design

2010

ARUP

Welcome to the Arup Design Yearbook 2010

Design is about identifying problems, taking decisions, creating solutions and achieving better results. Design is central to what Arup does – designing physical objects, plans, processes and systems too. We would like to share a few of the projects in which, over the past year, we have employed agile design thinking, methodology and processes to achieve success for our clients, partners and end users.

Design is the process of working together with our clients to face real-world practical and economic challenges. Our design solutions are always to be seen in the context of quality, cost, sustainability and time constraints. We understand that across the built environment and the business world things need to be more effectively connected, put together more sustainably, operated more efficiently, made to work better, to hold their value for longer, and to be delivered on time and within budget.

At any one time, Arup is working on a vast range of projects in many different geographies and sectors and with an increasingly broad understanding of design. Applied technical creativity and joined-up thinking are what Arup designers aim to bring to every challenge. Some of the projects are massive in scale and huge in impact; others are more modest but equally complex and positive in outcome. The projects in this book are ones where we think something exciting happened because of Arup's contribution.

Forth Replacement Crossing

Client
Transport Scotland

Location
Edinburgh, UK

When it opens in 2016, the Forth Replacement Crossing (FRC) will stand in exalted company. The two existing bridges that cross Scotland's Firth of Forth are Scottish landmarks. The Forth Bridge, which opened in 1890, carries rail across the estuary and is a marvel of Victorian engineering that graces many a Scottish shortbread tin. Next to it is the Forth Road Bridge, a suspension bridge completed in 1964, but which today is in urgent need of renovation. The effect of the inevitable closure for renovation of such a major economic artery – the most heavily used road in Scotland – put the need for a new crossing at the top of the agenda for the Scottish Government, who announced the FRC in 2007.

The £1.7bn – £2.4bn project, Scotland's largest ever infrastructure project, is being undertaken by Transport Scotland with support from a Jacobs-Arup joint venture. Lying to the west of the existing two bridges, the FRC will connect with motorways on both sides of the estuary, as well as the A90. Arup's involvement in the project includes identifying procurement strategies and the design of approach roads and infrastructure. The bridge will be 2.7km long, including two 'back-to-back' main spans of 650m each across the navigation channels. The bridge deck will carry four lanes of traffic – two in each direction – as well as hard shoulders, so that breakdowns or essential road maintenance do not cause congestion.

The proposed cable-stayed bridge with three slender towers has been designed to complement the three tower cantilever structure of the Forth Bridge sitting on the other side of the two-towered Forth Road suspension bridge.

Given the exposed location and Scotland's local weather, the designers have to make sure the bridge is stable in high winds as well as stiff enough to carry traffic loads. The Arup design team came up with a unique concept, one where the cables cross in the middle of the two main spans. The crossover of the cables will give structural stability and will also keep the towers slender. Although theoretical studies have already shown that such an approach is possible, this will be the first time it is being used in practice on a large scale.

Although the cable-stayed design complements the other two bridges visually, it also has many practical advantages over its neighbours. Unlike the suspension design of the Forth Road Bridge, which has problems with its two main load-bearing cables, FRC's cable-stayed design spreads the load among many smaller cables, which can be maintained individually.

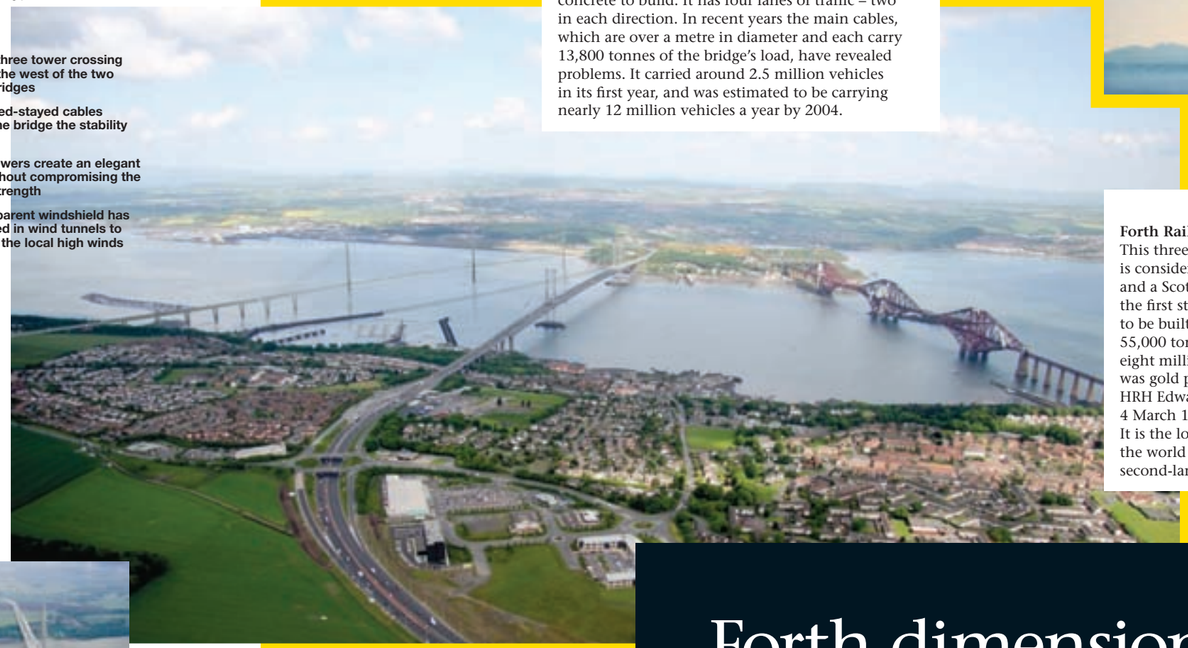
Those charged with maintenance of the new Firth of Forth bridge will not face the same hurdles as those maintaining the Victorian bridge, where the constant requirement to paint the surfaces has spawned the phrase "it's like painting the Forth Bridge", to represent a never-ending task. The FRC's cables will be anchored both inside the bridge deck and in the towers, which are de-humidified for a dry, controlled environment. In the zones subjected to wetting and drying from lapping waves and splash zones, the base of the towers and piers will be reinforced with stainless rather than carbon steel to enhance the durability against attack by the chlorides found in seawater.

The FRC structure is designed to be accessible, with a shuttle train inside the slender deck to carry maintenance staff along the bridge safely without interrupting the traffic. The towers and piers – the columns that support the bridge approach – are designed with maintenance in mind, including lifts,staircases and access points. To allow inspection of the bottom of the bridge, the designers also incorporated moveable gantries for access.

Throughout the design process, safety has been a paramount consideration for all. While high winds sometimes force the closure of the Forth Road Bridge, the FRC has been designed with windshields to protect traffic on the new crossing. The windshields are designed to be difficult to climb, minimising the risk of accidents. The performance of the windshields has been verified in wind tunnel tests. They will have clear panels, which not only improve the view of the Forth from the bridge but also the long distance view of the bridge from the banks of the Forth, from which the windshields are almost invisible. This is no accident – the sightlines from both sides of the Forth were considered by the team in its design.

The FRC will not just be beautiful, but is a key element of Scotland's infrastructure planning. Transport Scotland has developed a managed crossing strategy for the FRC based on assessment studies made by Arup which takes into account the existing Forth Road Bridge, which provides a dedicated public transport corridor carrying, buses, pedestrians and cyclists – and in the future, trams. This has enabled a slimmed down and much more cost-effective version of the new bridge to be designed, rather than having to provide additional dedicated capacity for provision of trams on the new crossing. When the FRC is completed there will be three working bridges across the Firth of Forth – uniquely, each constructed in a separate century – which form a coherent infrastructure that will help Scotland to continue to thrive and develop economically.

01

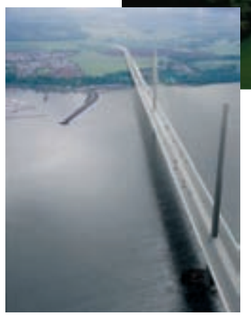


01 **The new, three tower crossing will be to the west of the two existing bridges**

02 **The crossed-stayed cables will give the bridge the stability it needs**

03 **Slender towers create an elegant profile without compromising the bridge's strength**

04 **The transparent windshield has been tested in wind tunnels to withstand the local high winds**



03

Forth Road Bridge, 1964
This two-tower suspension bridge connects Edinburgh with Fife. It is the only road crossing of the Forth east of the Kincardine Bridge, which is 15km upstream. Including approach viaducts, it is 2.5km long, which at the time it was built in 1964 made it the longest suspension bridge span in Europe and the fourth largest in the world. It took nearly 40,000 tonnes of steel and 115,000cm^3 of concrete to build. It has four lanes of traffic – two in each direction. In recent years the main cables, which are over a metre in diameter and each carry 13,800 tonnes of the bridge's load, have revealed problems. It carried around 2.5 million vehicles in its first year, and was estimated to be carrying nearly 12 million vehicles a year by 2004.

02

Forth Rail Bridge, 1890
This three-tower cantilevered bridge is considered an engineering marvel and a Scottish national icon. It was the first steel structure of this scale to be built in the UK. It uses over 55,000 tonnes of steel and more than eight million rivets, the last of which was gold plated and driven home by HRH Edward, Prince of Wales, on 4 March 1890 at its official opening. It is the longest cantilever bridge in the world for rail and the world's second-largest cantilever bridge.

Forth dimension

By 2016, Scotland will have the best of 19th, 20th and 21st century bridge design with the opening of the new Forth Replacement Crossing. This dramatic cable-stayed bridge will maintain a vital link on what is Scotland's busiest highway – boosting the local economy – and is the perfect complement to the Firth of Forth's existing much-loved bridges.

04

Denmark Expo Pavilion
Singapore Expo Pavilion

Location
Shanghai, China

As befits the world's largest ever World Exhibition, the ambition for 2010 World Expo Shanghai is grand in its scope. With the theme of 'Better City, Better Life', Shanghai's Expo explores the full potential of urban life in the 21st century and encourages those who visit to exchange ideas and learn about urban communities. It chimes well with Arup's ambition to shape a better world, and visitors to the Expo will be encouraged to reflect on how to create an eco-friendly society and to maintain the sustainable development of human beings.

Arup's involvement in two of the Expo's structures – Denmark's 'Welfairytales' pavilion, and Singapore's 'Urban Symphony' pavilion – shows how a creative design approach to engineering can bring to life a vision for inspiring, challenging, yet sustainable architecture.

03

02

01

Denmark Pavilion

The Denmark Pavilion is a striking design whose internal structure appears to float in the air. Inside, a continuous geometric 'knot' is cantilevered from its hidden main support and provides a column-free exhibition space. At its centre is a statue of Hans Christian Anderson's Little Mermaid.

Turning such a demanding design into reality required close collaboration from the very beginning with the architect. Arup's technical experience and skills combined well with its understanding of the creative process.

Involved from the early competition stage, Arup worked closely with BIG (bjarke ingels group) to design the façade for the pavilion and develop the initial architectural designs and drawings. 3D modelling was used to help create a pavilion that looked stunning and was also structurally sound.

A particular challenge was hiding the load path to maintain the perception of a floating structure. This meant pushing and testing standard engineering rules.

Collaboration between Arup's teams in London and China was essential to delivering the challenging structural design. Local delivery of the project was vital: Arup provided on-the-ground knowledge and understanding of local codes, practices and committees, a subject which can be complex and time-consuming for non-locals to address.

Collaboration was particularly important for the Danish Pavilion as its design deviated so much from traditional building structures. Arup was able to work with the expert panel and review committee so that this design could be safely built. It was a process that took time, and which involved demonstrating excellence and safety, working closely with the contractors before plans were even approved. By providing on-site support to the contractors in the build phases, Arup ensured the pavilion would adhere to stringent local codes and deliver the architect's vision of a beautiful pavilion.

01 **The design creates a floating structure**

02 **Hans Christian Anderson's Little Mermaid**

03 **The cantilevered continuous geometric knot**

04 **An open structure reduces energy use**

05 **The Singapore Pavilion**

05

04

Singapore Pavilion

From the beginning, this pavilion was conceived as a model to showcase Singapore's success in balancing progress with sustainability. It is meant to echo the city's vision of a high density settlement that is clean and green, with excellent connectivity and a very strong sense of space.

To reflect these sustainability ambitions, Arup and Kay Ngee Tan Architects worked together to incorporate strong sustainability principles into the design. This involved a passive design approach to developing the form and the arrangement of the pavilion, and a strategy that relied on natural ventilation.

The pavilion is not an enclosed structure. One side is open to the elements, which enables those outside the pavilion to engage and interact with it without necessarily entering the space. This also minimises the need for air conditioning, reducing overall energy consumption. As a result, only 25% of the floor space needs to be air conditioned. The pavilion is also shaped to allow wind to blow naturally through the ventilation slots in the façade and cool the space inside.

Focusing on sustainability was only one part of the design. Creating a successful performance space was also important, and this presented significant acoustic and audiovisual design challenges. Arup's understanding of these, and of the pavilion's complex structure, meant that Arup became the link between the building team and the creative designer. This ensured the architect's vision could be realised, while enhancing the overall experience for visitors.

The circular design of the structure was a particular acoustic challenge. Traditionally, circular shapes are not ideal for acoustic performances. But, by creating a 'wavy' wall, the sound was diffused and the wall provided a distinctive projection space. As a result, the pavilion's theatre provides a distinctive and immersive experience for the audience, projecting an image 150° wide.

