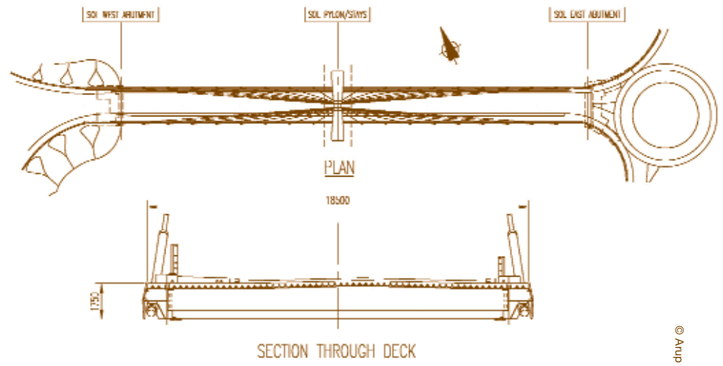
6. Arup was also Costain's landscape architect and ecologist on this project. Environmental surveys showed the area was home to many protected species, including dormice, for whom new trees and shrubs were planted. Aerial crossings were also built to link their habitats.

Client
Caerphilly County Borough Council
Client's nominee
Capita Symonds
D&B contractor
Costain Ltd
DBFO company
Sirhowy Enterprise Way Ltd

ACCESS TO STAYS AT PYLON HEAD FOR LENGTH ADJUSTMENT.







Patents pending

What is the damped outrigger system?
Arup's trademarked damped outrigger system, for which patents have been applied, reduces the motions of high-rise buildings in windy weather and results in cost savings in construction.

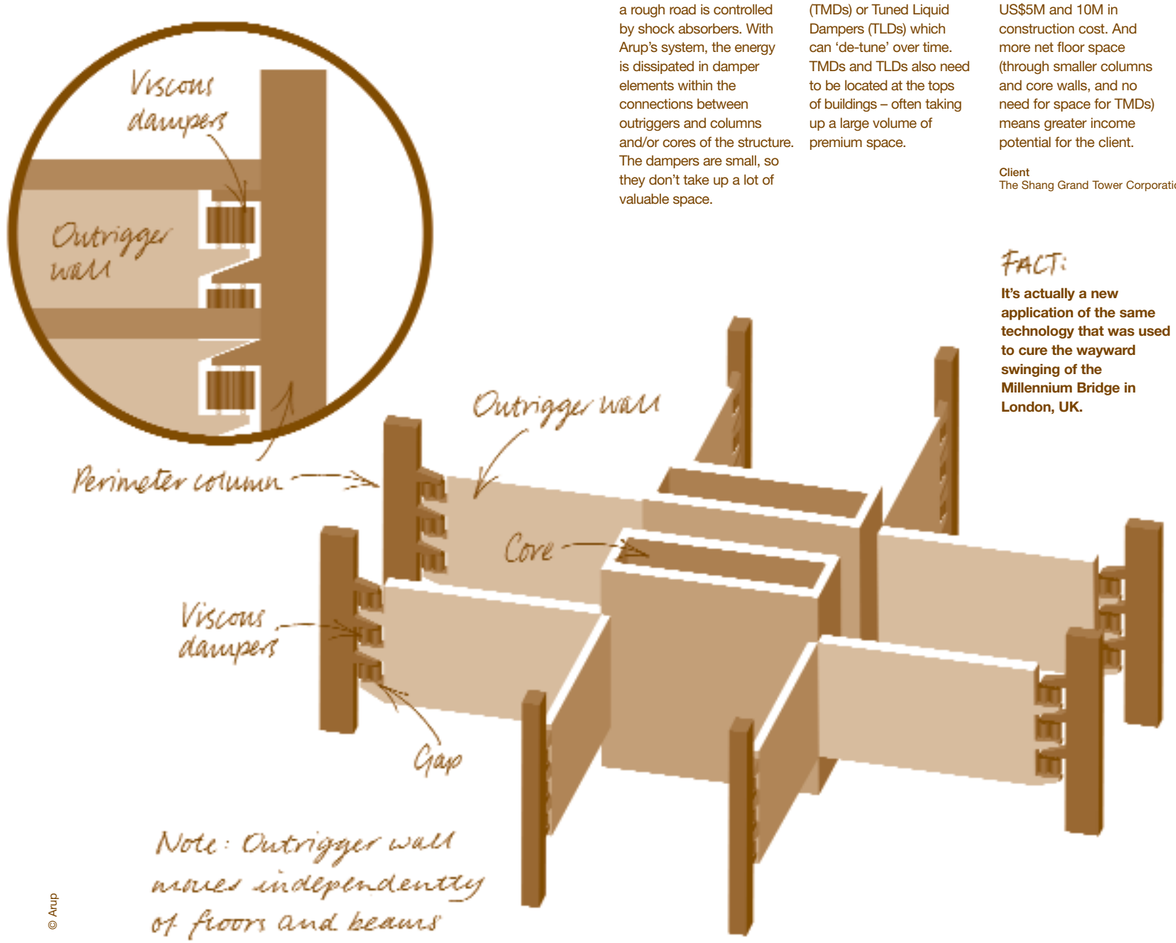
How does it work?
The system provides high levels of damping (a term for energy absorption) within a building's structure by incorporating components similar to the shock absorbers in a car's suspension. The system reduces wind or earthquake-induced sway vibrations of a tall building in the same way that the bounce of a car on a rough road is controlled by shock absorbers. With Arup's system, the energy is dissipated in damper elements within the connections between outriggers and columns and/or cores of the structure. The dampers are small, so they don't take up a lot of valuable space.

Why is it so great?
Arup's new system increases the level of damping that can be achieved in an economical way. It is so reliable that the design forces (and construction costs) of a tall building can be reduced. Arup's system is unaffected by changes to a structure's stiffness and is superior in performance to Tuned Mass Dampers (TMDs) or Tuned Liquid Dampers (TLDs) which can 'de-tune' over time. TMDs and TLDs also need to be located at the tops of buildings – often taking up a large volume of premium space.

Has it been used yet?
Yes, on the twin 60-storey St Francis Towers in Manila, the highest residential buildings in the Philippines.

And what were the benefits?
Reductions in the amount of concrete and reinforcement steel in the St Francis Towers structure saved Arup's client between US$5M and 10M in construction cost. And more net floor space (through smaller columns and core walls, and no need for space for TMDs) means greater income potential for the client.

Client
The Shang Grand Tower Corporation



FACT:
It's actually a new application of the same technology that was used to cure the wayward swinging of the Millennium Bridge in London, UK.

Around the world, ears have pricked up as new technology from Arup is allowing clients and architects to hear exactly how buildings will sound, before a single brick has been laid.

Words: Andrew Bennett

Are you listening?

Every building or space has its own unique acoustic signature, or sound characteristics. To date, what that signature will be has been nigh on impossible to recreate – until now. Using a technology originally developed at Arup's New York offices, sound characteristics can be accurately rendered to precise specifications. The magic takes place in the Arup SoundLab, a space designed to enable Arup acoustics experts and collaborators to listen to a variety of different spaces. There is no need to wear headphones and by building acoustics into the design process in such a way, money can be saved by avoiding adjustments later in the construction process.

SoundLab is the fruit of 25 years' experience in measurement, scale modelling, computer modelling and research, and design of performing arts buildings.

However, the technology is used in every imaginable kind of building and not just theatres and opera houses.

"Every time I had a workshop I would walk out of the office even more excited about the project. There was a wonderful spirit in the offices – warmth that is clearly embracing. Every time I was in the Arup office, it was a jaw dropping experience! Surprised by something new every time. Then you go back and get overwhelmed again."
Barbara Romer, founder, New Globe Theater

Left: visualisation of sound propagation on the stage of the New Globe Theater, New York.

Public transport interchanges such as London's forthcoming Heathrow Terminal 5 and the new high-speed TAV terminal in Florence also used the technology to make sure that public announcements are easy to hear. "The key thing for transport-related projects, or any large-space project, is speech intelligibility from public address and voice alarm systems," explains Raj Patel, associate principal at Arup's office in New York. "In large public buildings, for example, European codes require evacuation using voice messages, so speech needs to be clear and easy to understand. This calls for the optimum balance in the design of the transport facility's sound system and building acoustics. We work with the architect and client to offer a tailored, verifiable approach, ensuring that they don't over- or under-spend, giving local enforcing authorities confidence in approving design." This creative approach to urban sound management also carries the additional benefit of reducing noise pollution as much as possible.

SoundLab harnesses some powerful Arup-designed software and hardware to recreate the direction, timing and strength of sound reflections from a real or imagined space. This flexibility means that any space – indoors, semi-indoors, or outdoors – can be modelled to optimise its design from the outset.

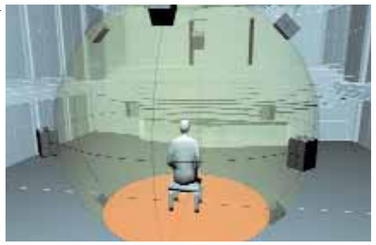
To make a powerful visual link with an existing benchmark concert hall, for instance, the listener sees images of the venue appear before them on a screen at exactly the same moment they hear its signature sound. The advantage to this is that you don't have to be a trained listener to hear the differences. So clients and architects using the listening space immediately understand the different aural qualities of various structures and spaces.

It is exactly this approach that is helping Arup to recreate the magic of London's old Globe Theatre in modern New York.

A derelict 19th-century fort on Governors Island, which lies between Manhattan and Brooklyn, is the proposed site for the New Globe Theater. The fort, known as Castle Williams, was chosen because of the many similarities it bears to London's original Globe Theatre, including the open central courtyard which is almost exactly the same in diameter, as well as its proximity to the water.

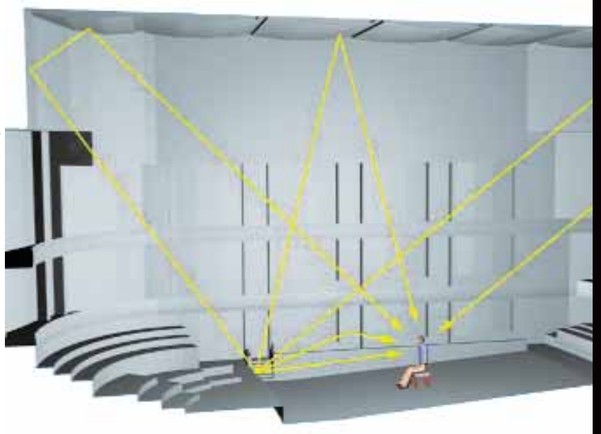
Above right: diagram indicates how sound was heard in The Sage Gateshead's concert halls. Below: rendering shows how sound is reproduced virtually in the Arup SoundLab.

© Arup



"In almost every respect we have been really very happy with the high acoustic standards the teams achieved throughout The Sage Gateshead. The natural room acoustics are particularly fine, and throughout the 530 performances we've so far staged here audiences and artists have consistently told us that the combination of clarity, warmth and depth they experience here have very few equals anywhere else in the world."
Anthony Sargent,
General Director,
The Sage Gateshead

© Arup



The brief to the architects was to create a new space within the courtyard of the listed fortification, incorporating a moving roof to shield audiences from the elements and provide a way to allow for different kinds of performance. Arup was asked to work with the architects to make the building sound like the original Globe.

Measurements were taken in the existing London Globe, along with recordings of Shakespearean actors. Recordings were also taken in a room where there were no sound reflections whatsoever. Both were used to compare sound in the New Globe to that of London's Globe. This work has meant that the theatre is now claiming that it is the world's most scientifically informed theatrical space.

Arup has coupled its experience in the acoustics field with powerful computing technology to overcome past limitations. In the same way that three-dimensional animations have transformed visual design, SoundLab has enabled architects and their clients to be in the middle of a three-dimensional sound field, sampling and adjusting the desired acoustics of their project.

Other applications include: helping to control environmental noise during the design of new residential projects; in hospitals, where music is used as part of the healing process; and the Beijing Olympic Stadium and Beijing National Swimming Centre, to create an atmosphere that will heighten the excitement and anticipation of both spectator and athlete.

SoundLab technology has been used in more than 150 projects and following the opening of the first in New York, others have been created in London, Hong Kong and Melbourne, the future is sounding better already.

The Sage Gateshead

The Sage Gateshead is already established as one of the UK's finest concert halls since its opening in 2004. Arup worked closely with Gateshead Metropolitan Borough Council and architects Foster and Partners to determine the acoustic requirements for the venue and then transform them into outline designs.

Although SoundLab was still in development when the design phase of the project was finished, Arup used the technology to allow both client and architect to listen to the halls retrospectively.

The need to cater for a wide range of acoustic situations was an integral part of the design. The venue hosts a variety of concerts including jazz, classical and amplified rock music. It also needs to allow for speech. Each of the halls has its own unique signature that required specialist analysis to allow for the fine-tuning that would produce the best acoustic results. For example, Hall 1 is a 1650-seat concert venue. Fine-tuning this building's acoustic signature included installing motorised sound absorbing curtains that can be deployed to cover most of the walls which, along with a moving ceiling, serves to reduce the reverberance to suit different performances.

Many concert halls require three months or more for acoustic tuning. The SoundLab allowed Arup to listen to different room set-ups in advance of testing, with the musicians in the room. This speeded up the commissioning process and gave the musicians more time to get comfortable with their new space.

© Arup

© Arup

GSA Courtroom

The United States justice system is using SoundLab to hone crisp sound qualities inside some of its new courtrooms, so that proceedings can be clearly heard.

At present all Federal courthouses in the US have a full-scale plywood mock-up of the courtroom built for the judges and design team to test and approve the sightlines. The downside is that the mock-up can't be used for testing any other specific performance issues.

General Services Administration (GSA) approached Arup to conduct a pilot study to provide a virtual reality model courtroom to test acoustics, lighting, sightlines and architecture all at the same time. Arup developed a system to create an interactive 3-D model allowing the architectural finishes and lighting to be accurately modelled and then modified during the design process.

The model was projected on to a large screen, so that it could be viewed by the whole design team and judges in one room at the same time. It meant that the design could be discussed and progressed in real time.

Working closely with the client and design team, Arup optimised the design to balance reverberation and clarity of speech.

The SoundLab also provided an environment in which all the design and client team members could experience the courtroom's acoustics and make collaborative decisions quickly and efficiently.

Based on the success of this effort, this process has been applied to subsequent projects for several clients.

The whole process can be conducted for approximately 40% less than the cost of a physical mock-up – a huge saving in both money and time.

These images show the courtroom virtual reality model in three stages. Above: the acoustic model alone and underneath, a render of the light luminance levels. Right: this rendering includes acoustics, lighting, sightlines and architectural visualisation. The final model is 'real time', allowing the client to move through to view and listen from different locations.

© Arup

The A470 is a vital link between North and South Wales, but a 7.2km stretch was proving a risky ride until the Welsh Assembly Government decided it was time to take action – now it's been called 'the greenest road in Britain.'

Words: Anthony Beachey

The long and winding road

In brief
In August 2002 Arup and construction company Laing O'Rourke won the design-and-build contract to upgrade 7.2km of the A470 – linking Dolwyddelan and Pont-yr-Afanc, near Betws y Coed. It's a £17.5M road improvement scheme in the ruggedly stunning Lledr Valley of North Wales, the eastern gateway to the mountains of Snowdonia. The Assembly Government is responsible for the trunk road network and has long recognised its importance and the need to launch a series of projects to improve it.

Setting in stone
Sketch, right: these stone-faced retaining walls and new stone boundary walls were built with a dry stone appearance in harmony with the existing walls. Where possible, stone taken from the improvement area was re-used in keeping with the area's natural surroundings.

Designing and constructing major roadworks in some of Britain's most environmentally sensitive countryside requires the kind of creative approach that Arup is well known for. At Lledr Valley, the existing highway's narrow alignment and tortuous bends represented a glaring safety hazard, particularly for heavy goods drivers. Poor visibility and minimal verges hampered overtaking, and prevented the road's safe use by pedestrians, equestrians and cyclists. Congestion, frequent delays and an above-average accident rate prevailed. Road widening and other improvements were an urgent priority. The main issue was that the project brief demanded the design teams to provide a safe and reliable route for road users, whilst preserving a landscape of lush pastures, ancient woodland and diverse flora and fauna without closing the road.

A further vital component for an additional route running through Snowdonia National Park was to mitigate environmental damage and enhance aesthetics. Such a project called for a sympathetic design and demonstrably sustainable credentials.

A comprehensive planning process and a non-adversarial partnering approach helped to minimise disputes and prevent delays. "From the outset, we developed an integrated design and construction programme, allowing us to deliver critical information on time and as required," says Dan Saville, Arup associate director and project manager for the Lledr Valley Scheme. "We also worked well with the Welsh Government Assembly and its agent, Halcrow. Our people adopted a proactive approach when dealing with problems and site queries, which helped relations and saved immeasurable amounts of time."