Expo experience

World Expo Shanghai is the largest ever World Exposition. Taking place from May to October 2010, its theme is 'Better City, Better Life'. Over 70 million visitors are expected from around the world to see pavilions and exhibitions from more than 240 countries.

High Speed Rail

Client
Various

Location
Europe, USA, Asia

01

02

01 **Tracks in California are designed to minimise damage from seismic activity**

02 **The cavernous roof space of Beijing South Station was made possible by Arup's innovative structural and fire engineering designs**

03 **Hollandsdieppe Bridge, The Netherlands**

04 **HS2 in the UK is planned to operate at 400km/h**

05 **Beijing South Station opened on budget and in time for the 2008 Olympics**

High speed rail now

Climate change, the global economic crisis and even the volcanic ash clouds of spring 2010 have brought the world's reliance on aviation into sharp relief. With transport-related carbon emissions rising, congestion in the skies and gridlock on the roads, a strategic approach is needed for the future development of transportation. This is where Arup and high speed rail fit in.

03

04

Rewind 100 years and rail travel was the only available form of mass overland transport across Europe, Asia and the 'New World'. It was an enabling technology, but most people still lived and worked their whole lives in the village or town in which they were born.

Fast forward to today, and it is clear that current transport infrastructure cannot cope with the ever-increasing numbers of passengers. In 2009, Earth officially became an urban planet, with over half its population living in cities or towns. The need for mass transport from city centre to city centre has never been greater. If the needs of future generations are to be met, such mass transport systems must be planned strategically, integral to urban form.

High speed rail (HSR) does for medium distances what aviation does for long distance travel. Today's high speed trains accelerate to cruising speed, slowing only at major stops. They are fast, efficient and have far lower carbon emissions per passenger than any other form of motorised transport. The travelling experience is easier too – passengers are not separated from their luggage and so do not waste time being reunited with it. Instead, they walk off the train to join metros, light rail, buses or other transport for their onward journey.

Provide a high speed railway connection to a city and the transformative effect is startling. In France, the dying industrial town of Lille has been reborn as a thriving city thanks to Europe's high speed rail system. In Portugal, where Arup is technical adviser to the lenders on the first section of the country's proposed high speed rail system, the new HSR will link the furthest corner of the Iberian Peninsula with the rest of Europe, transforming trade and travel to and from Portugal.

Some countries are ahead of the game. Populous Japan started developing high speed rail in the 1950s as a solution to the country's transport problem. Japan, France, Germany, Spain, Italy, The Netherlands, Korea, Taiwan, China and the UK have all followed suit and built their own high speed rail systems, and many other countries have ambitious HSR schemes on the drawing board. The procurement of HSR technology for a country or region's particular needs is complex, and operating procedures have to be created that are appropriate for each specific need. Arup is advising state governments in both the US and China on adapting different HSR technologies to local environments.

High Speed One (HS1) – the UK's first high speed link with continental Europe – engaged over 1,600 Arup people during its 20-year development period. It opened on time and on budget in 2007. With a collective 1,400 man years spent designing and project managing the rail link, the project trained a new generation of Arup rail specialists across every conceivable area of HSR design: noise and vibrations, large-diameter tunnelling, bridge design and systems integration, as well as procurement, contracts and PFI/PPF expertise. Their experience will be crucial in developing this new infrastructure all over the world.

Arup is the engineering consultant for the conception and route planning of High Speed Two, the proposed first stage of a high speed rail network for the UK. This high-speed connection will link London and London's Heathrow Airport with major cities to the north, creating a high speed network that helps to eradicate the country's 'north-south economic divide' in the process. The firm has also proposed an integrated transport hub to be built at Heathrow Airport that will provide even more connectivity by public transport to the airport and high speed network.

In earthquake-prone California, Arup is currently designing 380 miles of rail in two sections that will cross the San Andreas Fault line. The firm's seismic experts are researching how to engineer tracks that minimise damage from seismic movement, as well as ensuring that a rapid stop can be triggered by a few seconds' advance warning of earthquake activity.

When Hong Kong's Express Rail Link connects to China's network in 2015, it will become part of the biggest HSR network in the world. Arup's engineers have been instrumental in all stages of the design of this project, from the initial feasibility studies, through preliminary and detailed design stages, and through to construction. The team has also advised MTR Corporation Limited and the Hong Kong Government on using a long-tunnel fire strategy and emergency rescue sidings to pass through the mountains in 26km-long tunnels. Arup has also advised on ways to ensure that the new station is located right in the centre of Kowloon with ease of access to Hong Kong Island for maximum connectivity and accessibility to its passengers.

The stations that cater for the new HSR systems have their own design challenges. Both transport hubs and meeting places, these 'super stations' are at the cutting edge of what is technically possible. Arup's structural and fire engineers are innovating in the design of large span structures such as Beijing South HSL Station (which is the size of a football stadium), and underground stations such as Florence, Italy, where safety and evacuation of the public are key issues.

High speed rail is without doubt the future of mass transport on land. The advantages of this fast, clean and efficient technology are proven and will help to reduce transport-related carbon emissions. The biggest potential stumbling block to their adoption, however, is funding. Starting with its involvement in the innovative funding model for HS1 in the UK, Arup is at the centre of mechanisms for applying public and private finance to HSR. Strategic by nature, long term and with a high initial capital cost, HSR projects require long sighted political vision and great determination. A future in which HSR networks are a key mode of transportation in Europe, Asia and the US must also be an age of close public and private sector cooperation.

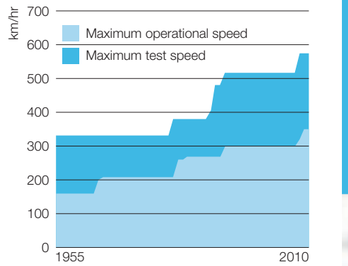
05

06 **Train running-speeds have effectively doubled in the last 50 years**

07 **Eurostar running on HS1, UK**

08 **Depot and Emergency Rescue Sidings – Express Rail Link, Hong Kong**

06



How trains got faster

Japan set a world speed record for narrow gauge trains at 145km/h in 1957, which led to its first standard gauge high speed train, the Shinkansen, which ran at 210km/h in 1964. Nowadays, the European Union defines HSR as rail travelling above 250km/h on existing track and 300km/h or faster on new track. High-speed trains in many countries now regularly run at 300km/h, while China's new high-speed rail systems are operating commercially at up to 350km/h, and 400km/h is becoming the new design standard. Under test conditions the world's fastest steel wheel on steel rail train recently set a new world record, reaching a remarkable 574km/h in France. Two Maglev systems (an alternative technology to steel wheel on rail) are also operating in Japan and China at speeds up to 581km/h.

07

Under pressure

HSR brings engineers a new set of challenges. High-speed trains running through tunnels create a pressure wave, causing a sudden change in aural pressure for passengers on the train. Arup's engineers are using complex modelling and fluid dynamic techniques to optimise tunnel sizes. The firm's noise and vibration specialists are also focused on lowering the level of engine and wheel rail noise which increase exponentially at high speed, both below and above ground.

08

Cedar Rapids
Disaster Recovery

Client
Sasaki Associates

Location
Cedar Rapids, IA, USA

01 **Bridges on the Cedar River were submerged during the floods**

02 **The waters reached well beyond the 500-year floodline**

03 **The Cedar River burst its banks in June 2008**

04 **The riverfront masterplan** (Sasaki Associates)

01

02

03

04

Flood responsive

It was while the civic leaders of Cedar Rapids were discussing a new riverfront park that unprecedented rainfall caused the Cedar River to overflow beyond its 500-year floodline. With 10 square miles of the city underwater, the city immediately went into disaster-recovery mode and turned its attention to the need for a major flood defence strategy.

With the downtown cultural, financial and industrial core submerged and more than 7,000 homes, businesses and municipal facilities damaged or destroyed, fast action was needed.

Led by Sasaki Associates, the Arup sustainability advice team responded to the city's new needs, making full use of its experts in flood prevention technologies, and drawing on the firm's extensive knowledge of working in post-disaster areas. All of these inputs were combined to ensure sustainability measures could be an integral part of a successful recovery effort.

By taking a look at the far-reaching effects of floods, a systematic review of neighbourhood planning in the city could be undertaken – creating an opportunity to address some of the pre-existing economic and social challenges, as well as dealing with the consequences of the floods.

The city hopes that the problem of neighborhood fragmentation will be eradicated as a result of the changes proposed, replaced instead by communities that have pedestrian access to local amenities and that are revitalised by the integration of arts and culture infrastructure.

To help with the adoption of such measures, Arup created a Sustainability Assessment Matrix as a handheld booklet for the design team to allow them to quickly consider, evaluate and implement sustainability strategies into the Neighborhood Plan process, which proved to be an invaluable tool.

In addition, a city-wide pre-flood sustainability baseline assessment, which looks at 19 'indicators' of a sustainable community, will help city decision-makers target investment and prioritise effort, and serve as a benchmark to document and track improvement in sustainability performance. And while it will take some time before all of the benefits are felt, the end result should be a more sustainable, thriving city and a safer place for its residents to live.

Palmas Altas Campus
Business Park

Client
Abengoa SA

Location
Seville, Spain

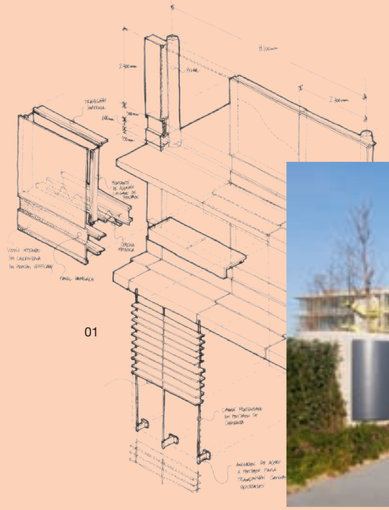
01 **Constructive detail for façade**

02 **Palmas Altas Campus**

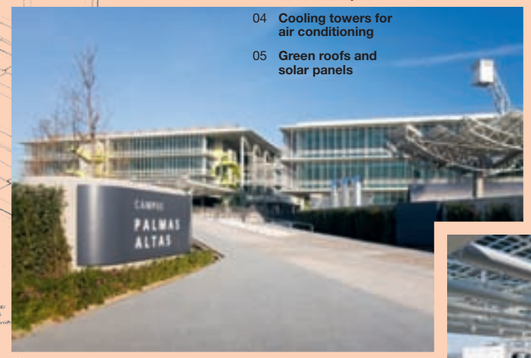
03 **Natural daylight floods the space**

04 **Cooling towers for air conditioning**

05 **Green roofs and solar panels**



01



02

03

04

05

This place means business

With a carbon footprint around 30% lower than standard Spanish office developments, Abengoa Palmas Altas Campus is Spain's greenest business park. It should be the first office development in the country to receive platinum LEED® accreditation – an achievement due in no small part to the expertise of Arup.

The business park of Palmas Altas Campus lies to the south of Seville in a new urban development area and is the largest commercial technological development in southern Spain. A joint venture between the city council and developer Abengoa, the client focused on sustainability from the very beginning.

Within Spain, the global challenges of climate change, reducing energy consumption and efficient use of resources are all having an impact on business – and particularly for construction. Abengoa took this opportunity to establish an exemplar sustainable business park, not only for the obvious operational and cost benefits, but to help attract investors and tenants.

During the first stages of the project Arup developed studies on potential sustainable options for the development. These included natural lighting studies that compared different building configurations to optimise natural lighting use and different air conditioning options including investment and pay back periods which saw the selection of a chilled beams solution. Arup's analysis allowed the client to make the best decisions for both investment and energy reduction.

The design team made sure that active and passive design features were incorporated to achieve such a major reduction in carbon footprint. These included making sure that the building's orientation actively aided sustainable elements such as green roofs, energy-efficient façades, PV panels, thermal solar concentrators, maximising energy efficiency through water re-use, natural lighting, and using chilled beams to air condition office areas. Arup's experience and expertise in sustainable buildings was influential in ensuring these were adopted.

The end result is an overall reduction in energy consumption of around 30%, minimising operational costs for the client. Water consumption is also significantly reduced through the use of rainwater for irrigation on site. And for those working in the development, better air conditioning solutions and increased natural lighting throughout the offices makes it a nicer place to work.

By working closely with the architects Rogers Stirk Harbour + Partners and Vidal y Asociados arquitectos and the client on sustainability initiatives from the beginning of the project, decisions could be made much more quickly and easily – which also helped in meeting the tight budget. The end result – which has exceeded client expectations – is a showcase for Arup's holistic approach to sustainable design.

The Edge

Client
State Library of Queensland

Location
Brisbane, Australia

01

02

04

03

01 **The Edge Launch**
02 **www.edgeqld.org.au**
03 **The Edge live toolbar**
04 **A studio at the Edge**

Creative edge

A riverside building in Brisbane has been transformed into a creative and collaborative space for young people – both online and in the real world.

The Edge, home to a digital culture centre for 15-25 year olds, creates a youthful contrast with its venerable neighbours, Brisbane's State Library, Gallery of Modern Art, and the Queensland Performing Arts Centre. The inner workings of this long, low building are clearly visible through both its glass and its digital media activities, providing an informal and open access learning environment that fits somewhere between school and university.

Glowing with light, the building provides real-time information on the building's energy use via a large LED monitor display in the foyer. Groups of people can work together in bays, and projectors turn the windows into giant screens, presenting the building's activity to the city beyond. Free Wi-Fi and power points are plentiful. Purpose-built labs for hardware hacking and video work, as well as 'boutique' recording studios are also available in the building. The auditorium may be pressed into service as a concert venue, workshop space and for many other uses. It is equipped with 'smart', cuboid, modular furniture, dubbed the Soapbox, that can be screwed together into a conventional stage, or configured to suit users' needs.

Arup contributed heavily to the design of the building and its activities, working with local firm m3architecture and the State Library. Just as the building incorporates informatics – sensors which collect information and show how the building is used – so do individual components like the Soapbox. Each piece of furniture has a small cavity to house unspecified sensors, which could gather information that ranges from the location and orientation of the Soapbox itself to the presence of mobile phones nearby. The furniture invites experimentation, just as the building itself offers interesting opportunities for artists and designers to incorporate local factors into its lighting and displays. The building therefore reflects the data within. Its displays and lights can be programmed to reflect the temperature outside or its global connectivity via network traffic, for example.

Arup's designers have helped the State Library of Queensland to design The Edge such that it feels 'authentic' and is attractive to creative young people. This strategic input extended to the design of job titles, organisational chart and recruitment processes, the various education and access models, new media platforms and hardware specification, plus numerous other elements of the 'soft infrastructure' of the space. It is notoriously difficult for government-funded projects to be credible within the youth market, but with Arup's help, The Edge feels more like a thriving community than it does a state-funded centre. The building has hosted Australia's independent music conference and Robowars, whilst offering programmes in wind-up toys and physical computing, citizen journalism and radio documentary making, open source code and using music software to make drone metal.

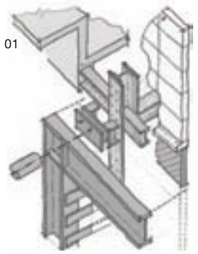
Like many of the teenagers it attracts, The Edge uses its various online alter egos heavily. Reflecting the diversity within, it has a Facebook page (The Edge, Queensland) and Twitter feed (@SLQedge). Although the aim was to provide a training ground for young people in Queensland, it is also welcoming creatives from South East Asia and beyond, thanks to its online presence. The Edge looks like succeeding in that trickiest of endeavours: to provide what tomorrow's creative people need today.

Regeneration of Newton and Arkwright Buildings

Client
Nottingham Trent University

Location
Nottingham, UK

01



02

03

04

05

01 **Newton goal post frames**
02 **The Arkwright Building**
03 **Aerial view of the site**
04 **The central court roof with Newton tower behind**
05 **Ground floor of the Newton forum**

Heritage revitalised

The Grade II* listed Newton and Arkwright Buildings at the heart of Nottingham Trent University were never designed to work together, but a scheme, which uses the space between them, has revitalised this city campus.

Regeneration of the Newton and Arkwright Buildings has transformed Nottingham Trent University. Not only has it provided much-needed new teaching and academic space but, by using the space between the two buildings and creating a central court, it also provides a unified approach to the University's new main entrance.

Substantial but sympathetic works were undertaken to ensure the two heritage buildings could be integrated into the new scheme by Hopkins Architects, creating an inspiring environment for students, staff and the city. Careful consideration was given to temperature and glare control, lighting, power and IT requirements.

Heating, ventilation and cooling was provided to each classroom in the Newton tower via bespoke active chilled beams. They also incorporate mountings for projectors, fire detection equipment and lighting controls; providing a discrete solution and giving control over the internal environment to create comfortable teaching spaces.

During the works, drainage channels within the floor of the chemistry laboratories were discovered and these were integrated into the design to provide horizontal distribution for power, data and audio-visual connections, maximising the floor to ceiling height.

The 1877 Arkwright Building has been transformed into usable academic space by employing passive design elements with natural ventilation and cooling. To solve circulation and access problems, major alteration works removed a number of buildings in the Arkwright complex and created a new quadrangle area.

The buildings also needed substantial works to address structural issues. One of the design challenges for the Arkwright Building was sympathetically remodelling what had previously been an internal wall – exposed by removal of part of the building – into an external wall. Restraints, ties and wind-girders were carefully integrated into the existing building fabric to ensure they didn't detract from its original characteristics.

Structurally, regeneration of the nine-storey 1950s Newton tower was equally challenging. To open up the space and provide access into new lecture theatres, existing stability shear walls and bracing at the base needed to be removed. New steel goal post portal frames were constructed, with temporary works carefully coordinated to keep the tower standing, as forces were transferred from the existing stability system to the replacement elements.

Arup provided full multidisciplinary engineering design and a highly creative approach to achieve the numerous interventions necessary to revitalise the two buildings, meet the stringent requirements of English Heritage, and target a BREEAM Excellent rating.

Joseph Vance Building

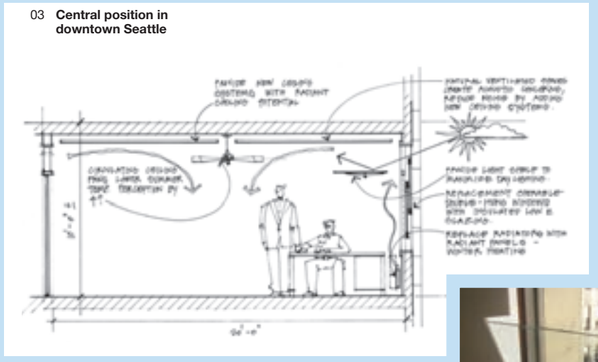
Client
Jonathan Rose Companies, LLC

Location
Seattle, WA, USA

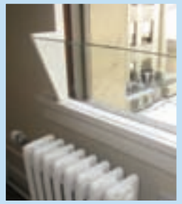
01 **Architect's sketch**

02 **Original 1920s ventilation deflectors are now back in use**

03 **Central position in downtown Seattle**



01



02

03

Renewal at heart

The Joseph Vance Building in downtown Seattle, a building that dates from 1929, has been restored to its former glory and is now in the top 3% of US buildings for energy efficiency. As well as its Gold EB LEED® rating for environmental performance in existing buildings, occupancy levels have since soared to 97% despite a challenging market.

The Joseph Vance Building has always looked good. This building was designed in the 1920s, but over the years has suffered from tinkering – some unwise renovations that had, in some cases, diminished its performance. When a fund sponsored by a green New York property developer bought it in 2006 it was an ideal candidate for an environmentally–friendly renovation. The plan has been an economic and environmental success; a clever combination of relatively small but cost effective measures has put the building in the 97th percentile of US buildings for energy efficiency. The building maintains historically high occupancy levels in a challenging leasing environment and economy. The key was to devise an economical green strategy for the building that not only increased efficiency, but enhanced its appeal to tenants. This, in turn, has enabled the owners to attract a diverse mix of entrepreneurial and environmental businesses, some of which rent quite small spaces.

Arup was initially contracted to work on the façade and preliminary mechanical, electrical and plumbing renovation strategies of the building, but ended up taking a much more central role, advising the owner, which had ambitious green goals but a limited budget. The team's first move was to understand how the original design was intended to perform. Like many older buildings, its performance over time had been compromised by ill-considered renovations over the years.

The team explored a range of energy-efficiency strategies, including the replacement, upgrade and customisation of the original double-hung sash windows. Designed in the 1920s to open, most of the windows have actually been sealed shut for years, since the introduction of air conditioning. The renovation restored them to their original condition returning the building to its naturally-ventilated state. During an early site visit, the design team noticed angled glass strips on the inside of the operable windows, around 70cm up from the bottom edge. The team initially wanted to get rid of them, but Arup was intrigued. The strips turned out to be 1929-style ventilation deflectors, which deflect breezes upwards, giving occupants fresh air but limiting draughts.

Another critical strategy recommended by Arup involved the commissioning of the steam system. By simply fitting local thermostats to every radiator, for example, the team gave temperature control to the tenants and halved the building's steam bills in the process.

Arup, together with the owners and architect, ZGF Architects LLP, produced a 'green tenant guide', which specifies how tenants can work with the building's natural ventilation and daylight when fitting out their individual space.

Arup's methodical and considered approach shows that it is possible to combine many small, simple and often inexpensive measures in existing buildings to achieve startling results.

Miami Science Museum

Client
Grimshaw Architects

Location
Miami, FL, USA

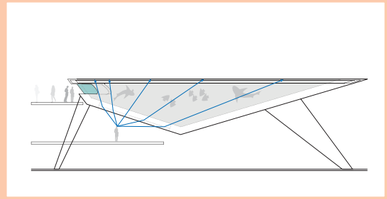
01 **Architect's rendering of the exterior of the tank**

02 **Sight lines from the lower viewing platform**

03 **The Gulf Stream tank is the last in a sequence of exhibits in the Living Core**

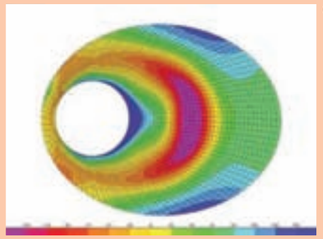
04 **Computer analysis rendering of the tank**

01



02

03



04

Underwater world

The design of the showpiece Gulf Stream tank in the new Miami Science Museum's aquarium has long been anticipated as its key attraction. Innovative thinking from Arup has created a structural solution that moves the aquarium closer to realisation.

One of the main attractions at the new Miami Science Museum will be a sequence of aquarium and wildlife habitat exhibits called the Living Core. Visitors will be taken on an aquatic journey through the Living Core, exploring habitats as diverse as mangrove swamps, seagrass lagoons and a live coral reef. At this point, the journey takes visitors outside to look down into the Gulf Stream tank, conceived on an impressive scale and home to sharks and stingrays.

This enormous elliptical pool of between 27.5m and 30.5m in diameter needs almost 2 million litres of natural seawater to fill it. The aquatic journey continues as visitors descend to a subterranean viewing platform. There, a 8.5m-diameter window allows an underwater view of the tank's inhabitants. The design is such that from this vantage point the viewer can experience the expansiveness of the ocean, since at no point can the sides of the tank be seen – only the water is visible.

This unique view is possible because of the tank's conical shape. The 'cone' is effectively tilted, sliced horizontally to form the open-top surface and then cut on the diagonal to create the circular viewing window at the bottom. It is an ambitious design that the client, aquarium exhibit designer, and architect all originally feared may be unachievable.

But Arup's solution makes the design feasible. Cast-in-place reinforced concrete, compressed with tensioned cables, will ensure it is watertight and seven columns positioned around the tilted cone will provide the aquarium with enough support to carry the enormous weight of the water.

The choice of concrete provides a viable structural solution, but it will also serve another purpose. Unlike structural steel, which interferes with a shark's sensory system, the concrete shell will act as a buffer between the sharks and the structure's reinforcing steel, providing an ideal living environment. Construction of the Gulf Stream tank is scheduled to begin in the next two to three years, with completion of the museum expected in 2015.

One Shelley Street

Client
Brookfield Multiplex

Location
Sydney, Australia

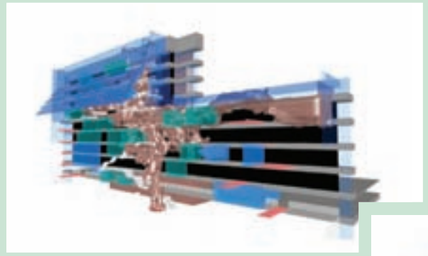
01 **The striking external steel diagrid structure**

02 **An understanding of fire and smoke behaviour in the space was crucial in the atrium design**

03 **The 10m-wide glass atrium creates a light and airy space**

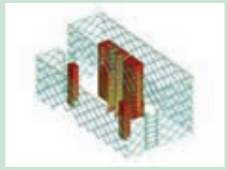
04 **Overall frame structure and core stress diagram**

01



02

03



04

Open safety

What started off as a standard residential building has ended up as a striking commercial building with a huge atrium, thanks to Arup's structural and fire experts.

There is no other building in Sydney like One Shelley Street. The striking office development – which has a 6-star Green Star rating from the Green Buildings Council of Australia – employs a unique structural system that sits outside its sleek glass façade. It also features an open glass atrium – a comparative rarity in the city because of the need for smoke control under Australian fire codes.

The external steel diagrid structural system supports the whole of the outside of the building, which 'hangs' off the external frame. Arup wanted slender, lightweight members for the diagrid that could be fabricated offsite to keep costs low. The steel members are straightforward while all the complexity is in the design of the four-way joints. As a result, the structure was assembled up to the level 12 in just five months.

The diagrid structure removed the need for internal columns, which has liberated the inside space, which is light and airy. The building also boasts a 10m-wide glass atrium that is open space rather than enclosed. This was made possible by the expertise of Arup's fire engineers, whose understanding of the behaviour of flames, heat and smoke provided a starting point for the design.

An atrium space is popular with occupants and designers alike, who value the sense of space it can bring to a city building, but in Australia fire codes usually demand that such open spaces be glassed-in, separating the atrium from the floors. The atrium at One Shelley Street contains open stairs, bridges between floors and meeting pods that cantilever out from each side. Arup's team took a performance-based approach to how fire, smoke and people behave, to design an atrium that could safely remain open. The floors can be sealed in an emergency and extractor fans at the top of the atrium will suck out smoke.