Soil nails (traditionally used to achieve steep slope angles) were included in the original illustrative design, but additional investigation, analysis and risk assessments showed them to be unnecessary. This reduced costs for Laing O'Rourke and minimised highway disruption, as construction was occurring next to a live carriageway. Arup repeatedly demonstrated its ability to respond quickly to design changes; for example, when the rockhead level measured at certain sites varied significantly from that predicted in the design – an important factor in terms of piling for the road's retaining wall. "We couldn't just halt the project to send our query 170 miles to Cardiff," says Saville. "Instead, the flexibility inherent in our modular design solutions prevented delays."

The team effectively translated the project's Environmental Action Plan into workable schemes. These included safely removing fish by electrofishing ahead of river works, and incorporating recesses in retaining walls to allow reptiles, birds and bats to nest and roost.

The project opened in January 2005, within budget and five months ahead of schedule, which allowed Laing O'Rourke to free up staff for alternative sites. Arup's own reward has been that the firm helped to build what Countryside Magazine has described as 'arguably the greenest road in Britain.'

"The entire Lledr Valley project team worked towards a common goal of delivering the road improvement in an environmentally sensitive way. The fact that this was achieved some five months early, within a partnering framework, and that the project is now receiving awards demonstrates that the team got it right."
Mike Gilbert
A470 Lledr Valley Improvement project director, Transport, Wales, Welsh Assembly Government.

The bats are back
Right: a pet project was the creation of a new local bat hibernaculum – otherwise known as the bat hotel – to make it attractive to the tiny mammals and help facilitate construction. Measurable performance targets such as recycling dismantled stone boundary walls in other parts of the project maximised sustainability whilst minimising environmental damage.

Client
National Assembly for Wales
Client's agent
Halcrow
Client's environmental advisor
Wyn Thomas Gordon Lewis
Contractor
Laing O'Rourke
Landscape architect
TACP
Ecologist
Cresswell Associates
Arboriculturist
Amenity Tree Care
Archaeologist
Gwynedd Archaeological Trust

© Irizar

Brand and deliver

Vehicle design is a fast-moving industry that is as much about the brands as it is about getting bigger, better products to market in double-quick time.

Words: Adrian Holliday

Car manufacturers are under enormous pressure to build new models faster, while model life spans are becoming ever shorter. Starting with an understanding of target customers' lifestyles and brand perceptions, Arup's work in vehicle design begins with accurately defining the concepts and requirements for a new vehicle.

The specialist team then integrates styling with engineering, feasibility studies and structural analysis assessments to produce innovative, yet realistic design solutions in timeframes that are far shorter than usual. Arup's approach, involving integrating brand analysis and engineering feasibility, ensures reduced costs, a better product and less risk. Resulting designs will also be easier to manufacture and more exciting for the target customer group.

"In today's highly competitive market, branding is everything," says Neil Ridley, a director at Arup. "We understand why some brands have emotional 'pull' and how to enhance and develop them. Often our brief is very much about what a client represents, rather than what it makes.

"Our ability to help clients develop their brands by employing thorough research at the start of the project makes us different. There is no such thing as an off-the-shelf package at Arup; each design solution is unique and appropriate – our approach is creative and the results innovative."

From understanding the owners' lifestyles and brand perceptions, to building engineering risk-assessments and computer-aided engineering evaluations, Arup's specialist vehicle design team knows how to define and build a new vehicle from the design board up.

Ground-breaking advances in computer-aided engineering (CAE) developed by the Arup automotive team are used to test and develop vehicles through simulation, rather than relying on expensive and time-consuming physical testing. Manufacturers are therefore able to build with greater confidence, without compromising on creating excitement for the driver.

These techniques have been evolving over the past 20 years, when Arup first began working in the automotive design sector. Computer simulation techniques, developed for the nuclear industry, formed the basis for a new generation of crash software that Arup pioneered for vehicle crashworthiness applications.

Development projects for all-new cars can be in the order of hundreds of millions of pounds and take between three and five years to bring to fruition. A combination of these two factors often results in substantial finance costs for the manufacturers involved.

But while the cost of testing a prototype is considerable, it's the time delay that really hurts. Ford's revamped GT, for example, was designed to invoke the spirit of the original, much loved, 1960s model. It also had to be developed in half the usual time, to help Ford celebrate its recent centenary. From design sign-off to production Arup helped Ford complete the project in just 18 months, thanks to this innovative approach to analysis. Now there's a driving force in vehicle design.

Irizar coach

The Irizar luxury touring coach is radically different from its peers. The design difference is immediately apparent in the swooping external curves, imbuing the coach with energy and Spanish flair.

Arup's automotive design and engineering experience brought a new approach to the coach industry, which was aided by using car-inspired design techniques such as ergonomic detailing and high-quality trim materials.

Inside, there's little sense of claustrophobia or a shortage of space as you move down the central aisle. Instead, using experience gleaned from designing aerospace industry jets, Arup created overhead luggage racks in the style of aircraft baggage compartments, which curve in a continuous S-shaped wave, deep into the interior. Cleverly, this creates a sense of space and calm, inviting passengers further in and generating the perception that the luggage racks are further away from travellers' heads than they really are.

Traditionally the coach sector uses relatively low-volume production techniques. This keeps down tooling costs, but results in the use of lower-quality components (such as seats and steering wheels). This detracts from the quality of the final product. However, the high-quality/low-cost prototype tools developed by Arup meant that higher production runs for Irizar were possible, resulting in cost-savings and increased quality for the Spanish coach company.

Get moving

Left: from sketch to the finished article, these are highlights of the design development process for the new Irizar coaches.
Right: Arup has worked with Nanjing Automobile Corporation on its product strategy for new MG products, projecting the values of the MG brand on to a modern global stage. This rendering illustrates what a future MG could look like.

© Arup

MG

Arup has worked in partnership with the MG Rover Group for over 15 years.

When the company collapsed into administration in April 2005, with debts of £1.4bn, pension black holes and no early signs of a buyer, it threatened the future of the car manufacturing industry in the UK.

The following month, Arup began working with Nanjing Automobile (Group) Corporation (NAC) on its purchase of MG Rover's assets, with two main roles: lead adviser on the transaction bid itself and providing Nanjing with in-depth advice on its strategic business plan. Due diligence advice and the provision of an outline blueprint for Nanjing to establish a viable UK business operated within the UK completed Arup's involvement in the project. Using Arup teams to carry out this work was a highly unusual move as the role of lead adviser is traditionally held by investment banks or major accountancy firms. Arup's transaction advice team advised Nanjing on the administration process, which is very different from that which prevails in China.

Obstacles such as increasingly bad press were neutralised by an Arup-led media campaign to highlight the firm's role as lead advisor, providing advice on the transaction and strategy that would help Nanjing achieve its goal to become a significant player in the global automotive field. As a result, Nanjing successfully acquired the assets of the MG Rover Group in July 2005.

It was the first overseas corporate acquisition from administration undertaken by a Chinese company.

"Our objective is to use our business and technological skills to deliver creative designs that have a direct influence on improving our clients' bottom line."

Neil Ridley, director, Arup

© Roman Keller/Gramazio & Kohler

The world's largest timepiece

In a city famous for its watches, an artistic statement centred on the concept of time could not be more appropriate.

Words: Clare McKenna

Working alongside Swiss architects Gramazio & Kohler, Arup helped to breathe life into the design of The World's Largest Timepiece, a contemporary veil of light that will now shimmer down the middle of Zurich's Bahnhofstrasse for 30 Christmases to come.

The new installation replaces another entitled Canopy of Light, a more traditional display funded by the Bahnhofstrasse Business Association. When the association commissioned the latest design, its members were looking for a new, more economical and environmentally friendly display that would reduce maintenance costs and last another 30 years.

The solution has proven extremely effective: it uses just a quarter of the electricity needed to power Canopy of Light. The lights have been designed to reflect activity in the street below as the Christmas season comes and goes. The interactive display responds to street activity, transmitting a unique sequence of light every time someone walks beneath it, time and street occupation are the key elements of influence. It is intended to stimulate debate around modern versus traditional art and re-establish Bahnhofstrasse as a premier destination for shopping and culture.

"The architect's concept gave us the idea of pixellating the individual lights so they could work in unison and function as a large screen displaying patterns along the street," explains Arup's Florence Lam. "We then suggested placing occupancy sensors along the Bahnhofstrasse. These could track movement of pedestrians along the street and send data back to a control point to generate images."

Arup created a 7m-long prototype light tube made up of 32 individually-controlled sections. Each section contained 28 environmentally friendly light emitting diodes (LEDs) supported and activated by a tubular circuit board with a unique chip behind each LED. A pure white light was chosen for its modern and clean look, further distinguishing The World's Largest Timepiece from the previous display.

"As each section has its own electronic identity it can be individually dimmed to create the illusion of movement along the street," explains Florence. "As the light is distributed evenly along the fibreglass tube there is no sharp demarcation when one section is turned off, which creates a flowing effect."

How it works

Working with Arup, Gramazio & Kohler devised a unique algorithm to computer-generate images along the screen of lights using real-time data generated by the occupancy sensors combined with the time and date. Each image is different as time and date are constantly changing – creating a stunning, contemporary display.

© Roman Keller/Gramazio & Kohler

How it was done

Cable structures are notoriously complex," explains structural engineer Andrea De Donno. "The stiffness of a cable is directly affected by its geometry, so every possible movement and reaction to temperature, wind and weight had to be calculated. We had to fine tune the geometry of the cable system to find the best balance between minimising the tension in the cables and respecting the deflection requirements."

Keeping the structure stable

Parallel to the creativity of the lighting, Arup faced the challenge of delivering a discreet support structure that would perform in extreme conditions. In addition to bearing the weight of the lights, allowances had to be made for the load generated by windstorms and temperature variations, while maintaining a strict clearance zone between the lower cables and the Bahnhofstrasse tram power lines.

Studies conducted at the initial feasibility stage established the locations and weight capacity of the existing anchor points from the previous Canopy of Light installation. The new design needed to minimise the anchor forces, to avoid the risk of damaging the buildings and allow as many of the existing anchors as possible to be reused.

A high-strength steel cable structure was designed and non-linear analysis was conducted to determine how cable tension and deflection would change in varying loading conditions. The design selected enabled 88% of the existing anchors to be reused.

Throughout the design and analysis stage, Arup shared its modelling, methodology and knowledge with the architects and contractors. Arup developed a straightforward but accurate installation procedure together with the cable contractor. This inclusive approach guaranteed the scheme's success and ensured the high specification of cable structure was realised exactly in line with the architect's original proposal. The World's Largest Timepiece was delivered on budget, on time and as promised.

© Arup

Design
Gramazio & Kohler, Zürich
ims Industrial Micro Systems, Winterthur
Kummler + Matter, Zürich
Encon, Felben

Realisation
ims Industrial Micro Systems, Winterthur
Gramazio & Kohler, Zürich
Cowex, Pratteln
Encon, Felben
Kummler + Matter, Zürich

Ready, jet, go

The advent of the low-cost airline has revolutionised the aviation industry's approach to pricing. Now the stakes are even higher, as the world's first low-cost airline terminal is about to be revealed.

Words: Andrew Bennett

© JetBlue Airways

The terminal, measuring approximately 60 000m², is being connected to an icon of airport architecture, Eero Saarinen's former TWA Terminal. Customers will be able to reach the new terminal via two walkways from the Saarinen terminal, which is due to be refurbished soon.

© JetBlue Airways

Airport terminals are often grandiose structures that can be frustrating places for the very people they are supposed to serve. Flying in the face of that tradition is an US$850M project at New York's John F Kennedy International Airport (JFK) for JetBlue Airways.

The airport's new Terminal 5, due to open in 2009, is a showcase project designed to demonstrate the kind of innovation and efficiency needed by such a fast-growing industry. JetBlue's new terminal is projected to handle 20M passengers a year when fully operational – double its current activity at JFK.

"The aviation industry has been through a revolution in terms of its cost base," comments Greg Hodkinson, Arup's Americas region chairman and Terminal Five's design team leader. "Competition means customers want lower fares and extravagant civic monuments are no longer appropriate. The new era being ushered in by JetBlue requires efficiency, but is also rooted in humanity."

Arup's aviation pedigree is a long one. It includes terminal and infrastructure projects at airports including Zurich, Switzerland, Terminal 5 at Heathrow, Beijing's Terminal 3, Nagoya in Japan, Washington Dulles' new terminal, Los Angeles/LAX, along with renovation of Terminal 6 at JFK for JetBlue and Terminal 7 for British Airways. Then there's the planning, design and engineering of JFK's Terminal 4.

© JetBlue Airways

The centrepiece of a large retail area in the middle of the terminal will offer a wide variety of food and other goods; this is important, since there are no in-flight meals.

© JetBlue Airways

The process engineering approach means passengers will have minimal walking distances and changes of level as they board and alight their planes.

Before the designs were even conceived for this project Arup worked closely with JetBlue, factoring in considerations such as flight schedules, growth projections and the number and type of customer-processing facilities required.

It will stand out for being extremely functional, avoiding frustrating layouts that result in queues both inside the building and outside on the taxiways. With aircraft turnarounds projected in just 30 minutes, there is a premium on common-sense thinking.

The resulting innovations include a highly 'pilot-friendly' approach on the airside and a highly automated set of building and operating systems on the inside. Far from cutting corners, low-cost airline operators have no room for anything but the most tightly run of operations – and that means ensuring that airports can cope with demand efficiently.

Richard Smyth, Vice President of Redevelopment at JetBlue, is quick to point out that tight budgets are not what this project is about. "Low-cost means being efficient, not using low-cost materials," he says.

"The building will look tremendous. Per square foot we are likely to be the busiest in the world, with 10 'turns' per gate, per day."

Client
JetBlue Airways
Architect
Gensler
Retail space architect
Rockwell
Civil engineer
DMJM Harris
Construction manager
Turner Construction

The shocking events of 9/11 challenged both industry and consumer perceptions of how safe tall buildings are. Since then, building owners, occupiers and developers have increasingly called for building designs that are not only taller than ever before, but more robust as well. The following three case studies demonstrate Arup's response to the new demands of this changing market.

Words: Chris Webb

Tall orders

Ever since the word 'skyscraper' entered into architectural vocabulary in the late 19th century, architects and engineers have strived to push the boundaries of structural possibility. Now, those boundaries are not only concerned with height but also with form itself – an area in which Arup leads the way.

Tall buildings are not, of course, all the same. First, they may differ in function, as Craig Gibbons, a director in Arup's Hong Kong office, explains. "A client's new headquarters may be there to make a special statement – an iconic structure. The primary design driver for a mixed-use building, such as one that includes apartments, offices and a hotel, will more likely be that of useable floor space – though the client may equally want it to be a landmark."

A statement, a landmark, lots of floor space: these are all important in tall buildings, where the need to accommodate many occupants in comfort is paramount. Nowhere is this more apparent than in Hong Kong, where population densities may be as high as 45 000km^2, space comes at a premium and plot ratios are high. The equation is simple: small footprint and high occupancy equals tall building.

Tall buildings may also differ considerably in their layout, a factor that can have serious implications on their viability, and consequently, their cost. By using the latest technology in 3-D and 4-D modelling and always considering the latest in materials and construction systems, Arup teams are always able to work within the parameters of any given project.

The result of this approach is a better understanding of not only the static and dynamic issues, but also the social and environmental problems a particular building presents. There are also considerations relating to building form. No longer must a client be constrained by simple building forms. Buildings can instead respond to their function.

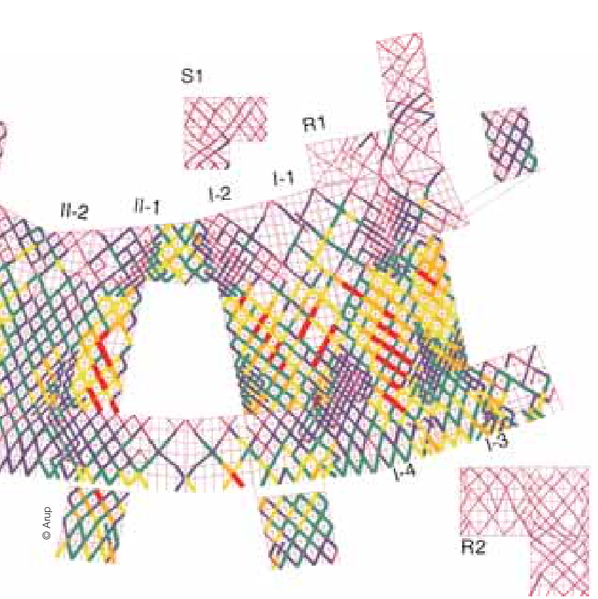
When disaster struck in America on September 11 2001, the viability of tall buildings came under siege and across the world the security in everyone's living and working environments came under unprecedented review. Nevertheless, tall buildings are also planned for construction in some of the most environmentally hostile regions on earth, where typhoon winds (Hong Kong), or unpredictable seismic activity (Beijing) present additional challenges. Such locations require special consideration and customised solutions. In the race to build higher and higher, the need for buildings to continue to do their job in extreme circumstances is pushing at the boundaries of engineering, requiring more and more from design and materials.