Typically, buildings that are open and which contain a lot of glass burn out very quickly in a fire compared with traditional buildings, which can 'cook' for hours. By analysing how quickly fire could spread within the spaces and how long it was likely to burn, the team was able to rationalise fire protection measures. Crucial structural elements – such as some steel floor members – received extra fire protection, while other elements were identified that could be less heavily protected simply because the load they carry could be taken elsewhere without compromising the structure.

Arup's performance-based design enables the elements that architects and building occupants value – open space and natural light – without compromising safety.

Hunters Point Shipyard
Candlestick Point Redevelopment

Client
The City of San Francisco

Location
San Francisco, CA, USA

01

02

01 **With over 50% of residents also home owners, there is great community pride**

02 **The Hunters Point community web portal**

03 **The derelict Hunters Point shipyards await redevelopment**

03

People first

The community-led redevelopment of one of San Francisco's derelict shipyards is enabling this area to put its past behind it, and focus instead on the social and health needs of its residents. With 10,000 new jobs being created for locals and 32% affordable housing, sustainability in this low-carbon development is defined as much by social conditions for residents as green technologies.

Less than a mile from some of San Francisco's most affluent neighbourhoods are the former dock-workers' districts of Bayview and Hunters Point. The fortunes of these two districts have followed those of the local naval shipyard, which at its peak employed thousands of residents at the time of the Second World War. But shipyard closures in 1974 left behind a bitter legacy of joblessness, pollution and health problems for its residents, and today, over 50% of the district's children live in poverty.

It is no wonder, then, that Arup's sustainability experts found residents were often suspicious, cynical even, when first introduced to the concept of a mixed use, low-carbon development on the old shipyard site. Residents felt there were more pressing concerns to address – high crime, poor health and unemployment. Would the development provide jobs for locals, safe streets and healthy homes, they wanted to know? Or would it only bring 'yuppie' jobs and expensive housing, forcing residents out?

A much higher percentage of houses in this district are owner-occupied – over 55%, compared to the San Francisco average of 35%, so people feel they have a stake in their community's future. Initially, residents thought that a low-carbon development would do little for them, so the team had to change the way it articulated the benefits. While the team's approach had always focused on the 'triple bottom line' of community, environment and economics, it started explicitly to define sustainability in terms of its residents.

Stark data on the high incidences in the area of heart disease, cancer and respiratory problems – 30% of residents are asthmatic – makes the case for a healthier environment. And during the course of hundreds of community meetings, the team developed a deep and nuanced understanding of residents' concerns. Measures to lower carbon emissions and improve air quality started to make more sense when viewed through the prism of their high utility bills and asthmatic children.

As a result, the development plan now reflects residents' priorities. Over 10,000 new jobs are to be created, and the arrival of high-tech, non-industrial businesses in the area is an opportunity for many residents, who will benefit from a US$17.85m workforce development and training fund to develop new skills. Nearly a third (32%) of housing will be affordable and aimed at low-income residents and families, who will see lower utility bills thanks to the use of energy-efficient design. The development plan makes commercial sense for the developer and improves the environment for future generations. It also offers a cleaner and brighter future for today's residents of Hunters Point.

Stonecutters Bridge

Client
Highways Department,
Hong Kong SAR

Location
Hong Kong, China

02

01

03

01 **Steel deck extends 49.75m into the first back-span**

02 **Segment of deck being lifted into position**

03 **Anti-vibration measure: dimples in stay cable**

Landmark resilience

Hong Kong is no stranger to typhoons, with one major event at the site of Hong Kong's Stonecutters Bridge as recently as September 1999. So for the bridge's designers, it was crucial that this cable-stayed bridge – with a span of over one kilometre – was stable and strong enough to cope with such an extreme event.

Stonecutters Bridge is part of an essential transport route in Hong Kong. It crosses the Rambler Channel from Stonecutters Island to Tsing Yi and gives access to the Kwai Chung Container Terminals, one of the busiest ports in the world and responsible for around 20% of Hong Kong's GDP.

In September 1999, Typhoon York struck Hong Kong, with gusts of up to 182km/h recorded on the site where Stonecutters Bridge now stands. Designing the bridge to withstand such an event was therefore not just based on theoretical possibility, it was based on historic fact, with every likelihood that a similarly strong typhoon will strike again. Although traditional bridge design tends to consider the effects of traffic loading first – with some strengthening included for the impact of wind – this situation was reversed in the case of Stonecutters, with wind loading driving the design.

The word typhoon derives from the Cantonese 'tai fung', meaning 'great wind'. Typhoon winds have certain characteristics: they are turbulent, with rapid variation in speed and direction, and they are extremely intense. And while a bridge may appear to be structurally rigid, its length actually makes it relatively flexible. As a result, the gustiness of the wind interacts with the dynamics of the bridge structure to create what is called a buffeting response. This is when the energy of the wind is imparted to the bridge structure as a wind load, due to the resonant vibrating response of the bridge to the fluctuating wind speeds.

To understand the nature of the wind and its potential interaction with the bridge, Arup carried out exhaustive monitoring and testing. Historical data from the Hong Kong authorities was studied, but it was also important to analyse the wind climate at the precise location of the bridge. The surrounding terrain impacts on the character of wind and in this case there were significant variations depending on whether the wind was coming from the ocean or from the mountains. A wind sensor was erected on a 50m-high mast in order to gather the necessary site-specific data for analysis.

Computer analysis was followed by extensive wind tunnel testing, firstly with individual components of the bridge to test their individual response and finally with a complete scale model of the bridge that included the surrounding terrain.

Once the turbulence characteristics had been established, the bridge could be designed with appropriate structural stability. The steel main span is kept as light and streamlined as possible, while the heavy concrete back spans act as anchors and have to work hard at times when the wind is buffeting the main span. With a split carriageway deck the bridge is given aerodynamic stability.

Arup designers also had to consider how the bridge would perform while under construction. Before the two halves of the bridge were joined, they were two large 500m cantilevers. The bridge also had to be designed to withstand an extreme wind event at this critical stage.

During construction of the deck cantilevers, 18m-long deck segments weighing up to 500 tonnes each were routinely winched up to the deck to be welded into place. Each lifting operation had to be carefully controlled and done in favourable weather, with every possibility that the bridge would need to be made secure part way through the lifting operations should problems arise. It was vital, therefore, that contingency plans were in place throughout the construction process, as well as keeping a close eye on the weather forecast.

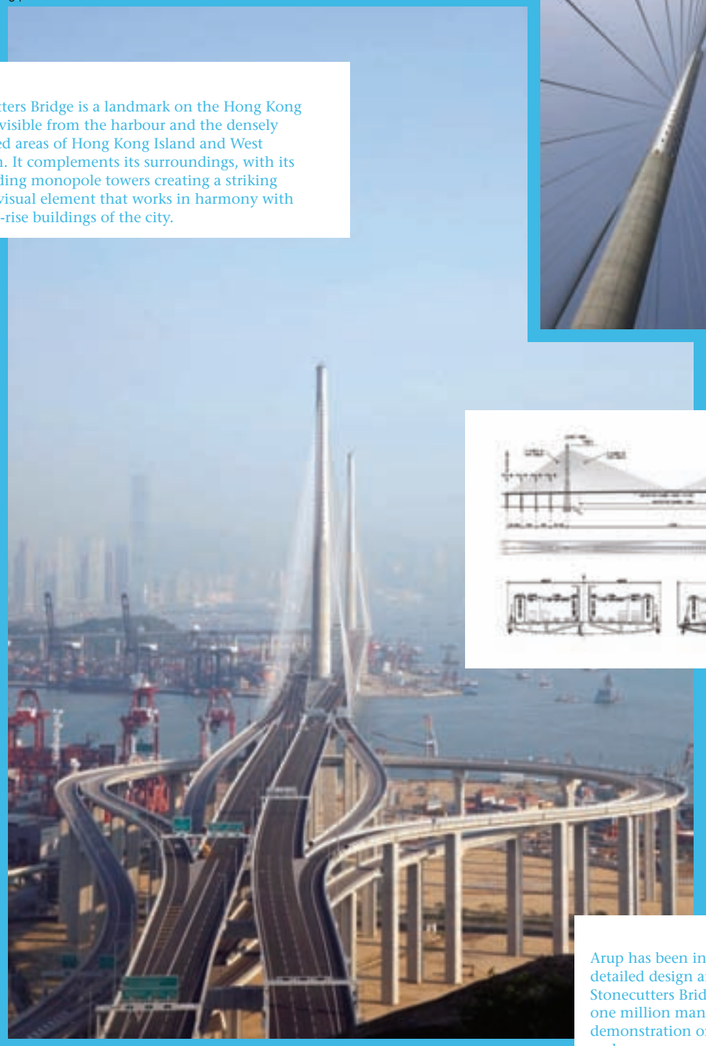
Another major weather-related design challenge is wind-driven rain, a less intense but far more frequent occurrence in Hong Kong than typhoons. For a cable-stayed bridge on the scale of Stonecutters, such rain can cause quite a problem for the stay cables. With the stays being up to 540m in length, wind-driven rain can cause them to oscillate, and the exact vibration pattern is difficult to theoretically model and design for. But by carrying out full-scale wind tunnel testing, it was possible to implement a surface treatment for the cables to solve this problem.

This involved introducing a dimpled surface texture to the normally smooth and cylindrical cable stays. The indentations, which are much like the surface of a golf ball, create friction, disturbing the flow of the water and therefore limiting the vibrations of the cable. Dampers were also added to each stay, acting as shock absorbers to limit the magnitude of any vibration that may occur.

Arup's work during the feasibility, detailed design and construction phases of the project helped to bring this truly iconic and vital piece of infrastructure to life, with the assurance that if a typhoon hits, Stonecutters Bridge is designed to withstand it.

Stonecutters Bridge is a landmark on the Hong Kong skyline, visible from the harbour and the densely populated areas of Hong Kong Island and West Kowloon. It complements its surroundings, with its freestanding monopole towers creating a striking vertical visual element that works in harmony with the high-rise buildings of the city.

04



05

06

04 **View of the bridge from Tsing Yi**

05 **Tower with two planes of stay cables**

06 **Elevation and plan of Stonecutters Bridge, west back-spans and cross-section of steel deck**

Arup has been involved in the feasibility, detailed design and construction supervision of Stonecutters Bridge and contributed well over one million man-hours to the project. It is a demonstration of the firm's ability to mobilise and manage resources on a large scale and across a broad spectrum of specialisations.

Heron Tower

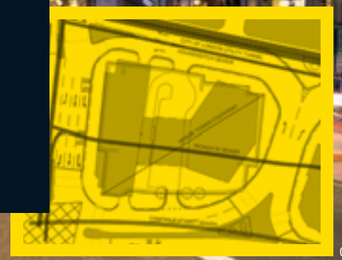
Client
Heron International Ltd

Location
London, UK

01

New tube

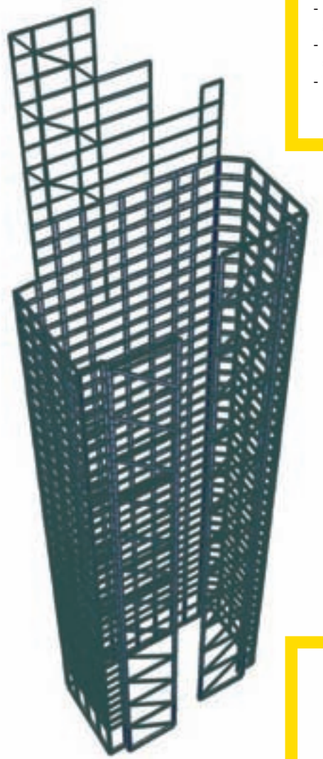
The City of London's first 'six star' office development combines luxury with strong environmental credentials. Heron Tower's excellent BREEAM rating for its overall environmental performance is thanks in no small part to Arup's integrated approach to structure and services design.

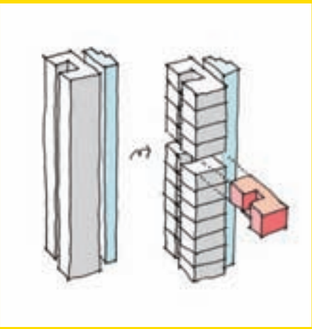


02

Heron Tower facts
- 46-storey slender glass and stainless steel clad structure
- 230m tall including mast, 202m tall without
- 40,836m² of office space spread over 36 storeys
- Designed to be rented village-by-village or floor-by-floor
- Each 3,252m² office village has a three-floor atrium
- Public restaurant and sky bar on floors 38 to 40
- Three basement levels for retail, parking, storage and the building plant

03





04

01 **Heron Tower is at the heart of the City of London**

02 **All construction took place within the perimeter of this island site**

03 **The 'open tube' structure gives the atria on the north side uninterrupted views and lets in maximum daylight**

04 **The building core (in blue) contains essential services and protects the office 'villages' (in red) from the sun's heat, affording them valuable views**

Many buildings have a simple concrete core, which acts as a backbone and gives the structure its stability and support. For Heron Tower, the architect's wish to achieve an open floor plate, with sweeping views to the north, made a central core out of the question. The site, too, hemmed in by roads on all sides, gave limited space for construction. The answer was a tube structure – to provide the structural stability needed by a 46-storey building, while also maximising the open floor space and therefore the lettable area.