Arup's response to the World Trade Center disaster was swift, establishing an Extreme Events Mitigation Task Force charged with evaluating the risks of disasters similar to those that have taken place in recent years, analysing the technical challenges they represent and developing design solutions to address them. With typical zeal, and chaired by the late Tony Fitzpatrick, then chairman of Arup's Americas region, the task force mobilised the might of the firm's in-house research and development capabilities and specialist teams on tall buildings, fire, materials, structural analysis and other disciplines to see what lessons could be learnt from the World Trade Centre disaster.

Under the direction of a single project director, the task force continues to play a critical role in the operation of facilities when unplanned or unanticipated events occur. Arup makes full use of its multidisciplinary fire, risk, security, information technology, telecommunications and systems skills to amass a rapid understanding of the threats and risks faced by the client. Based on this, the task force assesses reasonable risks and develops additional mitigating measures to address exceptional scenarios, where appropriate. Client requirements and cost-effectiveness are also taken into account in the overall design solution.

Despite the catastrophic events and subsequent uncertainty surrounding the future of tall buildings in relation to safety, the industry has continued to grow to be as mighty as the buildings themselves. In fact, there are more tall buildings on drawing boards now than ever before, making this one battle in which technology has triumphed over terrorism.

CCTV building, Beijing



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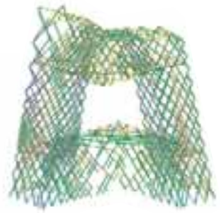


The CCTV project involved close collaboration between the architect and the engineer. Fold-out analytical models of the building were developed to convey the stresses in the diagonal braces and develop the precise configuration of the expressed form of the structure better.

CCTV building, Beijing

Chinese Central Television (CCTV), the Chinese state-run media company, has ambitious plans to compete on the world stage of broadcasting, transmitting in time for the Beijing Olympics in 2008. This expression of national pride extends to its new US$600M headquarters in Beijing's central business district. The commission to design the building was won by Ole Schreeren and Rem Koolhaas from Rotterdam-based Office for Metropolitan Architecture (OMA), with Arup. The Arup team, working closely with OMA and East China Architecture & Design Institute (ECADI), a Shanghai-based local design institute, delivered the design through seamless global collaboration, crossing time zones, cultures, cost centres and even the SARS outbreak.

Early on, the Arup team determined the only way to deliver the desired architectural form of the building was to make the two towers rise at an angle of six degrees, to be joined at the top by a 9–13 storey 'overhang' that is suspended 36 storeys high, all of which combine to form a continuous tube. The building will achieve its landmark status because of its form, as opposed to other buildings designed to achieve landmark status through their height alone.

The CCTV building is a unique, and structurally unprecedented, 450 000m², 234m-high cranked and leaning form consisting of a nine-storey base on a rectangular footprint.

Going up

Though the idea of building an incredibly tall building or structure may seem appealing at first, it can often be the most practical elements that put a stop to a project – like lifts, for example.

Tall buildings present Arup's vertical transportation team with vitally important opportunities to make a considerable difference to the viability of a project. Recent designs for a 100-floor tower included a required lift provision that would occupy almost 90% of the floor space in certain parts of the building. By using double deck shuttles and multiple sky-lobbies, this was reduced from 13 000m² to 8 000m². The value of this saved space in London would amount to approximately £50 million.

The team is constantly reviewing and questioning common practice to find areas where innovation can make a real difference to clients' businesses, either by improving the financial return or the business process itself.

Solutions can include anything from reducing the capital cost of the lift installation to reviewing lifting options where the net lettable space occupied can be reduced.

This approach often requires Arup to work well outside of normal parameters for a lift engineer, integrating solutions with other specialist considerations such as fire, security and acoustics. Consequently, the team works closely with lift manufacturers, often reviewing new products before they have even been released. It gives Arup the opportunities to discuss any potential challenges facing clients and to offer guidance on how manufacturers can adapt their products to better suit these demands.

© Sun Hung Kai Properties Ltd

International Commerce Centre, Hong Kong, China

Hong Kong's tallest building, the International Commerce Centre (ICC) is the centrepiece of the MTR Kowloon Station development. The total building stands 484m high and consists of 118 floors, housing hundreds of grade A offices and a world-class hotel. When complete, ICC will become Hong Kong's tallest building and the third tallest in the world.

The main structural skeleton of the ICC is formed from a high-strength concrete inner core wall, steel and prestressed concrete outrigger structures and eight mega columns on the perimeter. In partnership with architects KPF/Wong & Ouyang, Arup is providing civil/structural and geotechnical design for the Kowloon Station development, scheduled for completion in 2010.

© Sun Hung Kai Properties Ltd

Situated on opposite sides of Hong Kong's Victoria Harbour, Two International Finance Centre and International Commerce Centre will form a new gateway to the city.

2IFC Hong Kong

Winner of the prestigious Zhan Tien Yau award for engineering excellence in China, Two International Finance Centre (2IFC) is one of the most prestigious buildings to be constructed in Hong Kong in recent years. At the time of the 9/11 attacks in New York, the 2IFC building had been constructed up to the 30th floor. Perhaps not surprisingly, 2IFC was subjected to intense re-analysis and verification to assess the safety of the design and potential implications for re-design. The studies and their findings revealed that the design was inherently sound, requiring no changes, and provided direct feedback to world practice on the design of tall buildings post 9/11. Dynamic robustness concepts have taken an elevated importance on the world stage following 2IFC studies – specifically, the need for codified ductility requirements at floor plate connections to avoid disproportionate collapse. Towering at 420m and 88 storeys, 2IFC is one of the tallest buildings in East Asia, and just a part of the multi-phase US$3 billion IFC Development. In all, it provides a total floor area of 180 000m² of grade A office accommodation.

Arup also had to address special design requirements in order to provide for rapid construction of the building. These included several construction-led principles including the building of a 61.5m diameter temporary cofferdam to allow an early start to the raft foundation and the surrounding basement to be constructed from the top down, saving around eight months in the construction programme.

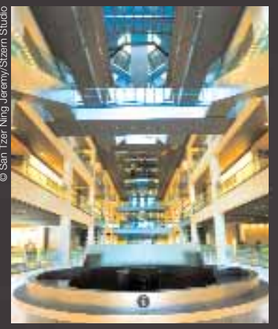
CCTV
Developers
Chinese Central Television
Architects
OMA/Ole Scheeren & Rem Koolhaas
Local Design Institute
ECADI

ICC
Client/Project manager
Sun Hung Kai Properties Ltd
Building services engineer
J Roger Preston Ltd
Architect
Wong & Ouyang (HK) Ltd
Concept architect
Kohn Pedersen Fox Associates

2IFC
Developers
Central Waterfront Properties
Architects
Cesar Pelli Associates
with Rocco Design Ltd

© Arup/Kenny Lo

© Foster and Partners



© San Tzer Ning Jeremy/Szarn Studio

Arup is using an insulated glass unit with a laminated stone-glass combination for the inner pane, made from Portuguese marble. It has resulted in an amazing quality of light passing through the façade into the office spaces during the day, and makes the whole building into a glowing lantern at night.

Smoke ventilation was an essential requirement in the development of the building's façade. Forward planning allowed Arup's team to work around the potential impact this may have on the appearance and meant that the client did not have to look into last-minute prefabricated solutions that would have looked completely different from the customised façade. The top third of the building's upper window units automatically open outwards, acting as smoke vents in the event of a fire, but no one can tell that these panels are any different from those lower down.

Client
The Supreme Court of Singapore
Architect
Foster and Partners/CPG Consultants Pte Ltd

Overview
Designed by Foster and Partners, the new Supreme Court building houses 12 civil courts, eight criminal courts and three appellate courts. Acting as façade consultants for the building, Arup worked alongside the architects to develop the building envelope from sketches on a napkin through to completion.

Arup proposed making the stone finish the innermost part of the building's envelope, allowing the stone to be the users' interface with the building and keeping it away from the weather.

The legal light house

The innovative use of stone and glass has transformed Singapore's Supreme Court building into a naturally glowing lantern at night.

Words: Hollie Boughton

NO
37
Kenya notes

The problem of finding a good home for travelling exhibitions has proved tricky in the past. Arup and architect Shigeru Ban designed and put together a permanent travelling home for the art exhibition *Ashes and Snow*, complete with a large-scale, column-free digital cinema in the central space. The project took just four short months – and it's opened up a new approach to the concept of collapsible building.

Principal Architect
Shigeru Ban
Associate Architect
Gensler
General Contractor
The RMS Group
Roof Contractor
Tenta
Project Director
John Picard
Featured Artist
Gregory Colbert

1. Called the Nomadic Museum, it has been built using almost entirely recyclable or reusable materials, including 152 steel shipping containers and paper support columns.
2. The entire museum measures 55m wide by 105m long. With the roof included, the total height of the museum is 17m.
3. The internal space is divided by hand-made curtains created from one million Sri Lankan tea bags.
4. The Nomadic Museum made its debut in March 2005 on the Hudson River Park's Pier 54 in New York City. Its other homes have included a parking lot at the Santa Monica Pier in California.
5. When its time at each location comes to an end, the entire exhibition is packed into just eight containers. The additional 144 containers necessary are hired at the next site.

The shipping crates are arranged into a checkerboard pattern pattern to create rigid walls and stacked 10m high to form the outline of the three main exhibition spaces.

Openings between containers have been secured using diagonal membrane panels.

PROJECT
Nomadic Museum
USA

ARUP

The portable gallery

The roof truss components include 300mm diameter paper tubes attached to 750mm diameter paper tube vertical support columns.

© Michael Moran

Inside, a central 3.5m wide walkway made out of hickory planks is surrounded by black river stones. Overhead the unframed artworks hang from cables and suspension rods installed between paper columns.

Natural beauty: LNG made safe and easy

The problem

Demand for liquefied natural gas (LNG) is on the increase because gas in liquid form is much easier to transport, satisfying growing energy demands quickly. But public concern over the perceived volatility of LNG means finding sites for storage facilities is difficult.

What can be done?

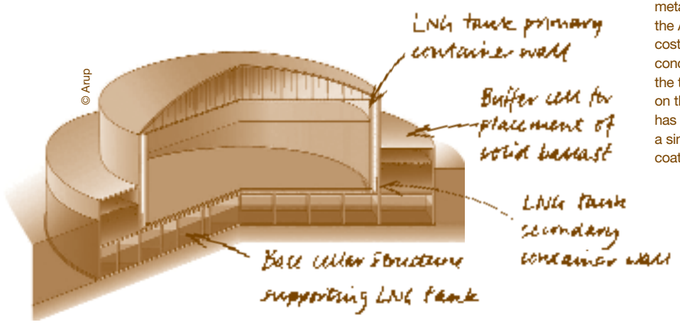
Operators and industry experts are looking at a range of solutions to the storage dilemma. One option is an innovative all-concrete LNG tank (ACLNG). Instead of opting for a traditional metal primary container, the ACLNG uses a simple, cost-effective, 'liner-less' concrete container. Also, the traditional metal liner on the secondary container has been replaced with a simple spray-applied coating. No more welding.

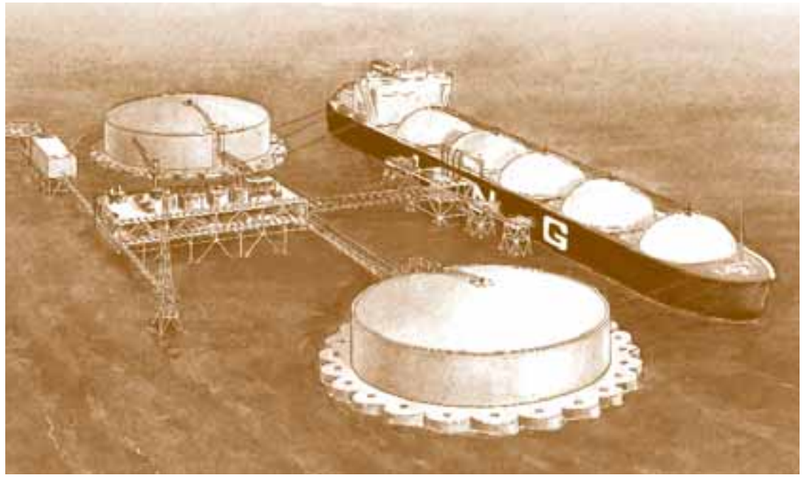
But that isn't all …

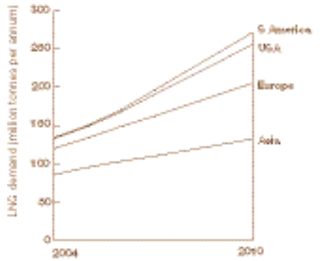
Offshore LNG storage facilities are an answer to the 'not-in-my-backyard' syndrome, and Arup engineers are again leading the way. Traditional thinking has dictated these structures must use a breakwater style of construction, a long rectilinear shape behind which the LNG transport vessel sits to protect it from the waves. Arup has led studies that have shown the breakwater is unnecessary, opting for a cheaper and more efficient cylindrical LNG storage tank design that resists wave forces instead.

What does offshore LNG storage mean for the industry?

It's not entirely clear. Fierce winds and waves are a tricky combination with the flammable and valuable LNG. To date, these off-shore projects have been prohibitively costly, but the US Compass Port LNG Terminal off the coast near Mobile, Alabama, is likely to proceed to construction soon, setting the benchmark for offshore LNG. Whatever happens, Arup expects to be a major player in this fast-growing field. "We're developing technology which will be the standard for tomorrow's applications," says Brian Raine, a project director and lead design engineer at Arup.







Forecast growth in global demand for LNG
Source: Deutsche Bank, July 2004

Inside out thinking

Client
Department of Primary Industries (DPI)
Victorian State Government
Architect
Lyons Architects
Project manager
Atkinson Project Management
Contractor
Kane Consultants

It all started seven years ago, when the Department of Primary Industries (DPI) in Australia set out to deliver an exemplary environmental project demonstrating the Victorian Government's commitment to sustainability. The result is an inside out, yet very attractive, US$20M energy-efficient intelligent research, development and education centre packed with futuristic gadgetry.

"This project has been very much a complete shared vision," explains Barry Steinmeyer at Arup's Melbourne office. "Its successful delivery came as a direct result of the collaboration between Arup and the client team, project manager, architect, landscape designer and builder."

What makes it inside out?

The concrete structure is exposed on the inside and timber cladding insulates the outside, maximising the benefits of thermal mass. Its walls and ceiling absorb heat in summer and naturally warm its interiors in winter. The building opens and closes the windows to let heat out. It also senses natural light coming through the windows and skylights and only turns the lights on when they're needed.

Doing the groundwork

The selected site, on the approach to Queenscliff, is a disused landfill site, which still has contaminants buried deep inside. Building on such a site required stringent environmental sensitivity, particularly because of its proximity to Swan Bay, which was designated a World Heritage Marine Park in 1999.

The ground had to be capped with 300mm of clay before any building work could begin (it reduces water infiltration across the landfill area and provides a physical barrier to contamination). The tricky part was supporting the building on ground that would continue to move for many years. The traditional solution, piling, wasn't going to work because of the risk of disturbing contaminants.

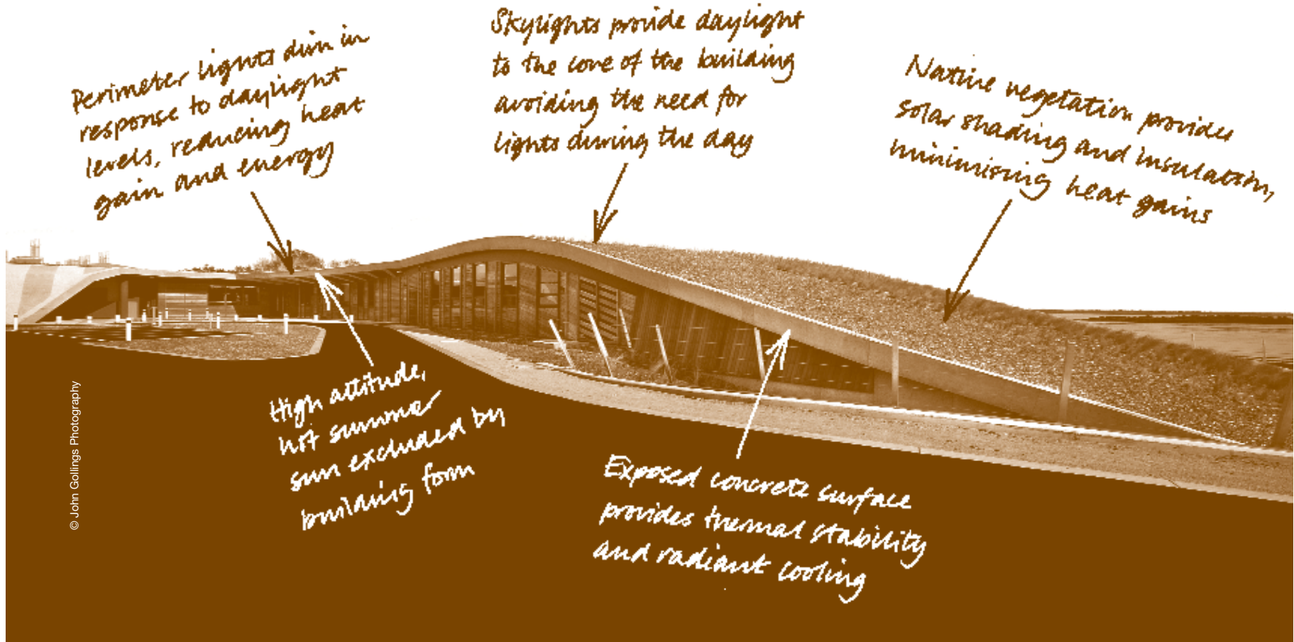
The innovative solution relied on a technique known as dynamic compaction. By working the site with an impact roller, the soil was compacted to a depth of 3m, resulting in a stiff upper soil layer which could support the building. It also reduced the ground level by 300mm, avoiding the need to take contaminated material off site and leaving room for the capping layer.

A little logical thinking

Every little bit helps when it comes to energy efficiency, so Arup oriented the building accordingly. Office workspaces sit on the front side, taking advantage of increased natural daylight and the prevalent sea breezes from across Port Philip Bay. This also protects the laboratories that need to avoid direct sunlight.

Water-wise

Precious rainwater is captured from the office roof, the laboratories and the courtyard areas, and stored in tanks to be used in the building for irrigating the roof. Fresh water is a pollutant to Swan Bay's precious eco-system. Excess stormwater and run-off from contaminated areas such as roads are infused into the ground by grass swales and a seawater wetland, preventing pollution from reaching the Bay.



NO
40
Rough notes

PROJECT
Wexner Center for the Arts
Ohio State University, USA

ARUP

Art attack

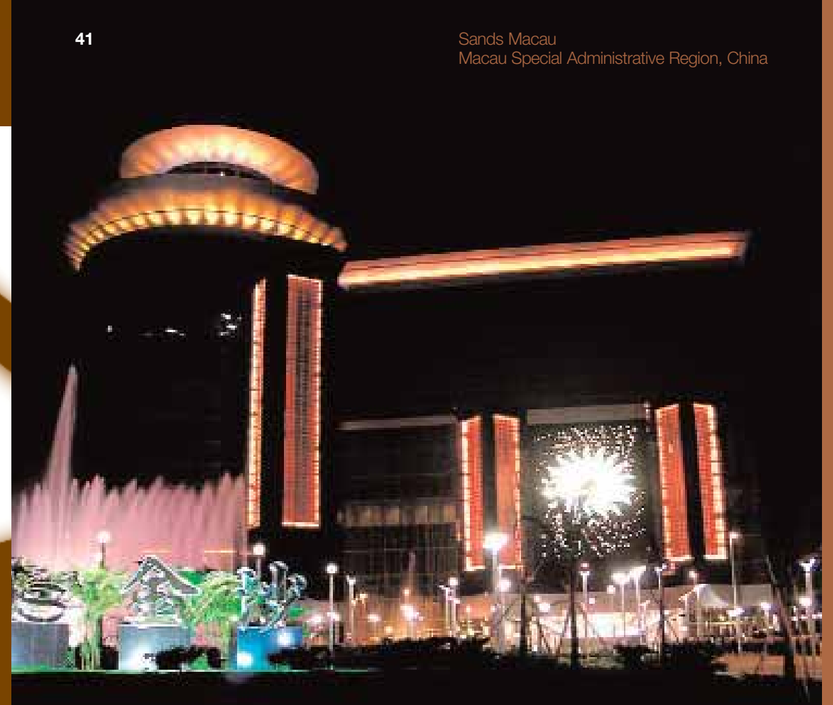
Architect Peter Eisenman's iconic Wexner Center for the Arts at The Ohio State University was originally designed as a tribute to contemporary art. But over time, his stunning design began to jeopardise the very work it was designed for. Eisenman's massive glass curtain wall of windows stretching over 1300m² let in so much light that remedial measures, such as shades and covers, became necessary to ensure a proper museum environment. Temperature and humidity fluctuations within the building were compounding the problem. In addition, the giant 650m² skylight leaked on occasion.

Trying to generate museum-quality conditions in a 'greenhouse' is difficult, but gallery bosses wanted to maintain Eisenman's design in all its bold, idiosyncratic glory.

The Center's galleries were closed to the public and with a tight schedule and even tighter budget, the Arup team set to work. They fixed the heating, ventilation and air-conditioning systems and replaced the curtain wall and skylight with a new and improved model that promised a better thermal performance whilst ensuring a proper range of luminosity.

The Wexner reopened to the public in October 2005 – fresh and invigorated from its three-year, US$15.8M refit.

Sands Macau
Macau Special Administrative Region, China



The best bet

You've got to work fast to stay ahead in the gaming industry – not only did the Arup team start the foundation work of the Sands Macau project on a site partially under water in less than four months from design inception, but also helped to enable the opening of business for the casino and restaurants in just 20 months.

Words: Clare McKenna

The Daido pile foundations of the building are precast, prestressed concrete piles of 600mm in diameter. They are prefabricated in factories located in Shenzhen and require only a very short lead-time before delivery. It's a cost effective pile type commonly used in Macau.

Client
Venetian Macau Ltd
Architect
Paul Steelman Design Group
Aedas

Overview
Project:
Sands Macau.
Size:
Total construction area of 102 000m².
Capacity for 20 000 customers and 2000 staff.
Arup provided:
Structural engineering, geotechnics, façade engineering, traffic planning, civil drainage, fire engineering, information technology, and mechanical and electrical engineering services.

Sands Macau is the first American-operated gaming facility to open in Macau, Special Administrative Region of The People's Republic of China. The region's economy has been growing at an impressive rate. Travel rates have exploded in recent years and indications suggest that these numbers will continue to rise.

Sands Macau is the first property in Macau from developer Las Vegas Sands Corporation and was designed to appeal to the growing tourism market in the territory, recreating the glitter and glamour of Las Vegas whilst adding a unique oriental atmosphere in keeping with the culture of the region.

However, an experienced betting man might choose not to gamble on the likelihood of anyone delivering a total engineering solution for a casino, from design through to construction, within 20 months. Especially, when the site in question was partially under water and required land reclamation before construction could begin.

There were challenges right from the start. The Arup team predicted that the soft marine mud would shift due to displacement by the driven precast, prestressed, concrete piles. Consequently, the team had to control the contractor's pile-driving sequence to minimise the mudflow. Arup advised that completing the project within the ideal timeframe of 12 months would only be possible if the development design could exclude a basement originally planned below sea level. This wasn't an option, as it was to house electrical and mechanical services and a 400-space car park.

With untiring efforts in refining the structural designs in order to save time during construction, Arup's project team overcame the crippling pile-driving problems and clawed back some much-needed time.

As planned, the major facilities of the Sands Macau including a large gambling hall, the first floor Paiza Club for VIPs and the 888 Las Vegas Buffet Restaurant, opened on 18 May 2004 and welcomed an estimated crowd of 35 000 visitors on its first day of business. Sands Macau's opening caught the attention of the media and the Macau community on day one due to the high visitor numbers, the plush decoration of the casino and the 45-tonne, 15m-high chandelier. Today the casino has 444 gaming tables, 921 slot machines, seven restaurants and other amenities.

Arup is now working on several more large-scale Las Vegas Sands Corporation projects in Macau.

Korea's New Songdo City Development is one of the largest private development projects ever undertaken. Its remarkable centrepiece, the convention centre, features a roof that has used a fraction of the steel originally anticipated.

Words: Lisa Clifford

A city without limits

© KPF

Songdo City Development
Korea

© KPF

Above: aerial view of Central Park and the canal system. The Northeast Asia Trade Tower (NATT) in the foreground, at 305m, will be the tallest building in Korea, and will complement the iconic beauty of the convention centre, shown left.

"By introducing a lot of daylight we are virtually able to turn the electric lights off, meaning you are way ahead of the game in terms of energy consumption and the amount of greenhouse gases produced."
Ashok Raiji director and principal, Arup

Rising up from 1500 acres of reclaimed land along Incheon's waterfront is Korea's US$20bn Songdo development. The city includes a park, golf course, seawater canal system, hotel, offices, school and a 300m tower – all of which Arup is designing, alongside the 140 000m^2 Convention Centre that sits at its heart. A wind farm will generate power to move the seawater through the canal system – just one of Songdo's many sustainable features.

Inside the Convention Centre, which comprises eight large exhibition halls, meeting and seminar rooms and banquet facilities, green is also the watchword. Arup has realised a structure at the cutting edge of sustainable development, using natural lighting, ventilation, a recycled (grey) water system and energy-efficient HVAC systems.

Outside, its mighty vaulted roof with curves, valleys, peaks and troughs forms a complex reverse boat design that is not dissimilar to the Sydney Opera House. "The large troughs and valleys result in some challenging wind and snowdrift loads. The roof works as a combination of an arch and a shell and spans 145m, coming down on two points. "It's a great structure," comments David Scott, the engineer leading the structural design of the project and a principal at Arup's New York office.

Elsewhere, a grey water system is planned for the second phase of the centre's development – important in Korea, where water is scarce.

Under this plan, wastewater will be collected from sinks, showers and dishwashers, cleaned and reused for non-drinking purposes.

When Songdo is finished in 2015 it will be a free economic zone housing 50 000 people – a place to live and work and a centre for trade between east and west. Flats are now being sold, though the first residents won't arrive for around three years. Most will come from the congested cities of Seoul and Incheon. Arriving at Songdo, with its world-class architecture and modern facilities, will be, quite literally, a breath of fresh air.

Developers
Gale International
POSCO E&C

Architects
KPF

It was working out a structure to support that roof that proved most testing. The roof is a long-span arch comprised of large-diameter tube sections. It works by bending at its connections, which must be designed to hold substantial loads as Korea's weather is extreme, to say the least: typhoon-force winds, earthquakes and heavy snow are common.

The tubes used on this project had large diameters and thin walls – they aren't covered by any design guides. Traditionally, the solution to this problem would be to make the connections rigid by inserting numerous stiffeners into the tubes, which are then welded closed, all at substantial cost for US developer The Gale Company, which is building Songdo alongside Korean conglomerate, POSCO.

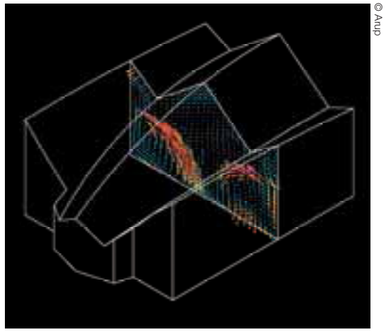
But a new design technique developed by Arup has minimised the number of joints that needed stiffeners, saving the cost of cutting and rewelding the tubes. The analysis has also minimised the number of stiffeners needed.

Using methods developed by the motor industry for car crash simulations, Arup engineers created a virtual prototype of the connections then tested them in a virtual laboratory to see how much load each could take under various combinations of extreme conditions.

From this analysis they developed capacity envelopes for each joint and then checked the joints for the hundreds of loadcase combinations that the roof experienced.

This modelling process, called 'virtual prototype testing,' had never been used before to justify a long-span structure. The analysis showed engineers exactly how many stiffeners were needed at each connection, ensuring nothing unnecessary went into the roof. "Using this technique is the only way we've been able to make this a cost-effective structure," explains Scott. "And that to me is really exciting. We are developing new ways to design cost-effective long-span structures, which has allowed us to work with architects KPF to create this remarkable roof."

Below: computational fluid dynamics (CFD) analyses are used to model thermal conditions and airflow in the Convention Centre's Exhibition Hall.



© Arup

In summary

April and November 2000
Serious flooding in parts of the Water of Leith. City of Edinburgh Council (CEC) undertake a Flood Study.
2001
Flood Study reported there was a need for extensive flood protection along the river channel and lowering the water level in three upstream reservoirs.
January 2002
Arup appointed to undertake scheme design, promote the flood prevention order and apply for planning.
August 2002
A week-long exhibition showcasing proposals held at three venues across the city.
September 2003
Flood prevention order promoted to 4000 residents, stakeholders and owners, followed by 90 days of consultation.
November 2003
Two Planning Applications lodged with the CEC and West Lothian Council; permission granted by WLC in April 2004 and by CEC in July 2004.
November 2004
Public Local Inquiry held.
Spring 2006
Advanced works packages prepared for tendering.
Main project to start in 2007.

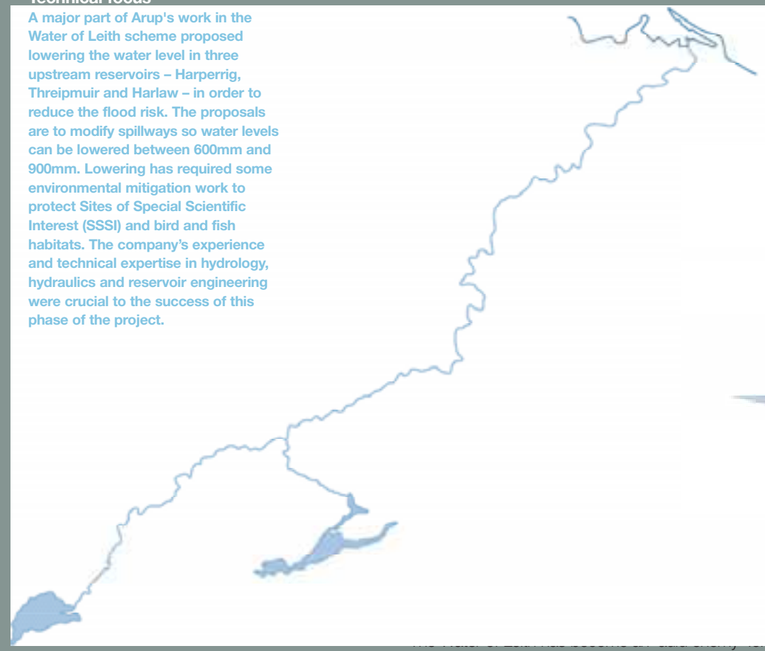
Flash flood prevention

When the Water of Leith burst its banks in 2000, over 500 homes and businesses were powerless to stop the flooding. But the City of Edinburgh ruled it would never happen again and launched the fastest flood-to-prevention notification scheme in Scotland.

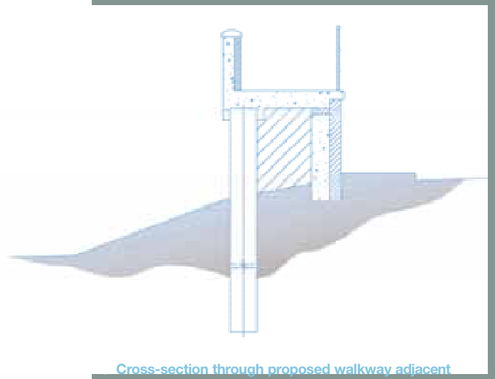
Words: Andrew Moore

Technical focus

A major part of Arup's work in the Water of Leith scheme proposed lowering the water level in three upstream reservoirs – Harperrig, Threipmuir and Harlaw – in order to reduce the flood risk. The proposals are to modify spillways so water levels can be lowered between 600mm and 900mm. Lowering has required some environmental mitigation work to protect Sites of Special Scientific Interest (SSSI) and bird and fish habitats. The company's experience and technical expertise in hydrology, hydraulics and reservoir engineering were crucial to the success of this phase of the project.



"Having attended a number of public displays in the city, it was great to see Arup taking a proactive approach with the residents. The scope of the scheme addressed all the main concerns of those living in the flooding areas."
Len Harvard, Colonies (resident)



Cross-section through proposed walkway adjacent to river (1 River bed; 2 Flood defence wall; 3 Raised walkway; 4 Steel sheet piles; 5 Existing walkway; 6 Existing road).