Arup modified the tube structure by cutting out a vertical 'chunk' down one side, which is uncommon for tube-stabilised buildings. The strength of a tube structure is in the continuous outside edge, so the team needed to restore its stability. They did this by devising a framing system to 'stitch' the open vertical edges of the cut tube together in key places. This approach, alongside the careful engineering required to achieve it, has resulted in office space that is flooded with daylight and has unimpeded views of the City of London.

The building 'core' – meaning the essential stairs and lifts – lies on the south side of the tower. As well as housing the building's double-decker lifts, cabling, fire exits and almost everything that is not dedicated office space, the south side provides Heron Tower with a solar shield. Studded with 48,000 photovoltaic arrays, this supplies enough power for the needs of its basement. The top of the building houses diesel-powered generators to provide 100% stand-by power in case of power cuts.

The tube had other advantages, such as faster construction. With no core, each level of the basement can be excavated without propping. Once the first level is done, excavation of the next level can start below it, with the tube providing the all-important stability for the frame construction above. Arup's construction strategy meant that the basement and the structure above could proceed in tandem.

The top-down approach also means that the load-bearing capacity of the foundation increases as construction advances. Arup's approach transformed what would normally be a problem into an advantage, by engineering the construction sequence to align the frame assembly with the construction of the basement. The foundations themselves are configured to match the load bearing demanded of them as construction advances, which made construction far less costly.

'Six star' luxury is pretty essential to a building that is designed to attract the City of London's most prestigious commercial tenants. The office space is designed to be rented out in three-floor chunks, each with a glass atrium overlooking the city, while the interior can be configured individually for each tenant.

Arup's work has allowed the architect's vision to be realised and with a faster than expected construction timetable. It was also fundamental to facilitating the positive sustainability and environmental credentials that have secured Heron Tower's excellent BREEAM rating from the UK's environmental agency.

Marina Bay Sands

Client
Marina Bay Sands Pte Ltd

Location
Singapore

Singapore is not lacking in ambition. Already Asia's busiest seaport and the world's fourth largest foreign exchange market, this 'Asian Tiger' wants to expand its share of the region's meetings, incentives, conference and exhibitions sector, increasing its annual visitor numbers by 70% over five years. To make this vision a reality, integrated resort schemes such as Marina Bay Sands are crucial.

This 581,400m² project is already destined for the record books. Over 2,500 en suite hotel rooms are contained within the three distinctive slant-legged towers. Crowning the three 200m-tall structures is a one-hectare, 340m-long Skypark – the largest cantilevered public observation deck in the world. The scheme also features a museum shaped like a lotus flower, as well as two crystal pavilions that appear to float on the sea like icebergs. All are unusually complex in their design.

The challenge of making the architect's grand vision a reality is more than matched by the engineering challenges posed by the coastal site's geology. As its name suggests, Marina Bay Sands sits on sand infill, which rests in turn on deep soft clay marine deposits. This soft clay makes excavations more than a few metres deep very difficult. The scheme required a large basement car park, with deep excavations across most of the site. As if this were not challenging enough, the team had to engineer a 35m-deep 'cut and cover' tunnel next to an existing bridge.

Arup started on the design in July 2006 and site work started in early 2007. With more than 40% of the concrete construction work occurring between 15m and 35m underground, there was little visible progress to be seen from above during the first twelve months. The project completion was set for less than three and a half years later, in early 2010 – a construction timetable that was made possible only by Arup's innovative approach to the excavation in the first year.

To speed up the ground works, the team designed four 'cofferdams' with a maximum diameter of 120m. Each circular cofferdam is a dry enclosure, within which excavation and subsequent construction work can be carried out without the need for conventional temporary strutted supports. While Arup has deployed them before, the 120m-diameter reinforced concrete cofferdams are among the largest ever used and are notable for their depth of up to 18m underground. Their circular design uses hoop compression forces to provide an open underground space – like that of a barrel buried in the ground. Its effect is to allow below-ground construction work to be carried out inside and outside the cofferdams independently.

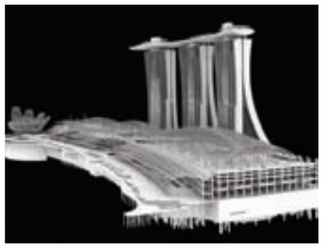
The cofferdams enabled the construction timetable to be accelerated. This also minimised the temporary support, which in turn reduced steel requirements. That this has been achieved in the soft ground conditions of Marina Bay Sands is a feat of innovative engineering design.

01

At a glance
- Scheme totals 581,400m² (floor area)
- 2,561 en suite hotel rooms
- 340m long with 65m cantilevered skypark
- Grand ballroom seating more than 6,000 diners
- 100,000m² of casino, retail and restaurant space
- Two theatres with total capacity of 4,000

02

03



01 **The three towers and Skypark from Marina Bay**

02 **Excavating one of the two 120m-wide cofferdams**

03 **CAD image of the development showing the deep pilings required to support the development**

04 **Construction progress during late 2009**

04

Raising the roof
Constructing and lifting the Skypark into place on top of the three towers was one of the project's many challenges. Arup's structural and bridge engineers devised the heavy lifting operation that is, at 200m, one of the highest strand-jacking operations ever undertaken. Other Arup specialists used dynamic studies to investigate and model how the Skypark's cantilever would behave in the face of Singapore's coastal winds, as well as the structure's response to human activity such as dancing crowds.

Well grounded

Delivering a 200m-tall development, complete with a deep basement car park and a podium structure, on a 16 hectare site of deep soft marine clay would be regarded by many as a lifetime's endeavour. Arup was given just three and a half years.

Control Towers
Frankfurt and Berlin

Client
Deutsche Flugsicherung

Location
Frankfurt/Berlin, Germany

01 **The control towers are each approximately 70m high**

02 **Inspecting the glass during production**

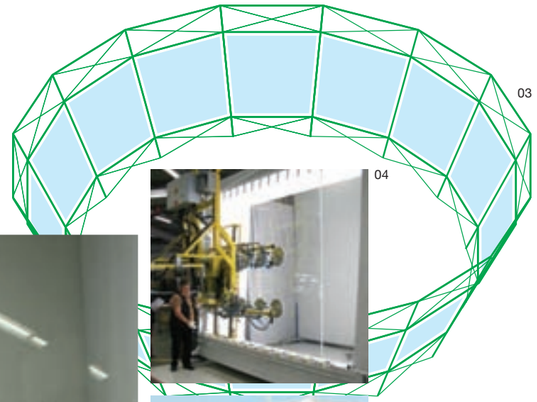
03 **The control tower is in the shape of an ellipse, so it is symmetrical but not point-symmetrical**

04 **The glass was inspected and subject to extensive testing during production**

05 **Installing glass panes at Frankfurt Airport**

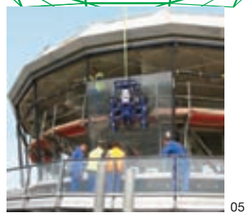
01

02



03

04



05

Strong views

Air traffic controllers at Frankfurt and Berlin airports will have better, and therefore safer, views through window glass that has been specially developed to be strong enough to be an integral part of each tower's façade, but thin enough to give a clear view of two of Germany's busiest airports.

For air traffic controllers, an unimpaired view is essential. All the technology found in a modern control tower is no substitute for being able to see the planes as they descend. Most air traffic control cabins enjoy a 360° view of the airport through floor-to-ceiling windows. But while the glass is clear, the view is often compromised by the mullions – vertical structural elements that carry the wind loads of the façade.

Working with architect Ondra & Partner, Arup wanted to find a way of using the glass as a structural element, rather than as infill. This would allow the team to reduce the width and depth of the mullions and therefore improve the air traffic controllers' view.

The team worked closely with the glass supplier to create a built-up glass strong enough to take on a structural role but not so thick as to cause production or installation problems. Annealed low iron glass was chosen for its clarity. Though tempered glass would have offered excellent structural strength, the tempering process causes little waves on the surface which would have given visual distortions. The team specified double-glazed units with panes that were laminated with a special interlayer. The panes needed to be thin enough to allow an additional high-performance solar coating, to reduce energy consumption.

Arup's façade and structural engineers were able to reduce the mullions from 300mm to just 100mm deep, and from 200mm to 80mm wide. Having done so, the next challenge was to convince Germany's building authorities to allow glass to be used in the structural bracing of a façade. The approach is not only new to Germany, but is at the cutting edge of what is technically possible, so the glass had to undergo extensive testing and its structural strength calculated precisely. The team calculated that at minimum two adjacent panes of the 16 could fail without compromising the tower's structural stability. The authorities were duly persuaded.

The panes are not standard, and require several weeks' production lead time. The two towers have the same geometry, however, being 16-corner polygons, so both airport owners will keep spare panes of glass on hand to be used in either tower in case of breakages. Such practical thinking significantly reduces the likelihood of either control tower at Germany's two busiest airports being closed for lengthy maintenance.

The Eight-Hour Bridge &
Switches and Crossings

Client
Network Rail

Location
Dumfriesshire and Wigan, UK

Against the clock

When renewal work is needed on Britain's Victorian railway infrastructure, finding innovative solutions that limit disruption to passengers and save time and money, is crucial.

01

02

01 **Holms Farm underbridge reconstructed with new precast concrete arches**

02 **Modular assembly of the eight-hour temporary bridge**

03 **Network Rail tilting wagon delivery of a pre-constructed modular switch and crossing track panel**

03

A speedy strategy that could be used to replace at least 70% of the planned underbridge renewals on the UK rail network.

A successful trial at Holms Farm, Dumfries, has the potential to revolutionise the way that redundant bridges are replaced. Instead of being a one-off solution, the trial validates a strategy developed in collaboration with Carillion and Network Rail that can be repeated with confidence on a wide variety of bridge types, spans and associated track arrangements.

It currently takes at least 54 hours to replace redundant railway underbridges. Any attempt to improve this timescale dramatically would need a radical departure from existing practice, but, the solution is deceptively simple. Arup's strategy uses a suite of modular temporary bridges that can be rapidly assembled and installed without any compromise to safety. Parametric 3D modelling was used to develop a prototype of the temporary bridge and its component parts and demonstrate its suitability for a wide range of applications.

What has become known as 'the eight-hour bridge' eliminates the need to demolish and rebuild bridges before allowing trains to operate on the line. Instead, trains are safely carried on the temporary bridge, while the existing bridge is replaced. All works that affect the operation of the line can be completed within eight-hour night-time possessions.

The strategy can deliver solutions that are safe and cost effective, help to introduce greater flexibility for programming bridge replacement works and avoid passenger disruption.

This modular approach to rail switch and crossing unit replacement halves disruption time.

When trials of a new approach to renewing switches and crossing units began in Bamfurlong, Wigan, the previous best endeavours stood at 40 hours possession time, leading to long disruption of the timetable. A modularised solution showed that a set of points can be renewed in almost half that time – just 21 hours.

Network Rail's acquisition of tilting wagons gave the platform for a new approach to renewing points. The brief was to create a modular unit design that could be constructed off-site and successfully installed by contractors.

Arup worked closely with the installation contractors to ensure that the design could be pieced together within the desired timescales, while simultaneously coping with a lack of uniformity in track width and junction design.

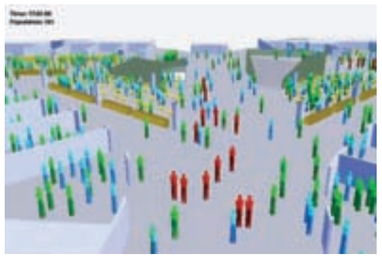
The resulting design work leads the way in keeping rail disruption time, due to renewal and maintenance, to a minimum. It delivers a solution that will help to increase train speeds and improve passenger comfort. Building the units off-site also improves their reliability and durability as they are fully constructed and tested prior to being delivered to site in modular panels.

Each of these very different projects show Arup's ability to deliver innovative solutions with as little disruption to the rail system as possible.

Terminal 5 Development, JFK International Airport

Client
JetBlue

Location
New York, NY, USA



01

02

03

01 **3D model showing passenger movement around the terminal**

02 **Retail space in the new terminal building**

03 **The generous spaces within the terminal minimise congestion**

Making it operational

JetBlue's new terminal at New York's JFK airport is the embodiment of functional design. Every part of the building is designed to meet the needs of passengers in the smoothest and most efficient way.

The lights of the old Terminal 6 building at JFK airport were switched off for the final time an hour after the last JetBlue flight of the day landed, just before midnight on October 21, 2009. There was no going back. This was crunch time for the new terminal and for the Arup team that planned every aspect of it – from the functional layout, the terminal and operational systems, to designing the transition to the new building and ensuring its all-important operational readiness.

Five hours later, the first flight of the day touched down at 06:00hrs at JetBlue's new Terminal 5 which, with 26 gates, can handle twice as many flights as the previous terminal. JetBlue crew members needed to replicate their famous efficiency in an entirely new building with new systems. During the event, all went smoothly, thanks to Arup's rigorous approach to operational training and a comprehensive simulation, with over a thousand volunteer 'passengers'.

It helped that the terminal is designed from the ground up with efficiency in mind, and has been planned to be expanded to provide extra space where needed. Arup started by analysing the needs and behaviour of different user groups. Passengers on the Florida routes – largely leisure travellers who make up 50% of JetBlue's customer base – tend to arrive three hours early. The business people who make up 20% of customers arrive with 35 minutes to spare, grab a last-minute coffee and check their emails. Families – about 30% of total passengers – often have strollers and small children in tow.