"The Water of Leith plans were put on display in the local libraries and at the exhibition. These gave me a valuable insight into the scheme proposals. The exhibition and public displays were well received from residents affected by the flooding."
Stuart Kinsman, Hanover Housing Association, Edinburgh

"I was consulted by Arup on all pressing issues through the exhibition and by phone, mail and email. This included everything from design changes to the reservoir weirs to more domestic flood prevention concerns. I also found the project manager to be very patient with good people skills."
Anne Fortune, Colonies (resident)

some of Edinburgh's residents who live upon its meandering banks. Since time immemorial the river has had a propensity to burst its banks, but the disruption in 2000 was the last straw, as local people struggled once again to recover from the devastating effects. In 2002 the City of Edinburgh Council commissioned Arup to develop and implement a flood alleviation scheme. This ran from a pre-feasibility stage to detailed design and site supervision. The pre-feasibility stage proposed that the flood-prevention works would encompass 9km of line flood defences, works to bridges, modification of building façades and major services and utilities interfaces. The scope also covered the modification of three Category A dam structures, to enable them to retain more water high in the Pentland Hills before it reached the Water of Leith.

"We were chosen for the project on the strength of a combination of cost and quality, taking into account our reliable track record in flood prevention consultation and appraisal," says Richard Clement, the Arup project manager. "It was our overall approach towards tackling the project and prioritising key flood prevention issues which set us apart from the competition."

Arup developed and delivered a Flood Prevention Order to over 4000 Edinburgh residents under the Flood Prevention (Scotland) Act 1961. Since 2002, the project team has progressed through the option appraisal stage, outline design environmental assessment, planning and detailed design. "To date the project has been the fastest flood prevention scheme to go from the planning to the legislation stage," adds Clement.

For this project, the firm had professionals working in areas such as the environment, sustainability, hydrology and engineering. But the team was not only charged with the task of evaluating flood prevention measures, it also had to manage residents' expectations. Playing a pivotal part in the scheme has been Arup's proactive consultation with local residents affected by the floods, including a series of public exhibitions, meetings and mailshots.

Arup's influence with the Scottish Executive has been key in driving the project forward. "We worked closely with the executive so it could make its planning and consultation process more efficient," adds Clement. "We have learnt many lessons throughout the project which we are now feeding back to the executive to assist ministers with future schemes."

Arup also advised the City of Edinburgh Council on procurement strategies, contract forms, legal aspects, contractor selection and phased programming of the construction. Following the passing of vital legislation for the project, Arup is preparing advanced works packages for tender in 2006, leading to construction in late summer and autumn. These packages include modifications to reservoirs, strengthening two buildings at Canonmills, relining of a large sewer at the Colonies and modifications to footbridges at Belford and Damside. The main three-year project is scheduled to start in 2007.

Client
City of Edinburgh Council
Landscape architect
The Smeeden Forman Partnership
Architect
Halladay Clark Architects

Moore's Law anticipates that computing power will double every 18 months. So far, this has proved true and as the following two projects show, it's giving Arup a ground-breaking opportunity to use advanced modelling to streamline the design and construction process further, while increasing quality, reducing time and costs and mitigating risk.

Words: Nick Kettles

Virtual world, real benefits

Arup has been using computer-assisted design (CAD) to create three-dimensional models for a long time, yet it's only in the last few years that the necessary computing power has been available to process the large amounts of data required to do this to a practical degree of engineering accuracy with detailed visualisation.

In the last 18 months Arup engineers have added a fourth dimension to the design and construction planning of large engineering projects: time. This 'real-time' layer, when applied to 3-D drawings, provides a level of visualisation that even the most experienced planners would find impossibly difficult to achieve in any other way.

Take city modelling, for example. By using snapshots of fine-grained topographical data held in Geographical Information Systems, instead of flat topography, Arup can create a realistic ground model with the building sitting on it.

In fact, Arup is currently bridging the gap between existing software shortcomings to develop models that will demonstrate the impact of multiple variables over time. The more data sets brought into a 4-D model, the more precise the visualisation and the lower the margin of error.

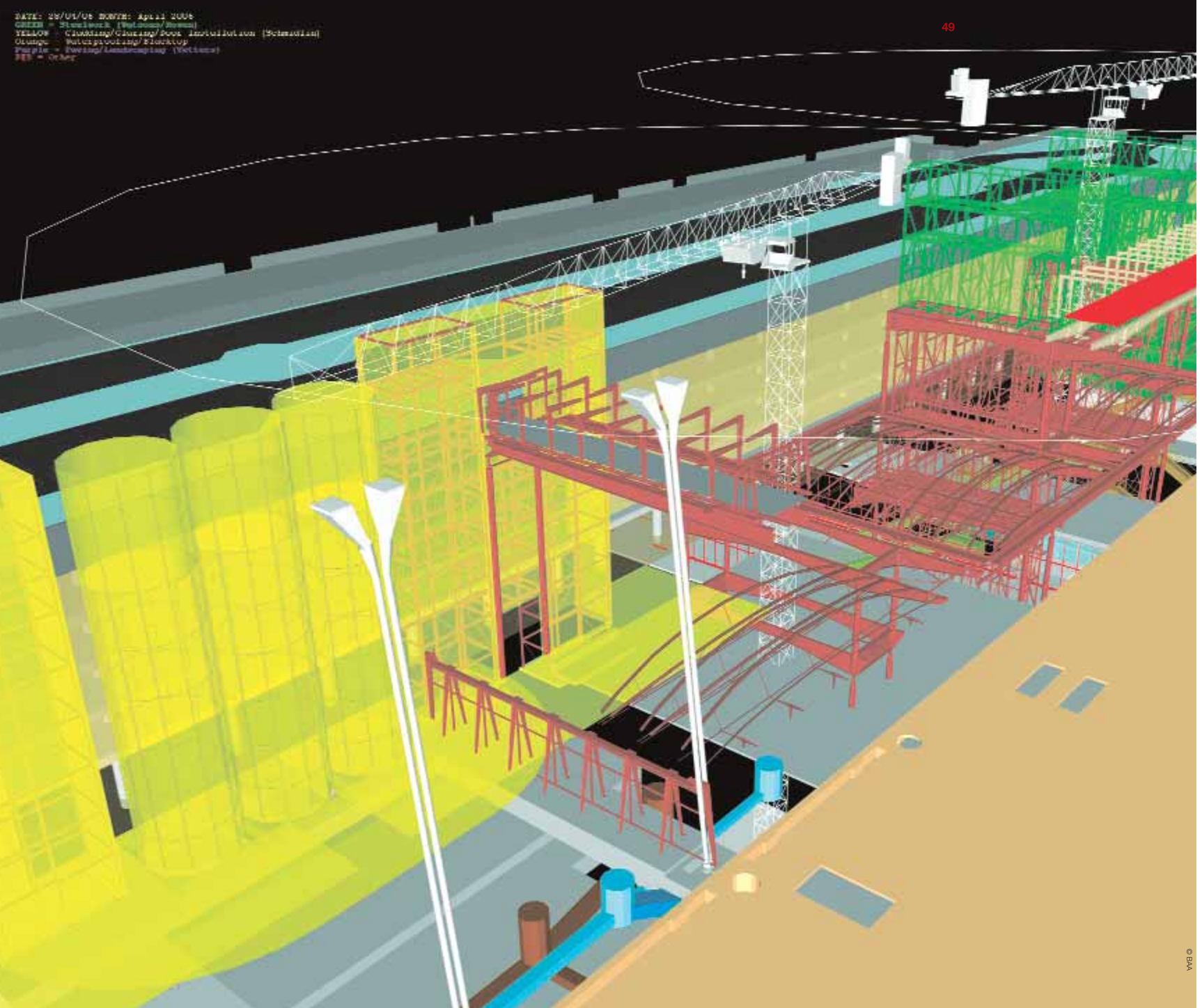
The approach makes for better decision-making and improved communication with stakeholders. Arup calls it Intelligent Visualisation.

Clients
British Airport Authority
Blackpool Council
Union Railways

Above and main pictures:
Arup's Manchester intelligent visualisation team has built a 3-D real time model of the sea front at Blackpool, UK, to investigate the impact of coastal defences on the famous sea front.

Airborne light sensors
LiDAR is a new form of remote sensing technology which uses a helicopter-mounted laser to pulse light at the ground to generate very precise geographical co-ordinates to within plus or minus 50mm.

The applications and benefits of LiDAR are many. It can extract the shape of the surrounding buildings around a proposed site, which coupled with photos provides a startlingly realistic model. Last year, Arup used LiDAR to carry out a 900m wide topographical survey of the M25 – that's 380km of motorway, earthworks and structures – in just six weeks.



Left: 4-D model of Heathrow's Terminal 5 clearly shows the many stages of the construction process.

"An outstanding example of engineering leadership under difficult conditions and in the middle of the world's busiest airport. This demanded a high quality solution, and by God it got it."
Judges' comments following Arup's award for Excellence in Collaborative Engineering at the UK 2006 Quality in Construction Awards, for the design of the Heathrow control tower

Heathrow Terminal 5

The potential of IV has already been clearly demonstrated through the use of 4-D construction planning during the development of The Interchange Plaza project at Heathrow's new Terminal 5. The project required extra planning due to the complex interface of three separate teams building the multi-storey car park, main terminal building and Heathrow Express rail station in close proximity.

"Typically, communication in these situations is based upon drawings and models, with either a basic timeframe illustrated or accompanied by a Gantt chart (which aims to show the relationship of different tasks or activities)," explains Tom Honnywill, head of Arup's project planning team. "However, either the timeframes are too broad, or the reader has insufficient skill in interpreting them, resulting in a limited understanding of what needs to be done where, when and how."

BAA appointed Arup to undertake 4-D planning for the interchange, and soon a high-level integrated 4-D model was established, identifying the overall build sequence including contractor exclusion zones, crane usage, access and general site logistics.

Weekly planning sessions were convened with the 4-D model simulation projected on a large screen, viewable at any time interval. Once individual clashes or issues were resolved, or a 'best fit' way forward was decided, the master programme was revised, along with the graphics. Until the advent of 4-D this would have required new phasing diagrams – a time consuming and expensive process.

Here, Arup's work demonstrated that efficiencies of six months could be gained against the initial Tri-Project master programme. The value of this saving, estimated by BAA, was approximately £2.5M.

Channel Tunnel Rail Link (CTRL)

A similar approach was used for the possession planning required to complete the high-risk re-alignment of the North London Incline onto a newly constructed viaduct for the Channel Tunnel Rail Link Project. A 4-D construction planning simulation was developed allowing the sequences from all contractor programmes to be overlayed, highlighting delays in an easily accessible format. A much more efficient programme ensued, resulting in the project being completed a day early, and avoiding severe financial penalties.

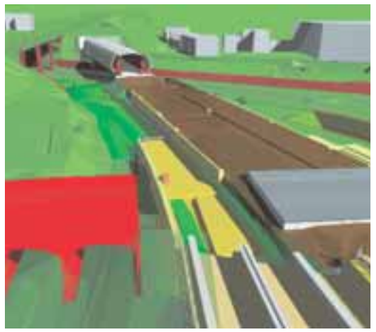
In both cases, Arup's intelligent interpretation of 4-D computer models resulted in better stake-holder communication, reduced risk, and promoted a co-ordinated 'right-first-time' approach.

"Intelligent Visualisation allows information to be presented to anybody, in 3-D over time," comments Jim Johnson, director, Arup. "They can then see what it looks like in the real world – retaining engineering quality and accuracy – but presented in an intuitive and easily understood way."
What Arup's Intelligent Visualisation potentially offers is the opportunity to bring many variables, previously assessed in isolation, together into one virtual environment to offer a more holistic design and planning process. Indeed, as remote sensing becomes ever more precise the potential is also there to test designs before they are built.

Johnson adds: "It can also help to prototype. You can take a model of a bridge and drop it into a detailed representation of a proposed space, and if it doesn't fit within a few centimetres, then you know you have an engineering problem."

With the people skilled in analysing the data from these systems so maximum value can be extracted from any simulation, Arup is currently assessing how to add cost as a fifth dimension to 4-D models, showing how costs vary with different proposals.

And, providing Moore's Law continues to prove itself, the firm will eventually be able to introduce an increasing number of variables into a model, including pedestrians, traffic, fire, wind and lighting.



China's newest super structure

By the end of 2009, the tallest structure in the world will stand as a unique iconic landmark on the skyline of Guangzhou, a fast-emerging city in southeast China – now there's something worth broadcasting.

Words: Andrew Moore

Guangzhou New TV Tower
China

Project progress:

March 2004
Amsterdam office entered the design competition with Information Based Architecture (IBA) from Amsterdam.

April 2004
Competition design submitted, 13 teams shortlisted.

June 2004
London, Hong Kong and Shenzhen offices joined with Amsterdam's team.

August 2004
Second phase competition design submitted, three teams shortlisted.

28 January 2005
Arup's Hong Kong office, as the lead consultant, signed the contract with the client in Guangzhou, under the witness of the Municipal Government officials. The date launched Arup's international assignment for the fascinating project.

May 2005
Approval of the Scheme Design.

November 2005
Approval of the Detailed Preliminary Design.

25 November 2005
Official ground-breaking ceremony conducted by the Municipal Government. The ceremony was officiated by the Secretary of Guangzhou and the Mayor of Guangzhou.

Present
Basement excavation work in progress.

Giants are often considered clumsy and ungainly creatures, but this is just one of the many conventions that the remarkable Guangzhou New TV Tower in southern China appears to flout.

The structure is an impressive feat of technical expertise and elegance, but at 610m high the tower has posed some tough total engineering design challenges for Arup's team, numbering 40 designers and engineers from the Amsterdam, London, Hong Kong and Shenzhen offices. It's designed to house TV and radio transmission facilities, observatory decks, revolving restaurants, exhibition space, conference rooms, shops and 4-D cinemas. Its slim waistline and complex geometry required the team to walk a tightrope between architectural form, safety and cost.

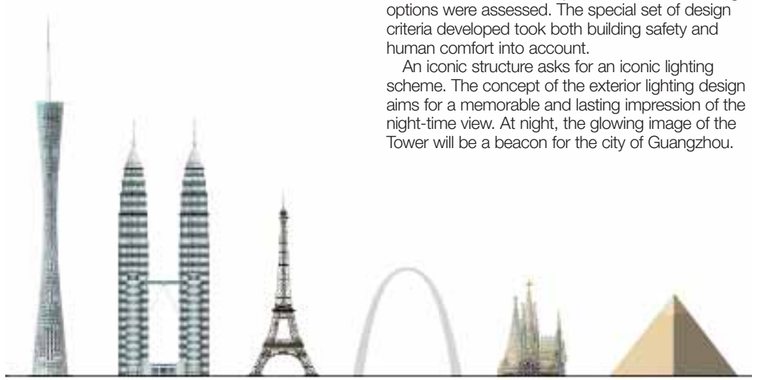
The tower, which will broadcast the 2010 Asian Games, comprises an external steel frame and inner central concrete core. This core is for the lifts, escape stairwell and vertical building services risers.

It is a highly functional building with a unique architectural form. The structure's shape is created by a rotation between lower and top-level floor plates, characterised by a twist and narrowing waist midsection. The complex geometry was designed by parametric associative software, which can generate geometrical and structural models based on a set of variable parameters and link the geometrical data to the analytical and drafting software.

The outer steel-framed structure consists of 24 steel columns with concrete in-fill, a series of 46 oval-shaped rings of different sizes and single-direction diagonals throughout the structure. Spatially, the tower appears as a series of mini-buildings hung within the superstructure, with mega spaces in between. The roofs of the mini-buildings are used as sky gardens where visitors can feel the weather variations at different heights.

Because of the tower's complex structure, the team has adopted the most advanced technologies in wind engineering and wind tunnel studies based on sectional models with computer stimulation. Using the wind data, a series of performance-based design options were assessed. The special set of design criteria developed took both building safety and human comfort into account.

An iconic structure asks for an iconic lighting scheme. The concept of the exterior lighting design aims for a memorable and lasting impression of the night-time view. At night, the glowing image of the Tower will be a beacon for the city of Guangzhou.



Guangzhou Tower
610m
Guangzhou, China

Petronas Towers
452m
Kuala Lumpur, Malaysia

Eiffel Tower
324m
Paris, France

Gateway Arch
192m
St Louis, US

Temple Expiatori de la Sagrada Familia
170m (when complete)
Barcelona, Spain

Pyramid of Khafre
143m
Giza, Egypt

Seismic shocks

The team had to factor in performance-based design based on a severe earthquake study. The designs focused on a second set of criteria based on constraints above current limits for buildings up to 200m high in mainland China. By introducing a new non-linear approach, the critical buckling load for each element in a structure can be calculated.

Architect
Information Based Architecture
Local Design Institute
Guangzhou Design Institute

A mining town in trouble

Deep below ground in northwest England, the future prosperity of a modest former mining town hangs on the outcome of one crucial civil engineering project.

Words: Clare McKenna

“Our ability to monitor and understand what is going on in four inaccessible salt mines will enable the town of Northwich to plan for the future and regenerate itself in a way that has not been possible for 100 years.”

Tom Brooks
project manager

For years, anxious residents and retailers have been hoping for progress on the fate of Northwich’s four abandoned salt mines. The four spaces in question are equivalent to 296 Olympic swimming pools in total, all filled with brine, 90m underground. The mines’ extreme depth has made access very difficult and the salt water made investigation even more so.

The unpredictable nature of salt degradation means the salt pillars currently supporting the roof of the mines could fail at any moment, opening up a 5m chasm capable of swallowing the town centre above.

This dire prediction has inhibited any notions of meaningful development over the past decades. While other towns have grown and prospered since the decline of the mining era, Northwich has been left behind, but the problem remains: the town’s mines require urgent attention.

In November 2004 a partnership between Wrekin Construction Ltd and Arup took control and began modelling the mines using ultrasonic surveys. The proposed resolution was to infill the mines using a grout mix made up of 96% pulverised fuel ash (PFA, a by-product from coal-fired power stations) and 4% cement lubricated with a fully-saturated brine solution.

Planning ahead
Above: location map outlining the location of mines and salt pillars.

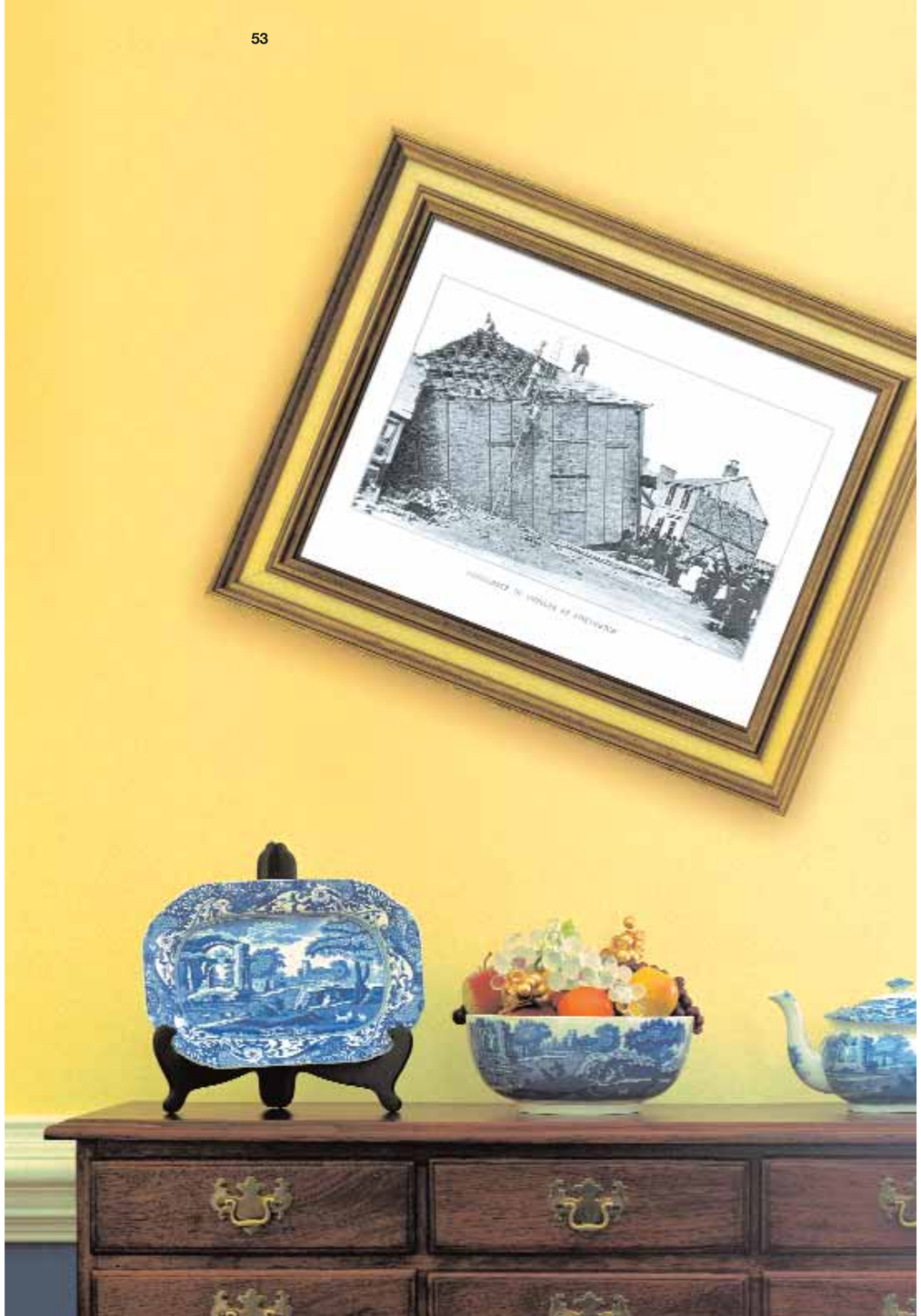
“No-one has ever used a saturated brine solution in a mix like this before,” explains Tom Brooks, project manager. “The brine prevents the pillars dissolving because the water can’t hold any more salt.”

Although optimistic the mix would be successful, Wrekin needed more information on the chemical environment to guarantee the outcome. Arup examined the mix to establish how it would respond in the mine. Tests concluded that the cement reacted with the saline water, grew and hardened around the PFA, making it solid enough to prevent the mines collapsing.

“Arup’s capability to provide scientific rigour and methodology to this project means we have been able to create value for Wrekin, the local authority and the backer English Partnerships, by making it possible for this technically challenging project to continue,” adds Tom.

“Our ability to monitor and understand what is going on in four inaccessible salt mines will enable the town of Northwich to plan for the future and regenerate itself in a way that has not been possible for 100 years.”

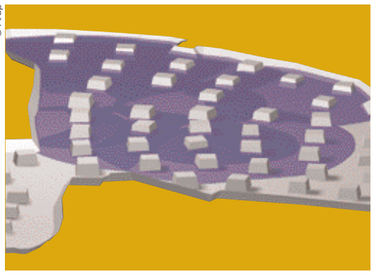
The smallest of the four mines was successfully filled during late 2005. The entire project is on schedule for completion in September 2007.



An explosive situation

Drilling the 200 boreholes to pump grout into, and extract brine out of, is proving risky. An air pocket was hit during exploratory drilling, blowing a casing 30m out of a borehole. Contractors are now using blow-out preventers to manage and vent air pressure.

Wrekin is carefully monitoring the rate of injection and extraction to ensure that pressure in the mines remains constant. If one of the injection pumps stops working or one of the grout pipes becomes blocked, the pressure within the mine can be adjusted to compensate.



Problem solved

When the infilling of the mines began, it quickly became clear the mix wasn’t gaining enough strength underground. Through a process of computational fluid dynamic (CFD) analysis, Arup’s numerical modelling team identified an issue with the daily flush-through of the pipes, allowing a superior injection methodology to be adopted.

Each mine is now being modelled in 3-D as the grout is injected, allowing engineers to predict where the grout will fall within the mine, giving a far greater level of control over the infill process.

Partnerships
Wrekin Construction Ltd
The officers of Vale Royal Borough Council
English Partnerships

All on this page: © Cody Andresen/Arup

The educational buildings market is now so sophisticated that gaining a competitive edge means designing buildings that are not just unrivalled learning environments, but can also be used as teaching tools in their own right.

Words: Anthony Beachey

Learning on location

Kirsch Center: (1) transparent infrastructure means that students can learn from the building in class; (2) lots of natural light makes the teaching environment a pleasant place in which to work all year round; (3) solar panels maximise the building's energy efficiency; (4) the exterior is fashioned to catch as much natural light (while blocking unwanted heat) as possible; (5 & 6) the exposed systems are used by students as part of their research.

People in economically advanced societies spend up to 90% of their time indoors. Small wonder, then, that the places that we inhabit can have a huge impact on the way we think about the world. By virtue of its very existence, a building can – and often does – create the momentum for change. This is particularly true when those buildings are academic institutions which, with research programmes, leadership roles and influence over current and future elites, are ideally placed to promote the 'green' agenda.

Understanding the purpose of the structures and work that will be conducted at each educational building is integral to Arup's design process. The firm's engineers often consult a building's future occupants before seeking to create optimal conditions for successful scholarship. Later, the teams share noteworthy innovations such as exposing the building's systems, like heating, to allow them to be used as teaching tools with the wider design and research community.

"Our innovations are a response to the programmes taught and researched in academic institutions, rather than a product of building for the educational market per se," says Cole Roberts, a senior engineer at Arup, USA. "Our focus is to support research and actually turn the buildings themselves into teaching tools. So the innovation is often driven by an issue that prompts research, rather than developed for its own sake."

Roberts cites studies conducted at Stanford University, California, into the effects of seismic events, corrosion and structural degradation on buildings as an example. In this case, a Stanford Environment and Energy (E&E) Department researcher wanted to attach sensors to a new faculty building that Arup is helping to design, in order to use it as an example to support her research.

Stanford's E&E building is just one example of Arup's ground-breaking work in educational design and construction. It all began with the Kirsch Center for Environmental Studies at DeAnza College, Cupertino, California. Kirsch, a two-storey, 2000m^2 construction, exemplifies the next generation in educational innovation. Kirsch showcases energy efficiency and renewable energy technology to a huge audience – it's one of the first sustainable green buildings within the California Community College system. The system includes 109 members and 2.5M students, and claims to be the largest system of higher education in the world.

From integrated photovoltaics, solar hot water and unique, high-performance thermal wrap to radiant cool/warm floors and demand-controlled ventilation, Kirsch highlights the clever use of technology to sustain the living world. It is also undoubtedly a teaching tool. Adjacent to one of the classrooms, for example, is a radiant manifold system that allows hot or cold water to circulate through the concrete floor. The system is housed behind a Plexiglas cover, enabling students to gauge the water's temperature, flow-rate and pressure, so that they can work out how much energy the system is using.

The exposed radiant system is only one example of many. Ground-breaking design apart, the unique feature at Kirsch has been the input of the building's occupants, who formed a committee and played a central role in the building's development, from fundraising through to the initial concept and thematic design, right up to the building's construction and operation.

© Hopkins & Partners Architects

Climate control

With an emphasis on plenty of natural light and passive solar heating, the NAU ARD atrium creates its own microclimate and captures nearly all of its heat from the sun.

All natural

The Stanford E&E building is currently at design stage. The sketches below show the effects that the planned designs will have on the building's heating and ventilation systems.

© Boora Architects

Natural ventilation

Daylighting

Kirsch has now been put forward for a coveted Gold Leadership in Energy and Environmental Design (LEED™) rating. Meanwhile, Roberts is playing a role in educating the students that pass through Kirsch, by delivering lectures in the building that he helped to design.

Stanford E&E and similar projects, such as the Northern Arizona University Applied Research and Development Facility (NAU ARD), have already adopted many of the ideas used in the development of the Kirsch building, as well as introducing fresh concepts. At NAU ARD, the desert climate, high elevation and low rainfall will shape innovations in water-saving technology that will be passed on to the local community. Once complete, the ARD will be the most energy-efficient laboratory building in Arizona.

The concept of creating buildings that teach may be relatively new, but it is already filtering through to the mainstream in countless ways. Luckily, the chances of being outsmarted by the building that you study in are still a long way off.

DeAnza Community College
Design architect
Van der Ryn
Executive architect
VBN

Stanford University
Architect
Boora Architects

Northern Arizona University
Design architect
Hopkins & Partners
Executive architect
Burns-Wald Hopkins

© Arup

The making of a microclimate

Words: Hollie Boughton

Overview:

Arup's investigation covered:

- Energy efficient air distribution systems
- Ecological-enclosure thermal and ventilation studies
- Underground water cooling
- Outdoor and indoor cooling tower schemes
- The building's thermal and pressure distribution
- The building's solar and daylight access
- The building's energy simulation
- Chiller plant heat rejection study
- Ventilated façade
- Air-side and water-side free cooling
- Hybrid ventilation
- Night cooling
- Radiant cooling

Architects:
Integrated Design Associates

Green Plaza is one of China's biggest sustainable architecture projects and it marks the beginning of a new approach to architecture in the region. Not only is it the first building in Beijing designed to be environmentally sustainable but the creation of a microclimate, designed by Arup's Hong Kong team specifically for this development, has also set the standard for a completely new approach to this kind of project across modern China.

A microclimate is defined as any contained environment within which the effects of weather are both relatively uniform and easily modified. Microclimates are affected by factors such as air speed, temperature, moisture content, light and visual effect. Green Plaza includes two nine-storey and two 18-storey buildings. Inside, there's a retail area, offices and a six-star hotel and all four buildings are encased in a transparent glass and ETFE (ethylene tetrafluoroethylene) envelope.

The biggest benefit in constructing a microclimate is that once it has been established, energy bills will be kept to a minimum for the lifetime of the building. Winters in Beijing are harsh, while the summers can be very hot. To keep the development's temperature constant, the team created an air 'buffer-zone' between each of the buildings and the envelope.

This buffer-zone increases the thermal insulation in winter reducing heating loss and, consequently, those energy bills. To prevent overheating in summertime the team needed to create a mechanism whereby the trapped heat could be let out in the most energy-efficient way. Part of the solution included installing ventilation louvres at the very top of the envelope that would act as a chimney and allow the warm air to escape. As the hot air pulls in cooler air from the bottom of the buildings it creates movement and natural ventilation. The prohibitive heat means that the building still partially relies on air-conditioning in summer and autumn, but far less than normal.

Innovative though the microclimate may be, it is ultimately its contribution to the continuing strides in the field of sustainable building design that makes this achievement so significant.

"Sustainable building design is more than just an environmental strategy," Raymond Yau, a director at Arup, points out. "It's a means of making buildings that are more humane places to inhabit, more intelligent in the way they balance their energy flows, more respectful of nature and the resources it offers and more understanding of the substantial changes that buildings will undergo during their lifetime."

The environmental shield helps create the solar chimneys for heat stack effects, which provoke fresh air movement and bring natural ventilation into the interior spaces.

© Integrated Design Associates

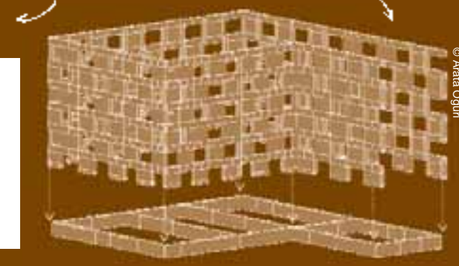
Design features of the 'microclimate envelope' to enhance ventilation
1 Cool fresh air intake
2 Office façade windows for natural ventilation
3 Hot air discharged through office air shafts
4 Hot air discharged through inclined roof vents
5 Hot air discharged from top vents

NO
57
Ronga notes

PROJECT
SOB
Sendai, Japan

ARUP

To create the appearance of 'floating masonry' the pattern is arranged so there is no horizontal overlap between each panel or between the adjacent panels.



© Arata Oguri

Space invaders

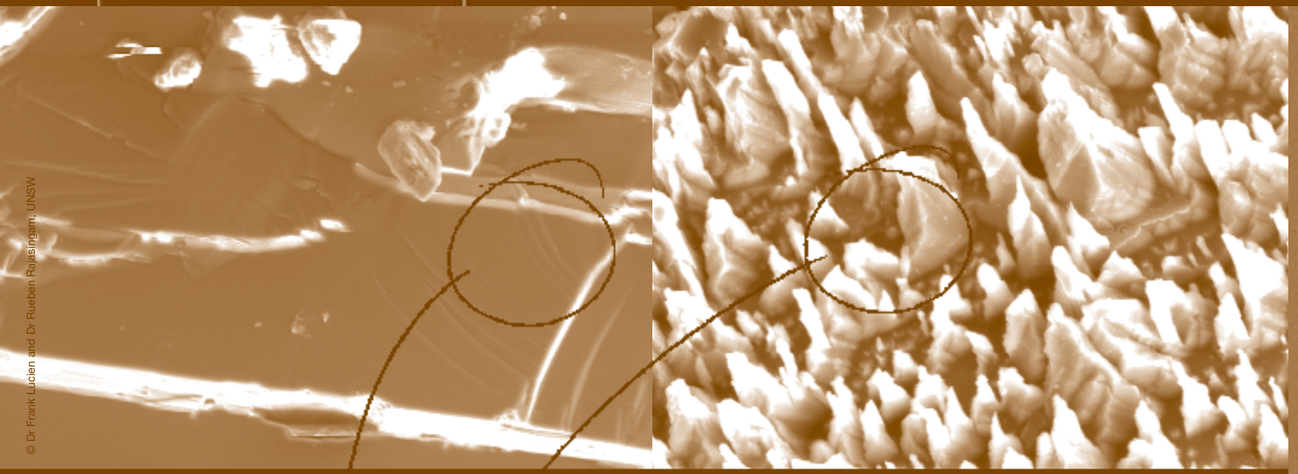
In the densely populated residential area of Sendai on Honshu Island in Japan, space is in very short supply. Yet in a small corner of this busy suburb, there's a major column-free, 10m-high space in a three-storey manufacturing workshop.