Arup built a computer model based on JetBlue's flight schedule that factored in passenger behaviours and processing time. The 3D model output shows individual passengers walking around the terminal and was invaluable in planning the building. With extra space to accommodate wheelchairs, JetBlue's elderly and disabled passengers are now better provided for. Arup also designed a security checkpoint that gives people ample space to put their belongings in a container, get through the scanners with minimal stress.

The result is a cost-effective terminal that is remarkably efficient and with every bit of space used well. It reflects JetBlue's brand message – a low-fare carrier with the highest satisfaction ratings of any airline in the US.

Fishlake – Biodiversity Action Plan Habitat Creation

Client
Environment Agency

Location
Doncaster, UK

01

02

03

01 **Wetland areas at Fishlake**

02 **Terrestrial LiDAR data model of Fishlake BAP habitat**

03 **Terrestrial LiDAR survey extent for Fishlake**

Space for biodiversity

65 hectares of land, rich in biodiversity, are being created in an Arup-designed scheme for the Humberhead levels. The scheme will restore some of the freshwater marsh habitats and diverse ecology that existed in the early 17th century – before they were drained by order of King Charles I.

The restoration of the Humberhead Levels into a Biodiversity Action Plan (BAP) habitat will create one of the largest new freshwater sites in the UK. It will also make a significant contribution to the Environment Agency's commitments to provide for wildlife while managing flood risk. Designed to cater for a wide range of diverse and ecologically important habitats, the scheme controls naturally-occurring waterflows from the River Don in a managed way.

Arup designed the scheme, oversaw construction and supported the Environment Agency in community meetings, providing a 3D graphical visualisation and video flythrough of the proposals. This helped to reassure local residents that the recreation of the marsh would not increase flood risk. This concern was particularly high in community minds, as the site is close to the community of Fishlake, which was cut off for several days during floods in 2007.

After initial investigations to understand the variations in the daily water flows at the site, Arup planned the dynamics of waterflow around the bi-monthly spring tides to deliver required inundations for the wetting-drying regime and water margin habitats.

Controlled breaches in the flood embankments allow water in at regular intervals, and a system of channels and ponds let the water out. All have been carefully designed to enable fish to return to the river as the water levels subside following an inundation.

2D hydraulic modelling was used in two ways: firstly, to demonstrate that there would be no increase in flood risk as a result of the scheme; and secondly, to confirm that the wetting-drying regimes necessary to create the marsh habitat could be delivered. Achieving the correct water levels to balance these dual requirements was vital for the scheme to work.

Each change to the landscape affects the pattern of water displacement and, due to the need to keep the spoil from the drainage system on-site, a complex cut and fill exercise had to be undertaken. Arup used its hydrology and modelling expertise to resolve this issue, identifying an opportunity to use the spoil for flood alleviation measures downstream.

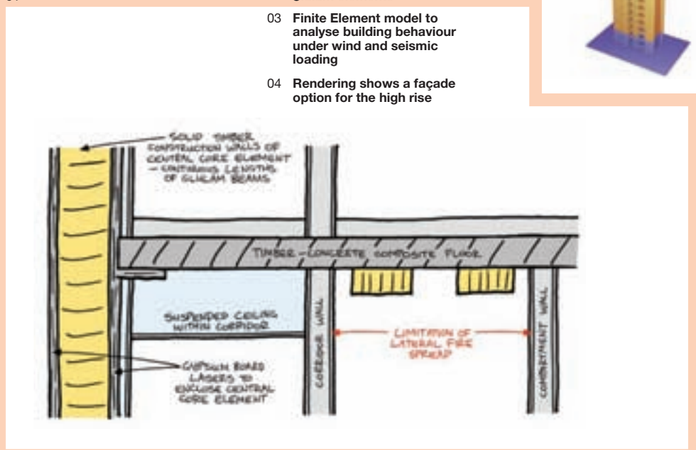
This project will help to replace habitats and ecology lost for almost 400 years, contributing to the region's green infrastructure, while managing flood-risk.

Life Cycle Tower

Client
Rhomberg Bau GmbH

Location
Austria

01



01 Fire protection of timber with timber using a fire stopping interlayer

02 Core layout – two-storey concrete base – timber core consisting of 2.4m glulam elements

03 Finite Element model to analyse building behaviour under wind and seismic loading

04 Rendering shows a façade option for the high rise

02

03

04

Timber tower

Timber is one of the most sustainable materials available, yet its use for anything more than low-rise structures in Europe has been prohibited by building regulations. But when Austria recently relaxed its building codes, Arup designed the Life Cycle Tower, a prototype timber high-rise that – in the event of fire – will safely protect the structure and its occupants.

Imagine a high-rise that has a carbon footprint of just 10% of what it would normally be. It is built from timber, a highly sustainable material, is inexpensive and quick to build. Yet historically, even with these advantages, timber high-rise buildings have not been allowed under European building codes because of their perceived vulnerability to fire.

The result of such conservatism has been a dearth of timber buildings of any height in Europe and consequently there is a limited understanding of their performance. Now, building codes in Austria have been changed to allow timber high-rise buildings, as long as they can be shown to be as safe as conventional buildings. Other European countries have also adapted their codes to give designers more freedom to use timber.

When Arup's structural and fire engineers, together with Austrian architects Herrmann Kaufmann, developer Rhomberg Bau and contractor Wiehag worked on the Life Cycle Tower, they were designing with structural performance in mind. The building had to perform at least as well as conventional buildings in the case of fire. The team started by understanding timber and how it behaves, which led to the idea of using the timber itself as fire protection. Obviously timber burns when exposed to fire and will continue to burn as long as there is oxygen available. As it burns, however, it is transformed into charcoal, an excellent insulator, which protects the remaining timber from the heat.

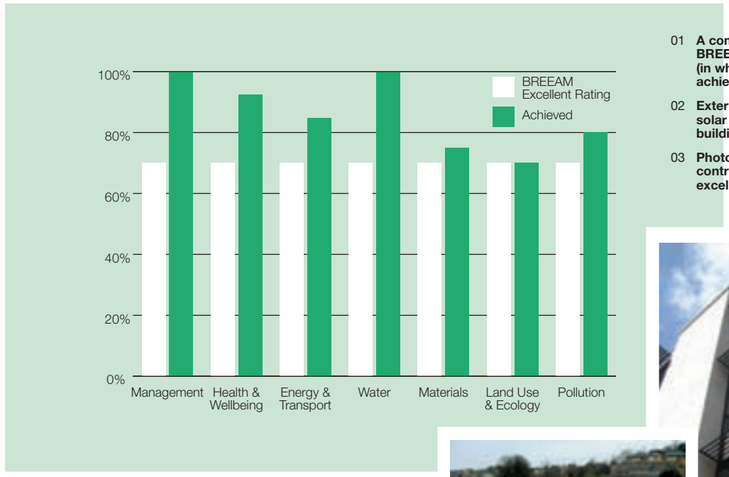
Arup designed a sacrificial layer of timber, behind which the load-bearing timber core of the building remains safe. The structural core of the tower is glulam, which is created from strips of wood that are glued together to form long, strong and stable vertical beams – of which about 10 are fixed together to form a panel. The glulam panels are joined together at each end via steel plates which allow the horizontal movement that may arise from the wood moving or shrinking. On top of the glulam is an interlayer of fire-resistant glass fibre mesh, which is laminated with epoxy glue for further fire resistance. The 63mm deep sacrificial layer on top is designed to withstand the 90 minutes of fire required by safety codes. As this layer is carbonised, it ceases to burn and protects the underlying material from the fire, maintaining the tower's stability while its occupants are evacuated and the fire is extinguished.

Horizon House

Client
Westmark Development

Location
Bristol, UK

01



01 A comparison between the BREEAM excellent threshold (in white) and that actually achieved (in green)

02 External shading minimises solar gain and keeps the building cool in summer

03 Photovoltaic panels contribute to the building's excellent energy efficiency

02

03

Green determination

With the Environment Agency as the ultimate occupier, Arup, the developer, the contractor, and his design team ensured that Horizon House in Bristol achieved an exceptional score under the BREEAM rating system. The result is the UK's highest-rated office building to date, with an unprecedented environmental score of 85.06%.

When the UK's environmental regulator assesses a building, it awards credits over a range of categories such as carbon emissions, transport, water conservation and re-use of materials. The threshold for the highly coveted excellent rating is 70%. It is relatively easy to achieve the early points, but they become progressively harder (and more costly) to achieve as you go up the scale.

Most designers and developers aspiring to a high BREEAM score therefore focus their energies on the easy wins up to the 70% 'excellent' threshold. Working with its committed client however, Arup set the strategic direction of the design early on: to aim high, maximise the building's performance in every category and avoid a 'tickbox' approach. For example, a biomass boiler is a fashionable and relatively low-cost means of winning credits, but it was ruled out, primarily because of the need for constant deliveries of fuel from outside the city, which was not considered sustainable.

Horizon House benefited from having a highly determined client. In an unusual move, the Environment Agency and, subsequently, the developer introduced a tapering financial penalty to all those involved in the project to provide an 'incentive' to achieve the agreed BREEAM credits. This galvanised all parties to aim high, particularly the contractors, who developed a much more focused approach to site management. The contractors agreed to monitor the carbon, energy and water impact of the construction site and committed to using timber certified under ISO guidelines. They also recorded deliveries and where they were from, and tracked recycling rates and the destination of demolition and site waste. Arup specified that when the former building on the site was demolished concrete from its superstructure was to be crushed and graded, and used again in the new building sub-base.

The design did particularly well against other excellent rated buildings in the tricky category of land use and ecology, and for its contribution to the wellbeing of occupants; they will enjoy a large open office, with mixed mode ventilation, external views and a sophisticated lighting control system, which provides both presence detection and daylight linked dimming.

The team credits its success to developing a strategic approach from the outset along with the commitment of the contractors and wider team. The building is a local landmark for the city and proof that, given enough determination, the UK's commercial real estate sector can become more sustainable.

Rossington All Saints School

Client
Church of England, Diocese of Sheffield

Location
Doncaster, UK

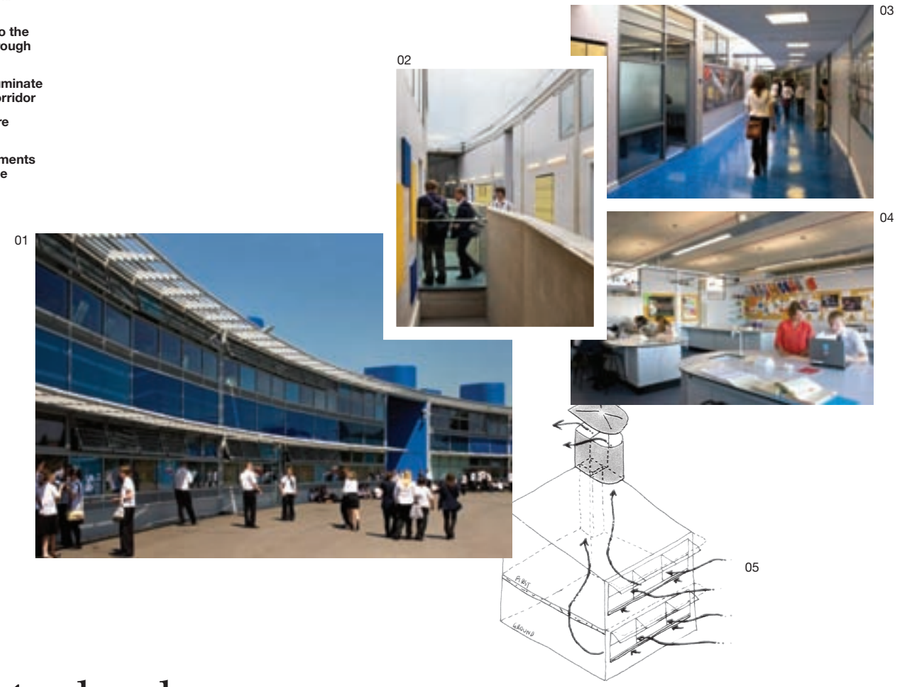
01 **External shading helps keep the classrooms cool in summer**

02 **Daylight comes into the upper corridors through a polymer roof**

03 **Light wells help illuminate the ground floor corridor**

04 **New classrooms are bright and airy**

05 **Passive design elements help maintain stable temperatures**



A bright school

Rossington All Saints School in South Yorkshire is a model for sustainability on a budget. With natural ventilation streaming into the classrooms and the entire building bathed in light, this new school shows its students how choosing an environmental approach can help them to learn.

The new design for the school was always going to be a challenge. Budget constraints meant that the building had to be affordable to both build and run, but Arup showed that this need not limit the desire for creating a supportive and sustainable environment for learning.

Central to achieving this was the elimination of mechanical cooling from basic teaching classrooms. Not only is air-conditioning costly to run, but artificially-sealed air-conditioning units are widely considered to hamper concentration in the classroom.

Exposed concrete ceilings provided enough thermal mass to make natural ventilation a viable option, and great care in the specification and execution of the concrete works ensures they are an attractive feature within the school.

Air circulation is further improved by the strategic placement of chimneys throughout the building, creating a natural through-flow of air from the inlet louvers integrated into the façade, detailed to minimise cold draft and acoustic problems. External shading on the outside of the building also helps to keep the classrooms cool in the summer by minimising solar gain, resulting in a comfortable space for lessons to take place.