Working in partnership with one of Japan's most talented architects, Professor Hitoshi Abe of Tohoku University, in association with the firm Atelier Hitoshi Abe, Arup created the three-storey building with an entire external façade that is the only load-bearing and seismic-resistant element. Put simply, there are none of the expected internal supporting columns occupying much-needed floor space. The external walls are the only thing keeping the ceiling up.

The unique chequered façade allows each elevation to act in its entirety under horizontal loading, using precast concrete panels measuring approximately 2m x 2m.

All the factory-made concrete panels were secured together on site using horizontal prestressing tendons. This ensures that there will be no slippage at joint lines due to force under either long-term or short-term loading cases.

Client
Sasaki-Gishi Prosthetic & Orthotic Services Inc.
Architect
Atelier Hitoshi Abe
Contractor
Ando Corporation



0013 20KV X430 10µm WD39 0007 20KV X1,100 10µm WD39

Clever concrete

The claim
Arup is helping to make the world a greener place by researching and developing more environmentally-friendly construction materials.

How are you doing that?
Actually, it's all about the development of a chemical binding process that will produce a cleverer, environmentally friendly kind of concrete. The resulting product would be a *bonded calcium carbonate* with similar material properties to concrete.

Sounds complicated, is it?
CO_2 is used as a means of bonding together calcium carbonate particles. In effect, the process sets out to copy the metamorphosis of limestone to marble, but in minutes rather than millions of years.

What makes it so special?
The manufacturing process used to make it will reduce the pollution levels associated with cement production. It will also have a much lower ecological footprint than conventional Portland cement.

What's an ecological footprint?
In general terms it's a measure of the amount of fossil fuel that is consumed, and the amount of CO_2 emitted into the atmosphere resulting from the actions of an individual, a household, a company, or even a country.

So what's that got to do with cement?
The production of Portland cement is an energy intensive process which requires high temperatures and results in environmentally damaging by-products, including lots of CO_2.

Is it nearly finished?
The process is currently under Arup-funded investigation at the School of Chemical Engineering's laboratories at the University of New South Wales in Australia.

Will it save the world?
Not quite. But it involves turning the CO_2 generation problem on its head, so that the gas is consumed rather than generated in the process. Rather than emitting large amounts of CO_2 during production, some CO_2 could be captured during limestone particle bonding. All this takes place at room temperatures instead of the extreme temperatures needed for cement. It's a double bonus with big environmental implications.

The particles demonstrate that our team grow fibre-like crystals on a calcite surface. This is the first step in the cementing process - if we can grow these crystals between particles of limestone we have a new type of concrete.

Client
Chevron

Environmentally friendly engineering

Situation
US oil and gas company Chevron has found natural gas in the Gorgon Gas Field approximately 70km offshore and plans to pipe it to Barrow Island. The company is proposing to build a liquefied natural gas (LNG) processing plant on Barrow Island, for which Arup is doing the ground engineering.

However...
The proposed plant will draw natural gas from the field and after processing on Barrow Island, it will be shipped and sold on international markets. Arup's work on the project included geotechnical site investigations and analysis, management of drilling and testing subcontractors, development of groundwater monitoring and testing bores. All of this work had to be conducted without harming the surrounding environment.

Barrow Island was classified as a Class A nature reserve in 1910 and its relative isolation, along with Chevron's stringent quarantine management procedures, has helped to protect it from introduced species of animals and plants now common in Australia.

We left no footprints
All aspects of the ground engineering project require strict environmental controls on a wide range of activities. Arup has had to devise new ways of working to minimise the impact on the Barrow Island ecosystem and the team discovered that there's huge scope to be genuinely kind to the environment.

Equipment, clothes and boots were meticulously steam cleaned and treated to remove any trace of dirt, grease or seeds that may have promoted growth of foreign plants. Drilling programmes were scheduled to avoid disturbing turtle breeding patterns and all waste from the drilling process was shipped back to mainland Australia. Even the grasses were left undisturbed.

Appraisal time

What is SPeAR?
The Sustainable Project Appraisal Routine (SPeAR) is another innovative Arup-developed system to enable companies to categorise, measure and improve sustainability. It can be used to appraise a wide variety of projects and masterplan proposals, buildings, corporate and operational performance.

How does it work?
It assesses sustainability performance and identifies strengths and opportunities for future improvement. SPeAR allows managers to decide what changes they would like to make to improve performance. Additional assessments over time can track changes and demonstrate continuous improvements through design, construction and operational stages.

Has it been used yet?
Yes. By over 100 clients worldwide.

Why is it so great?
Let's look at an example. Since 2004 Arup has been using SPeAR with its client Kingspan Insulation, which manufactures polymer-based insulation boards in Herefordshire, UK. Following the SPeAR audit, Arup presented Kingspan with an improvement action plan. A year later Arup returned to carry out a second assessment to check on the effects of Kingspan's implementation. By adopting SPeAR, Kingspan has undergone a rapid cultural change. The next step is to raise staff awareness so they can submit their own sustainability suggestions. To make this possible, Arup developed the Team SPeAR coaching package which helps teams to work together to gain a clear picture of their strengths, opportunities for improvement and blind spots, and to promote more productive ways of working. All of this has been carried out under Kingspan's existing budget arrangements – proof that being sustainable does not cost you more!

And what are the benefits?
Undergoing a SPeAR analysis and then acting on its findings will make a company:
- more competitive
- more resilient to shocks
- nimbler in a fast-changing world
- more unified in purpose
- more likely to attract and retain customers and employers
- more at ease with regulators, banks, insurers and financial markets
- better positioned for the future.

These diagrams form the foundations for the SPeAR analysis process. They display a range of established criteria for measuring sustainability. Categories measured include the impact a product has on natural resources, energy use, waste, procurement, working conditions and a company's economic sustainability.

Rendering of Beijing's Water Cube (National Swimming Centre), from an external perspective.

Fire fighters

Stories about the devastation that fire can cause are the stuff of legend. But the solutions are not always simple, which is why Arup has teams across the world that are dedicated to turning up the heat on fire safety.

Words: Nick Kettles

When the American artist Donald Judd passed away, his will instructed the Judd Foundation to preserve his installed spaces by turning them into museums – including his home at 101 Spring Street, New York City. The historic building is not one where the ceiling can be easily torn open to install sprinklers and smoke detectors, as this would impact the building's appearance.

So, when fire safety codes required the main staircase – a key feature of the building – be closed off on one floor, the Judd Foundation considered this an unacceptable intervention.

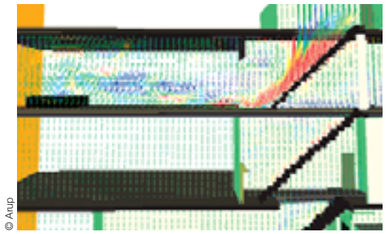
In fact, meeting this requirement would have caused the organisation to re-evaluate its mission statement. Until, that is, Arup's fire engineering and design teams conceived an innovative fire strategy that limited the impact to the aesthetics of this historic building and its contents, provided a cost-effective solution and met the client's mission statement in one fell swoop.

The resulting fire strategy even incorporated the use of a set of coloured lights (part of an exhibit by artist Dan Flavin) wired-up to the back-up power supply for emergency lighting, avoiding the need for aesthetically intrusive emergency lighting on some floors. This is a typical example of Arup's approach, which tailors its fitting of fire and life-safety measures to meet the individual building's requirements.

Chris Marrion, associate principal at Arup's New York office, says the firm's local and global fire engineering knowledge is paramount to successfully meeting clients' needs on projects like these: "Having already established our credibility with the fire department by working with them on various committees to rewrite the NYC Building Code, they were very willing to listen and work with us when we did our analysis and showed that these alternative approaches would be safe."

Arup's extensive experience in developing performance-based codes and fire engineering guidelines, reflecting the local vernacular and regulatory regimes of cities and countries, is vital in addressing clients' objectives successfully.

Left: exterior view of 101 Spring Street, home of the late artist Donald Judd. Below: CFD analysis showing a proposed model for a smoke management system.



This experience has allowed the firm to adopt an open-minded approach, bridging the gap between individual needs and prescriptive regulatory codes, at times demanding a compromise in building design or functionality. This has created opportunities for Arup to author books such as *Extreme Event Mitigation In Buildings* (Editor: Brian Meacham, Associate Editor: Matthew Johann) and *Egress Design Solutions* (Authors: Jeff Tubbs and Brian Meacham).

Life-safety is reassuringly central to Arup's performance-based design approach, but this does not exclude the need for innovation. Arup's solutions can also embrace broader issues, including business continuity and the protection of assets.

For the US$100M Beijing National Swimming Centre (the Water Cube), Arup addressed fundamental challenges about its design at a conceptual stage of the project, so that it could be used safely for the 2008 Olympics.

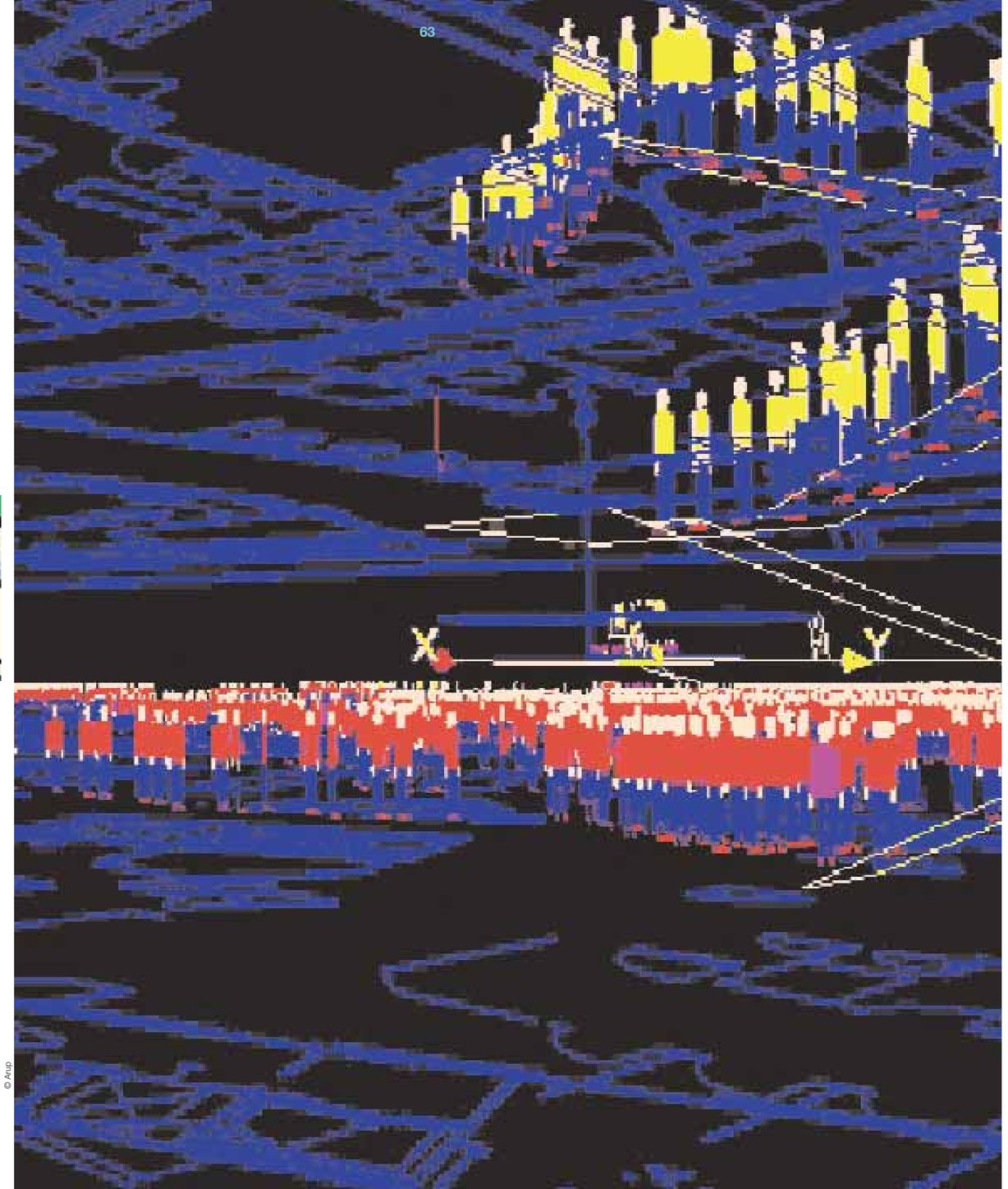
Ethylene tetrafluoroethylene (ETFE), the amazing-yet-combustible material proposed as the skin of the Water Cube's revolutionary soap-bubble design, did not conform to local fire codes, until the firm's complex analysis demonstrated that it shrinks away from fire – self-venting to allow smoke out of the building.

The local code would have also required the Water Cube to incorporate over 100m of exit doors, further impacting the aesthetic appeal and creating a significant security issue. Using advanced computer modelling to help predict the spread of smoke and movement of people, Arup was able to design for the optimum safety of the Water Cube's capacity: 17 000 spectators and athletes. "People prefer to enter and exit from the same place, so the fire design favours open circulation routes, and incorporates fire safety systems like sprinklers and smoke exhaust – making the building safe for longer periods of time and allowing the more familiar circulation routes to be used for exit," adds Marianne Foley, the project's fire engineer based at Arup's Sydney office.

The value of the performance-based design approach to fire safety can equally be applied to infrastructure-related projects, such as underground stations.

Fiona Tsui, from Arup's Hong Kong office says: "Fire engineering is a viable means to address the fire safety challenges posed by subway stations and tunnels – particularly those entrances with long tunnels located deep underground, where new technology may be applied to approach fire safety issues such as high capacity lifts for underground evacuation."

By considering the performance of each building's structure, service systems and functional planning in case of fire, the result is typically a cost-effective design that meets fire safety objectives, as well as the design and functional objectives of the stakeholders.



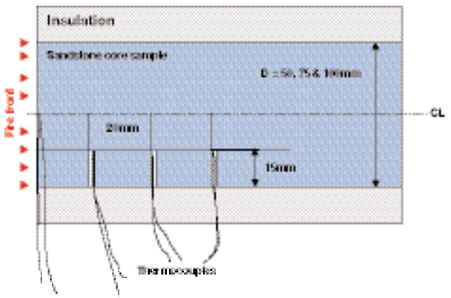
Left: computer models such as these help Arup's fire engineering teams to predict the flow of smoke and people in the event of a fire and plan accordingly.

Research breakthrough

As part of their ongoing study into the quantifiable physics of fire, Arup's David Moorehead is researching how unlined tunnels constructed in sandstone, an area of research not well understood, could provide equal or superior safety standards in concrete-lined tunnels.

"Better understanding of this will provide more confidence in the prediction of tunnel performance in fires, both for cases of untreated rock, and where provided with a protective layer such as concrete," explains David. Under laboratory test conditions with additional computer modelling, the sandstone did not break up due to the build up of water vapour pressure within the stone, a key advantage over concrete. And while yet to be completed, the research may also eventually be used to produce a predictive modelling tool for use in real tunnel design, in similar sedimentary rock.

Below: Schematic description of experimental set-up for sandstone lining



Tower Environs snapshot

The Tower Environs project was an essential part of the last phase of an eight-year scheme to improve the setting of HM Tower of London. Originally commissioned by Historic Royal Palaces (HRP), the engineering works were largely invisible – yet vital to preserve various features of Tower Hill. In collaboration with Stanton Williams Architects, Arup designed new additions to existing buildings including the Tower Vaults Canopy, the Salvin's Pumphouse, and the new West Pavilion.