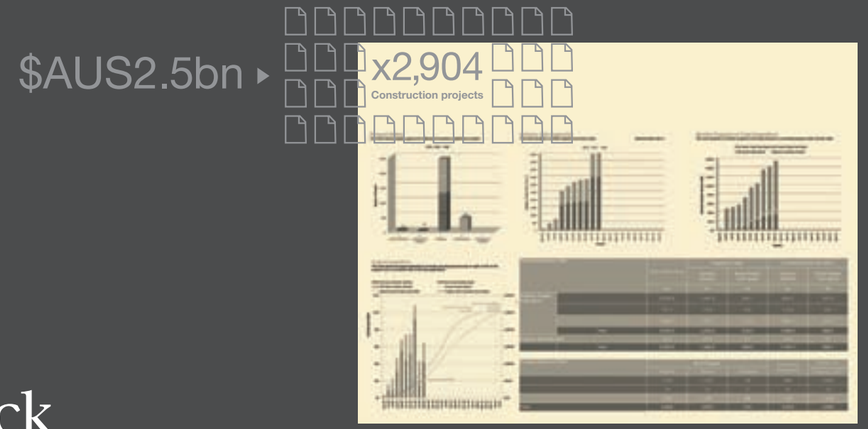
Daylight pours into the school's corridors through a polymer roof, and double-storey light wells placed at regular intervals along the corridors help to capitalise on natural lighting at ground level.

Finally, a central meeting area provides a place for the whole school to assemble, something that staff felt was crucial and which had been lacking in the previous school building. The classrooms feed off this central space – a layout that helps promote circulation of both people and air, and enhances the use of natural daylighting throughout the building. In this way, the architect's innovative layout and the passive building service elements work closely together to create a better learning environment, and a school that teaches green design by example.

Building the Education Revolution

Client
Department of Education and Early Childhood Development

Location
Victoria, Australia



Fast-track value

With the Federal Government's economic stimulus package for Victoria putting nearly AUS$2.5bn into nearly 3,000 Government education projects between June 2009 and March 2011, a new approach to programme delivery was needed. The task of keeping this complex and massive programme on schedule fell to Arup, who rose to the challenge of keeping focused on quality as much as quantity.

Arup's long experience of working on capital expenditure projects has stood the firm in good stead for managing the delivery of the Federal Government's Economic Stimulus Plan (ESP) in Victoria. Keeping the Building the Education Revolution (BER) programme on track – with construction projects across primary and secondary schools throughout the state – meant Arup working closely with the Department of Education and Early Childhood Development.

A new programme management delivery framework was designed using methodologies developed for the UK Government to manage major projects.

A core element of Arup's framework was a Programme Management Office (PMO) providing a centre of excellence for financial management, reporting and design template expertise. With such a high-profile project, the need for extensive reporting is essential, so a bespoke database system, PRiSM, was developed to track project status, finance and programming of all 2,904 projects.

The Arup team took on the task of managing not just delivery of the challenging programme, but also ensuring that quality would not be compromised by the extremely tight timescales.

The Arup team did this by encouraging the use of design templates across all of the projects. Templates offered quality and flexibility and have enabled the construction of world-class education facilities.

The unrelenting pace of the programme demanded a new approach to the procurement process. The key to success was the ability to get projects started as quickly as possible. From initial commission in April 2009, the team delivered contract awards for 240 competitively-tendered projects valued at AUS$450m by the end of June 2009. This was an unprecedented achievement for the Victoria construction industry.

From the outset, Arup worked closely with the client and government lawyers to ensure that the procurement process was as streamlined as possible while meeting all of the State and Federal Government's probity requirements. By adopting a pragmatic and standardised approach, the team was able to progress through the detailed design, tender and award stages of literally hundreds of projects within a matter of weeks.

The result is a flexible approach that has proved vital to the Australian construction industry during the recent economic downturn and will provide a lasting educational legacy for the State of Victoria.

Integrated Development Plan for Ninh Thuan Province

Client
Ninh Thuan Planning and Investment Department

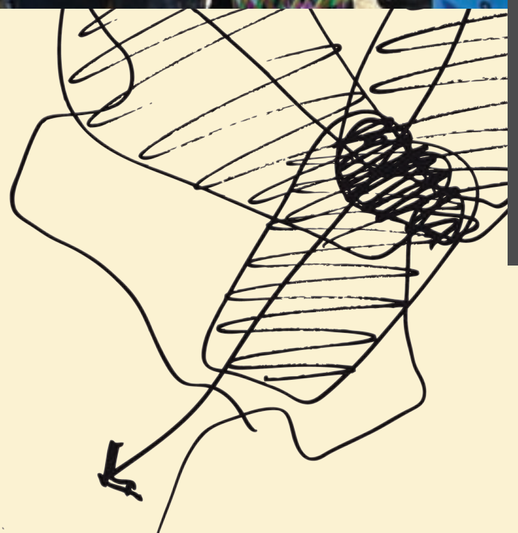
Location
Ninh Thuan, Vietnam

01

02

Finely balanced

A new vision for a sustainable future has been created for one of Vietnam's poorest areas, Ninh Thuan province. As a demonstrator project, the integrated development plan that balances social, economic and environmental factors can be replicated in other parts of the country.



The development plan creates a catalyst for socioeconomic growth by:

- Linking industrial activities and manufacturing with clean and renewable energy generation
- Enabling Ninh Thuan to be an attractive destination for tourism and eco-tourism.
- Improving urban-rural connections and preserving high-value agricultural land and forest preservation zones
- Educating and training the future workforce, improving access to education
- Cultivating and promoting a distinct identity for Ninh Thuan by leveraging its main commodities and resources

01 **Arup's strategic plan aims to improve the quality of life for local people**

02 **The integrated spatial development plan for Ninh Thuan province**

Ninh Thuan province lies in the south-eastern region of Vietnam. Historically one of the country's poorest areas, it covers a vast and varied terrain, with over 3,000km^2 of mountainous forests, agricultural land and beautiful coastline.

The area faces many challenges, not least its vulnerability to extreme weather events, such as typhoons, which frequently hit the Mekong Delta region, and such instances are likely to be exacerbated in the future due to climate change. Ninh Thuan is currently experiencing substantial growth, which, though positive, will put increasing pressure on finite resources.

To capitalise on the growth and to ensure future investment, Arup was commissioned as planning and urban design consultant on a strategic development plan for the province, working with the business strategy advisory firm Monitor Company Group.

The approach to the development plan combined aspirational objectives for the province with key performance indicators and high-level targets. Throughout, the main principle was to achieve

This was the first time a Vietnamese provincial government had chosen international consultants to develop a strategic plan for an entire province. The resulting integrated development plan creates a sustainable vision for the long-term development of the area.

economic and social growth in the region, while balancing environmental considerations and ensuring continued access to key resources such as water, energy and land. In order to make the detailed technical information accessible, Arup organised the development plan into five distinct networks – economic integration, quality of life and infrastructure, ecosystems and heritage, clean energy and climate change resilience – which together aim to achieve the overall objectives.

By structuring the plan into these networks, each of which explored both spatial and operational issues, the Arup team ensured that the sustainability principles underlying the plan were effectively communicated, achieving buy-in from the government and the community, and supporting the delivery process.

A hierarchical approach to implementation means low-cost, simple strategies can be done first, so communities can start to benefit from the changes as early as possible, without the need for huge up-front investment.

Given the long-term nature of the proposed development, which runs until 2030, the process is designed to be iterative, allowing for flexibility as circumstances change and new technologies become available.

Ninh Thuan's natural assets mean the province has the potential for economic development and job creation in a wide range of areas, including aquaculture, tourism and the intensification of industries such as salt production, granite processing, mineral water production and agriculture-forestry product processing.

To create a unique identity for the province, the proposed strategy positions it as a centre of excellence for energy production and innovation in Vietnam, with particular emphasis on waste-to-energy, or closed loop systems. Year-round sun and wind make the area ideal for the development of clean energy industries such as wind and solar power. Ninh Thuan's selection as the site of Vietnam's first nuclear power plant gives further opportunity to benefit from its resources and create a dynamic economy.

Ninh Thuan's path towards sustainable living and quality of life is made up of two main strands: sustainable urbanisation and an integrated infrastructure plan. A sensitive approach to development will preserve as much of the existing fabric of the province as possible, minimising the need for relocation of villages, and helping to protect and strengthen existing rural communities, integrating them into the future economy.

An urban village is to be created in the provincial capital of Phan Rang-Thap Cham to safeguard the Cham heritage villages, which are a unique part of the province's culture. Conservation of forest land and marine ecosystems, and enhanced access to these assets will be invaluable, particularly for eco-tourism, a future economic cluster for the area.

03

04

05

03 **Bicycles are a common form of transport in rural Vietnam**

04 **Dense urban village, while creating an intense community identity, pose a challenge for future upgrades to the urban fabric and infrastructure**

05 **Visitors to the villages are a rare attraction as yet**

Optimised Network Systems

The Integrated Development Plan aims to create a holistic development framework. The five optimised networks work towards the central goals of promoting resource efficiency, achieving a low carbon economy, and enabling reinvestment of resources. The result will be quality of life for residents, a positive working environment, and an attractive and desirable place for people to live.

DUSEL

Client
National Science Foundation (NSF),
University of California, Berkeley, South
Dakota School of Mines and Technology
and Lawrence Berkeley National Laboratory

Location
Lead, SD, USA

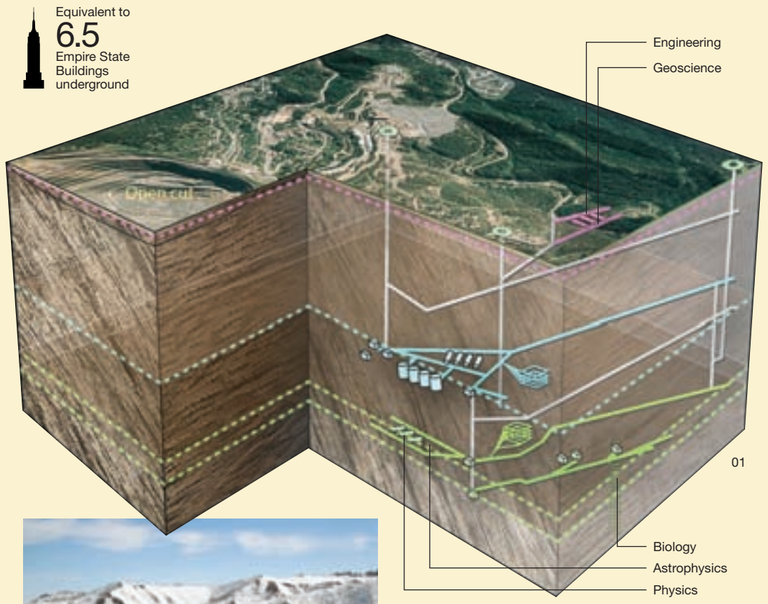
Design in deep

Converting a former mine into a deep underground scientific research laboratory is a uniquely challenging project. Such extreme engineering is utilising every ounce of Arup's creativity and flexibility.

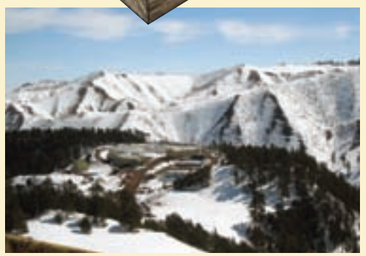
Homestake Mine, in the frontier town of Lead, South Dakota, was the largest, deepest and most famous goldmine in America. Its depths have yielded more than US$1bn worth of gold and its closure in 2002, after more than 125 years of operation, marked the end of an era. Its second incarnation, as America's Deep Underground Science and Engineering Laboratory (DUSEL), will yield greater treasures still. Its scientists will be exploring and expanding the frontiers of science.

Homestake Mine was considered alongside multiple other bids in a Federal Government competition to secure the US$750m DUSEL project. Although not part of the original bid team, Arup became involved thanks to its breadth of expertise, and was awarded two of the four preliminary design contracts for the project. This includes the underground infrastructure and underground laboratory design, as well as the associated construction costing, scheduling and risk assessment services. Currently in the preliminary design stage, construction is set to begin in 2014. Arup's team includes diverse engineering discipline specialists to deal with the unique challenges of this huge project.

DUSEL will provide office and laboratory space for scientists to investigate astrophysics, dark matter, particle and nuclear physics, geology, hydrogeology, geo-engineering, biology, and biochemistry.



01



02

01 **Conceptual design cut away diagram shows underground campuses**

02 **Homestake Mine water treatment facility**

03 **Miners and scientists in Homestake's underground tunnels**

04 **The headframe building contains the original vertical conveyance**

05 **Open cut mine at Homestake**

03

The tunnels, shafts, boreholes and waterflow patterns in the area will allow scientists to study the dynamics of the earth's crust, carbon sequestration and rock mechanics over long time periods. The dedicated access and the diverse geology at Homestake are well suited for studies of microbiology and life at extreme depth. The campus's two levels are 1,480m deep and 2,255m deep respectively. Between them, they provide scientists with the ideal environment for experiments, devoid of background noise and shielded from cosmic rays. The more strategic, and larger, experiments are focused on studying neutrinos and their interaction with other sub-atomic and dark matter, and the search for the elusive Higgs boson particle.