© Arup

"The Tower Environs project is a huge improvement. Before the scheme, the Tower Hill area was heavily congested with traffic and overgrown with trees. The project has created an interesting and exciting open space for the public."
Geoffrey Field, resident governor, HM Tower of London

Living history

Designing new solutions for old buildings in highly developed areas such as London calls for an intensely creative combination of sensitivity and innovation.

Words: Andrew Moore

© Stanton Williams

London's melting pot of modern and historic buildings requires designers to be increasingly creative when it comes to making old and new designs work in harmony. Although Arup is no stranger to innovation, renovating heritage buildings and sites in a highly developed city such as London inevitably comes with major challenges.

Arup's ability to combine modern design infrastructure with a building's legacy has been well-documented. During the firm's involvement with the Tower Environs project, launched in 1999, the team was charged with preserving the entrance and surroundings of Her Majesty's Tower of London. Originally commissioned by Historic Royal Palaces (HRP), the work was an essential part of the last phase of an eight-year, £12M scheme to improve the setting of the Tower. The scope of the project included pedestrianising the area around Tower Hill so it became an open space flanked by three new buildings, designed to make the Tower of London more visible.

The buildings were designed in collaboration with Stanton Williams Architects with Arup contracted to undertake structural and civil engineering and provide building services design. Key elements included establishing a retaining wall for a moat ramp and terrace, together with new building additions such as the Tower Vaults Canopy, the Salvin's Pumphouse and the new West Pavilion.

Steely resolve

The biggest challenges were posed by the revetment and conservation of the tower's moat ramp. Due to instability problems, Arup's team devised a scheme to prevent the embankment sliding into the moat, which also required the installation of a pedestrian ramp. The presence of the Docklands Light Railway tunnels below the surface meant that the engineers had to install sheet piles into the ground to a limited depth. These were installed using a 'vibration-free' pile driver, while parts of the embankment were reconstructed using lightweight polystyrene block fill to minimise loading. The period retaining wall was then tied to the sheet pile wall with a reinforced concrete slab that forms the new moat path. "Arup is often asked to blend old and new architecture considerately," comments Richard Henley, Arup's project director. "We were able to create a modern public space which complemented the historical architecture." Use of specially designed steel for the new buildings won the 2005 Award for Building in an Historic Context, awarded by the Royal Institute of British Architects (RIBA) London and English Heritage.

Right: the new additions to the RGS building have been designed to complement the existing architecture.

© Arup/James Morris

© Arup/James Morris

Below: Coliseum auditorium roof under restoration.

© Arup

Measuring up

But it isn't just projects that focus on a building's exterior that continually test Arup's design mettle. In 2002, Arup participated in an open competition to reshape and revitalise the Grade II-listed London Coliseum, the largest auditorium in central London and home of the English National Opera. The firm's role was to act as structural, building services and acoustics engineers, overseeing major structural alterations combined with the introduction of air conditioners within the auditorium and modifications to public spaces.

Arup was co-designer of the new features, such as a new glass and steel barrel-vaulted roof, extensive remodelling to front-of-house areas, modern toilet facilities and an innovative low-noise ventilation system. The building needed a vastly upgraded air-conditioning system in order to satisfy stringent regulations. So Arup sourced and modelled an innovative solution by mapping the analysis using a computational fluid dynamics (CFD) model. Caroline Ray, project manager, explains: "The real challenge was to achieve technical solutions to meet the demands of a modern audience within the particular constraints of a Grade II-listed building."

Carrying out the work in harmony with the opera seasons was vital, as modifications to the foundations and the basement area had to be made before the opera season ended. To enable the auditorium to look and sound the part, Arup helped co-ordinate a low-noise ventilation system.

© Arup/James Morris

"The building we now have ideally suits our needs and provides much better aesthetic space. Arup's engineering solution for maintaining a cool room temperature has paid off. Materials are now preserved in a much better environment."
Dr Rita Gardner, director, Royal Geographical Society

Less is more

Another project that has made noises as part of Arup's own design portfolio was the refurbishment of two buildings owned by the Royal Geographical Society (RGS), launched in 1998 after a joint win in an architectural competition by Arup and architects Studiodownie.

The project involved helping the RGS to devise a strategy to create a purpose-built modern archive store, reading room and garden pavilion, complemented by extensive refurbishment of the existing Grade II-listed buildings. The scheme also proposed the creation of seminar and education spaces and the refurbishment of the Ondaatje Lecture Theatre.

"Although the RGS wanted us to add more space and function to these buildings, our aim was to make the most of what the RGS already had," states Tim Snelson, project manager. "The project called for a great deal of joined-up design between the architect, structural and services engineers."

Arup first looked to make the most of the building's traditional features by installing a cooling system within the voids of the jack-arch flooring, for example. This allowed an old map room to be converted into a teaching and seminar room.

The team also developed sensitive solutions to safeguard the existing structure. "Outside the lecture theatre we designed discreet but strong concrete frames to allow parts of the walls to be removed without disturbing masonry walls above."

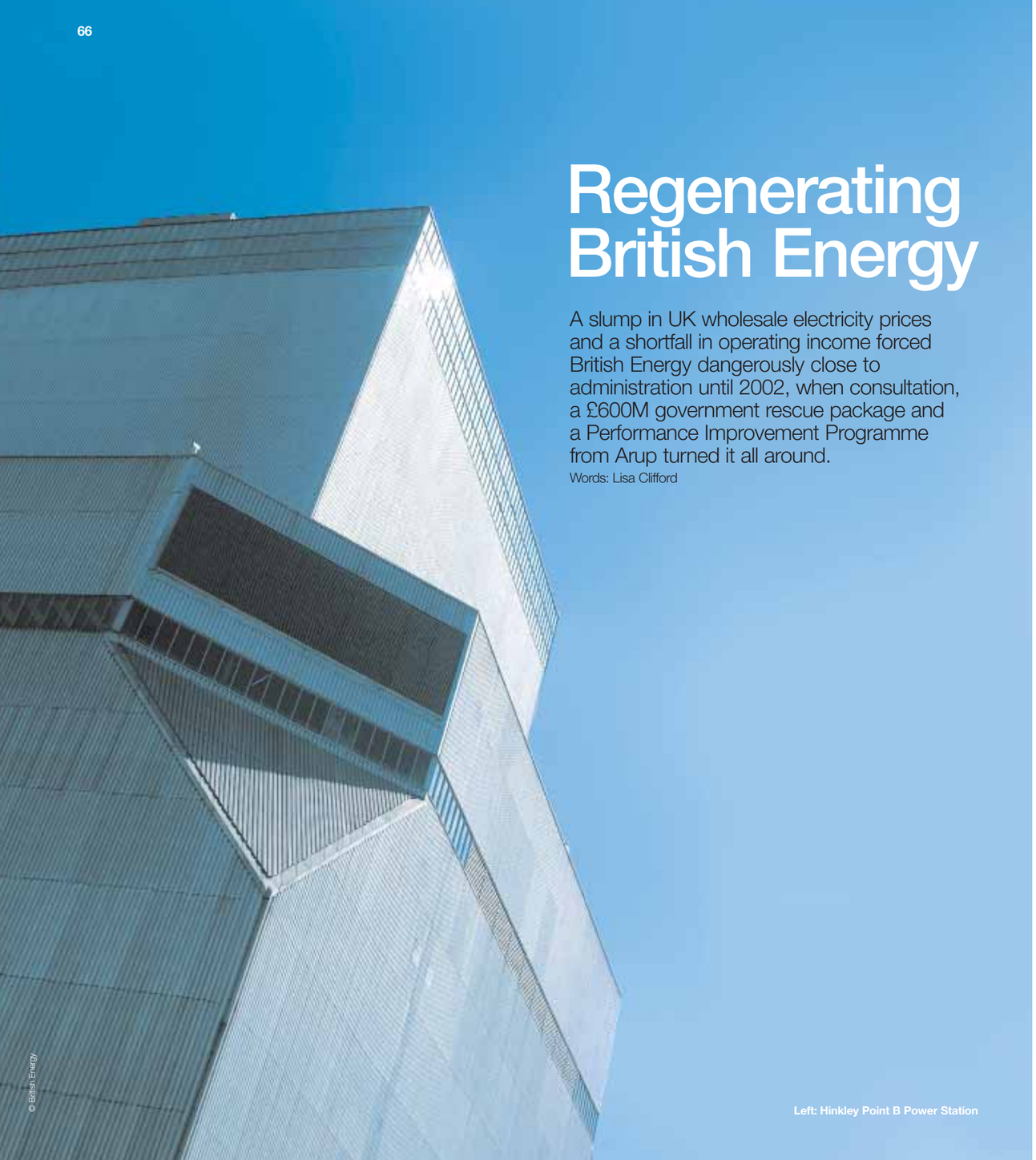
Arup's design approach also resulted in a low-energy servicing strategy, using spare capacity on the existing boilers for the new development.

"We enhanced the building in keeping with its architectural style," sums up Snelson. "It's simple, with an elegance that comes from the fact that the design is not flash or gratuitous in any way."

Tower Environs
Client Historic Royal Palaces
Architect Stanton Williams Architects
Cost consultant Gardiner & Theobald
Contractor Wallis

English National Opera
Client English National Opera
Architect The Arts Team
Project manager GTMS
Theatre consultant Carr and Angier
Construction manager GTCM
Quantity surveyor G&T
Lighting designer Lightmatters

Royal Geographical Society
Client Royal Geographical Society with IBG
Architect Studiodownie Architects
Cost consultant Davis Langdon Everest
Contractor Durken Pudelek Ltd



Regenerating British Energy

A slump in UK wholesale electricity prices and a shortfall in operating income forced British Energy dangerously close to administration until 2002, when consultation, a £600M government rescue package and a Performance Improvement Programme from Arup turned it all around.

Words: Lisa Clifford

Left: Hinkley Point B Power Station

When nuclear power generator British Energy (BE) was first set up in 1996, its focus on low-cost electricity generation made it an extremely promising business proposition. However, the introduction of New Electricity Trading Arrangements (NETA) in 2001 radically changed the UK's wholesale electricity market. In 2002, a shortfall in operating income put BE into severe difficulties and close to going into administration. BE sought financial support from the UK Government. The Government approved the offer of a £600M working capital and trading collateral credit facility, on the condition that BE put in place a restructuring plan and a Performance Improvement Programme (PIP).

As a consequence of the aid package, BE invited companies to tender for PIP and Arup was selected in open competition. Never before had a rescue operation of this size (it covered eight operational nuclear power plants) and complexity been attempted concurrently in the nuclear industry.

Arup led the investigation phase with US energy group Entergy, consultants Rossmore and Severn Trent Utility Services, and set about analysing the business from top to bottom, including all the power plants and staff employed by BE. The findings confirmed that the company was operating at around 80% capacity, as opposed to the 98% achieved by top generators. Following the initial 12-week investigation phase, Arup presented a report to BE with over 250 recommendations, including between £700M and £1bn expenditure on resources and power plants. All this would require considerable planning and management, so Arup was retained to deliver a tangible action and execution plan.

Previously the approach to improve plant performance was to take it offline and shut it down. However, because British Energy provides 20% of the UK's electricity, that wasn't an option – all eight of BE's plants needed to remain fully operational during the PIP to meet the country's power needs.

A nine-month mobilisation phase followed, based around six fundamental strands: foundation, training, human performance, equipment, reliability, work-management and operational focus.

Arup recognised that in order to deliver change within BE's organisation, the organisation itself needed to be bought into the change, which had to occur at all levels and all locations across the BE fleet.

While the emphasis for the mobilisation phase was on an action plan, the following phase concentrated on delivering actions at the required locations.

Thirty months into the programme, the World Association of Nuclear Operators has called the turnaround at BE 'exceptional'. An increase in wholesale power prices has helped the share performance, but Arup's efforts across the BE fleet and the changes currently being made will ensure the continued health of the business if prices fall. It's a very different picture from the one that all parties involved faced at the beginning of this miraculous journey.

The work is ahead of schedule so far and in addition to praise from the industry, results include a 40% improvement in accident frequency rate, 68% reduction in the defect backlog and a 30% improvement in the unplanned automatic trip rate.

No longer synonymous with the words 'troubled' and 'struggling', the nuclear power generator's share price has more than doubled in the past year and has recently made a triumphant return to the FTSE 100 index, in line with British Energy's vision to be a 'Safe, Profitable and Proud' company.

The new nuclear era

British Energy is now well placed to become a major player in the new nuclear era and Arup is finding its hard work is also paying off in other ways.

When Westinghouse, US, wanted to improve the performance of three nuclear facilities, the company approached Arup to create an enhancement programme based on a recommendation from British Energy. "This is the most rewarding testimony we can achieve when recommended by one satisfied client to another," says Dr Gary Walker, Arup's global director for Major Projects. "Because we took on the challenge at British Energy in the first place, we are now recognised as market leaders in this kind of programme management."

Great ideas come from stepping away from the ordinary and devising new ways of tackling old problems. So to keep the creative juices flowing at Arup, we encourage our people to work interactively with each other in a variety of ways.

Words: Lisa Clifford

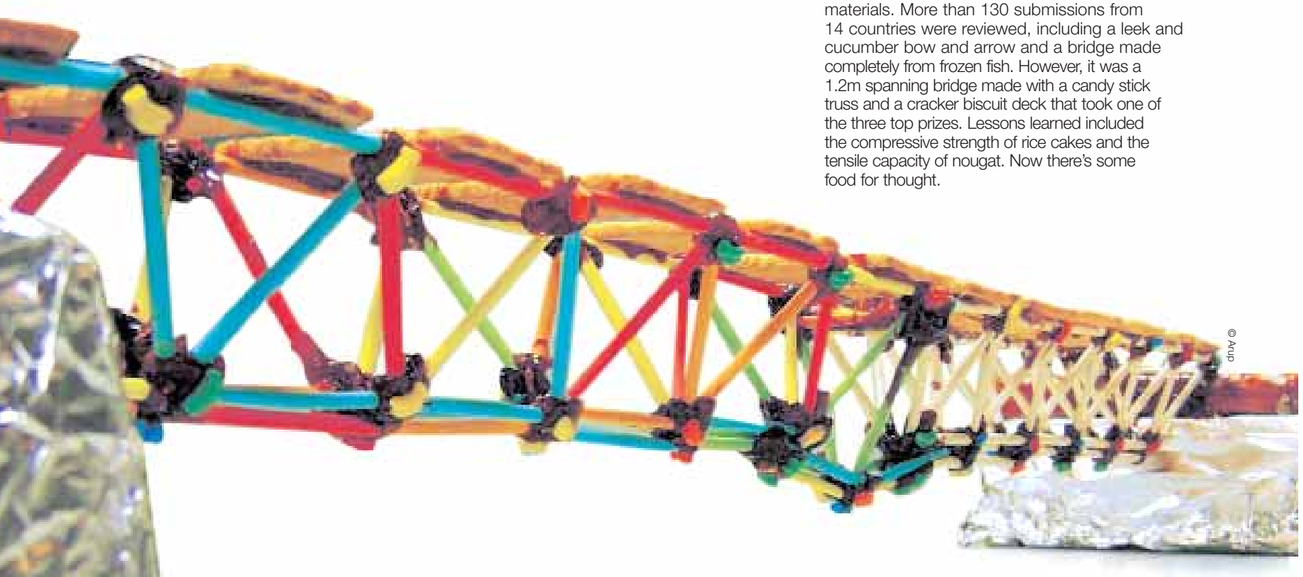
People power

The philosophy behind the design school workshops, which operate globally, is simple: think freely and laterally about design issues with colleagues from all disciplines. Attendees work in groups on a series of imaginative design exercises, most of which are outside the scope of their normal work. At a recent East Asia school, for example, participants were asked to design a boardroom table for the opening of Arup's new office in western China. But even after school's out, the work continues.

Arup runs in-house skills networks offering people throughout the company forums on which to share knowledge, ask questions, propose solutions and build on past experiences. "Through the skills networks you can dip into a pool of knowledge much broader than the people sitting around you," explains Faith Wainwright, skills network director.

But even though being innovative is part of everyday life at the firm, demonstrations of sheer outstanding creativity are promoted through schemes like the first-ever edible structures competition held in the summer of 2005.

Run in three rounds, the simple brief required each structure had to be made entirely from edible materials. More than 130 submissions from 14 countries were reviewed, including a leek and cucumber bow and arrow and a bridge made completely from frozen fish. However, it was a 1.2m spanning bridge made with a candy stick truss and a cracker biscuit deck that took one of the three top prizes. Lessons learned included the compressive strength of rice cakes and the tensile capacity of nougat. Now there's some food for thought.



Right: design schools offer an opportunity to develop skills in teamworking, communication, planning and group decision-making through an intensive weekend of collaboration. Here, the American Design School 2005 challenged participants to produce a vehicle that would pass a rigorous crash test and move two eggs as far as possible.