The very qualities that make this deep underground location ideal for scientists, however, make it extremely difficult to engineer. The scale of the endeavour, too, complicates matters; everything, from dealing with piped liquids at great depth, to understanding underground ventilation and microclimates, must be approached from base engineering principles. The original Homestake Mine's working environment was typically 2m high and 1.5m wide, reaching the gold ore deposits. For DUSEL, alongside SRK, Golder and HDR, Arup is part of the integrated team designing cathedral-sized caverns, infrastructure and laboratory campuses to hold large tanks for water, cryogenic liquids and other chemicals. For a project of this magnitude, a traditional approach to design engineering simply will not work.

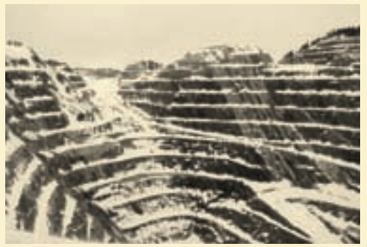
Consider New York's Empire State Building. If six and a half such buildings were stacked on top of each other, the pinnacle would be the same distance above the surface as DUSEL's deep campus is below it. Each aspect of designing underground infrastructure is complicated by its distance from the surface. Rock pressure is higher at greater depth but, unlike water pressure, it is not homogeneous, because the rock itself is not uniform. Temperatures at the bottom of the mine are 30-40ºC higher than at the surface. Elements such as cryogenic liquids must be kept cold or they risk volatilising so fast as to push the air – and therefore oxygen – out of the mine faster than occupants can be evacuated.

Arup's fire and life-safety strategy for the underground campus is a case in point. No US fire code exists for underground facilities at such depths. The US mining codes focus on short-term stability and safety – just long enough for minerals to be extracted and for miners to abandon the mine. By contrast, scientists at DUSEL will work underground in conditions that are very different from life above ground and for which they have no special preparation, unlike astronauts or submariners, who are trained to live and work in abnormal conditions. Arup's behavioural psychologists, too, have therefore contributed to some of the concept design principles.

04

Unlike a tall building, which is designed to allow a fast, mass evacuation in case of emergency, DUSEL's design ensures that its scientists avoid the elevators (called hoists in the mining industry) at the main shafts and retire instead to underground refuge areas. They can stay there for several days if necessary, while they wait to be rescued. The team has minimised evacuation time by factoring-in walking distances and even the number of doors to the shelters, which in some cases double as everyday communal break rooms, offices and conference centres, making them familiar in an emergency.

Some refuge areas are sized to accommodate as few as five people and others more than 240 people near the main shafts. The chambers are electronically interlinked, allowing people to communicate both with each other and with the surface.



05

While life safety is paramount, Arup is also focusing on continuity of services. Many of DUSEL's experiments will be immense in scale and value. A power failure in the middle of a nine-month experiment would be disastrous. Many of the underground experiments will generate data, which must be captured and processed, necessitating data centres on the surface. The services between the campus and the surface include robust electrical, mechanical, plumbing and IT utilities, as well as exhaust systems, lighting systems and oxygen supplies to refuge areas during emergencies. As if this were not enough, that part of the campus which is below the water table must be pumped constantly to keep dry.

Arup is extending its own engineering knowledge and is helping to give scientists the room to push boundaries. At DUSEL, they will be able to investigate some of the biggest mysteries of our universe – the nature of the neutrino; the origin of the elements; identification of the dark matter that makes up five times the mass of the universe compared to normal matter; the dominance of matter over anti-matter; exotic forms of life in the underground; and understanding the processes in the earth's crust. When DUSEL is built it will be a testament to the determination and creativity of all those involved in the project.

Client
C40

Location
Global

C40 is a group of 40 of the world's largest cities committed to tackling climate change.

The C40 cities share a combined GDP of US$8,800bn and represent over 300 million citizens.

Arup is a strategic expert adviser to the C40 group for a period of two years.

C40: Practical solutions for cities

A series of 'UrbanLife' workshops is helping cities around the world to find local solutions to global issues.

As strategic expert adviser to the C40 group of Mayors, Arup is helping some of the world's largest cities to become more energy efficient and address the challenges of climate change. By taking a multidisciplinary approach and fusing the practical with the political, Arup is supporting city mayors and other government stakeholders in delivering robust, realistic solutions specific to particular cities' needs and problems.

Its combination of design and technical know-how with an understanding of policy and politics takes Arup beyond the role of a traditional consultant. A deep knowledge of the engineering and infrastructure implications of policy objectives enables consistent advice from policy to delivery.

The workshops are a collaborative process between Arup and the city. Each one is the culmination of several months of research and site visits by Arup during which knowledge transfer works both ways. The workshop then brings together a wide group of participants – from government, non-governmental organisations and the private sector – and fuses Arup's global expertise with best practice in individual cities. Arup believes that taking an integrated approach to addressing city-scale problems – for example, involving energy and transport officials in a discussion about waste management – is the only way to deliver solutions that are sustainable in the long-term.

Toronto, Canada
Mayor Miller, while chairing the C40, has made Toronto one of the world's leading cities in tackling climate change. Yet, despite an electricity grid that is rich in renewable energy, high levels of energy consumption still leave the people of Toronto with a higher than average carbon footprint.

This C40 UrbanLife workshop focused on the challenges of translating the Mayor's energy and climate change targets into action at a neighbourhood level, using a real community as a case study. Alongside the technical considerations inherent in retrofitting buildings and creating community energy systems, the project also considered the bureaucratic challenges of delivering far-reaching programmes that cut across the traditional departmental boundaries of city government.

Melbourne, Australia
Given Australia's reliance on coal for the majority of its power needs, it is almost inevitable that the country is responsible for some of the largest per-capita carbon emissions in the world. Patterns of consumption in Melbourne, where there is high car and home appliance usage, inflate this further.

Beginning with the principle that people make bad decisions because of poor information, the focus of the C40 UrbanLife project in Melbourne was to explore how the city could use information technology to encourage its citizens to change their behaviour and enable city managers to better understand the impact of their climate policies and to manage services more efficiently.

From energy meters to smart travel cards and artistic public visualisations, the workshop considered the many different elements that could be used to create an 'Information Architecture' for Melbourne.

São Paulo, Brazil
São Paulo, Brazil's largest city, has one of the lowest carbon footprints of any city in the C40. But its ambition to be carbon neutral by 2020 is being put under significant pressure from an ever-increasing population and economic growth.

For the city's administration, achieving carbon neutrality means moving to a new economic development model. Their goal is to use renewable resources more efficiently and to deliver improved quality of life rather than following the 20th century western model of measuring success in terms of consumption growth. Arup's C40 workshop explored how a new approach to waste management could create a renewable energy resource, reduced healthrisk and creating new economic opportunities in the 'favela' areas of the city.

Ho Chi Minh City, Vietnam
The rapidly growing Vietnamese city of Ho Chi Minh ranks in the World Bank's top ten cities most vulnerable to the effects of climate change. The UrbanLife project here focussed on how to marry the city's rapid development with greater resilience to the threats of flooding and potable water shortages.

From new land-use policies that would create natural flood defences, to hi-tech underground water storage facilities, the workshop considered an integrated programme of new infrastructure, based on Arup's practical knowledge of international best practice.

Addis Ababa, Ethiopia
Addis Ababa, the self-styled 'political capital of Africa', is a dynamic, forward-looking city that hosts the headquarters of both the African Union and the United Nations Economic Commission for Africa. The city's built infrastructure has improved significantly over the last decade, with massive new housing and road building programmes, and a raft of new schools, hospitals and clinics.

Mayor Demeksa wants to ensure that this growth is sustainable. Arup will be helping build capacity in the city administration to create a low-carbon development framework across waste, water, transport, energy and agriculture.

Europe
At the time of going to press, it had yet to be agreed which European city would join the C40 UrbanLife programme.

Springvale Road and Rail Grade Separation Project

Client
VicRoads

Location
Victoria, Australia

Fast, safe and reliable

When it came to helping the Governments of Australia and Victoria create a safer and more reliable rail network, Springvale Road level crossing was the first project to be tackled. By locating the station outside of the operating rail corridor, the design team was able to significantly reduce disruption and minimise on-site construction – saving precious time and money.

The Springvale Road and Rail Grade Separation Project is a major step forward for the Victoria State Government's AUS$38bn Transport Plan. As it is one of Melbourne's busiest level crossings – with more than 50,000 cars, 218 trains and 5,000 pedestrians using the same space every day – the design challenge was considerable. However, by locating the new station outside of the rail operating corridor, the station and rail shutdown was reduced from 35 to 10 days. Also, by carefully studying traffic flows and assessing multiple options, the team was able to reduce the Springvale Road disruption from 12 weeks of temporary lane closures to a planned 10 day road closure. It was actually achieved with five days of 24 hour round-the-clock construction. The end result is safer and more reliable travel for train passengers, drivers and pedestrians.

This AUS$140m project was designed and built in just seven months by the Springvale Road Rail Alliance (SRRA) including VicRoads, John Holland,

01

02

03

04

Arup, KBR Pty Ltd, the Department of Transport, previous rail operator Connex and Metro Trains Melbourne (MTM) the current rail operator. The proactive way in which the alliance operated throughout and it's work methods was key to the project's success – the work methods were highly integrated, creative and innovative.

From the beginning, an alternative but compliant design was proposed. It showed how a different approach would save significant time and money, while meeting the demanding timescales and reducing disruption to commuters and local residents.

The station design was broken down into component pieces which could be installed without large cranes, avoiding the need for numerous rail shutdowns. The alternate platform configuration also provided an innovative solution: the improved operational design was for a central platform as opposed to a central track with side platforms. This, too, was built off-site, saving much time and money. By prefabricating almost 80% of the station buildings, major civil works could continue in parallel with construction, again significantly reducing disruption and closures.

To reduce road disruption from 12 weeks to just five days, the team used 4D modelling to fully visualise and analyse the works. This helped to optimise the construction sequence and enabled the team to show how a full closure of Springvale Road would be better than a lengthier period of lane closures. It also assisted VicRoads in assessing and confirming the full-closure approach as the better option. The Alliance attained the VicRoads Division Award for the September closure of Springvale Road and its innovative approach to transport planning.

05

The Alliance was also influential in communicating with the project's stakeholders, including local communities that would be affected by these works but ultimately benefit from them. The community was proactively engaged throughout the project with regular mail drops, local news media, on-site information boards, a dedicated project website, community information displays and face-to-face meetings. Other activities included a charity auction to thank the Nunawading community for their support and patience throughout the project, with all proceeds going to a local charity, the Reach Out for Kids Foundation.

The project successfully improved road and rail safety, reducing congestion and providing more reliable travel times for all. As John Brumby, Premier of Victoria, said at the official opening of the station: "the project has been delivered on time and on budget and sets the benchmark for future projects."

01 **Safer access to the station for passengers**

02 **The station concourse**

03 **Faster and more reliable train travel**

04 **Space for pedestrians and passengers**

05 **Greater urban integration**

Pedra Branca
Sustainable Urbanism

Client
Pedra Branca Empreendimentos Imobiliarios SA

Location
Florianópolis, Brazil

Too good to waste

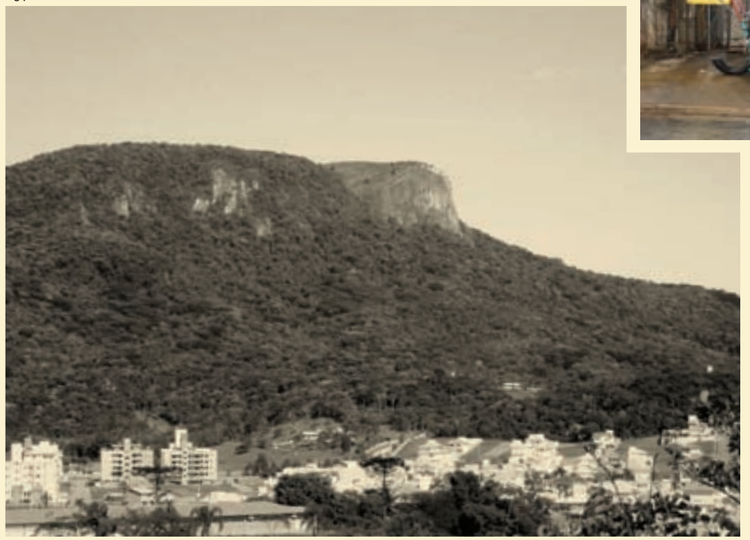
Residents of this new downtown development won't be the only beneficiaries of the sustainable infrastructure strategies as it is envisaged to also improve the lives of people living in a nearby favela. And as one of 16 cities sponsored by the Clinton Foundation, these low-carbon strategies are likely to be echoed in the planning of future cities elsewhere.

01 **Pedra Branca sits at the bottom of White Rock**

02 **Brazil's litter pickers, the catadores, are well equipped and an integral part of favela life**

03 **Pedra Branca unit interface and smart panel**

01



02

When Pedra Branca heard a presentation from one of Arup's climate change experts, it realised that its mixed use development 18km west of Florianópolis, the picturesque island capital of Santa Catarina, was missing a trick. It asked Arup to develop low-carbon conceptual infrastructure strategies on water, energy, internal transport and ICT and to devise a sustainable solid waste and wastewater management plan.

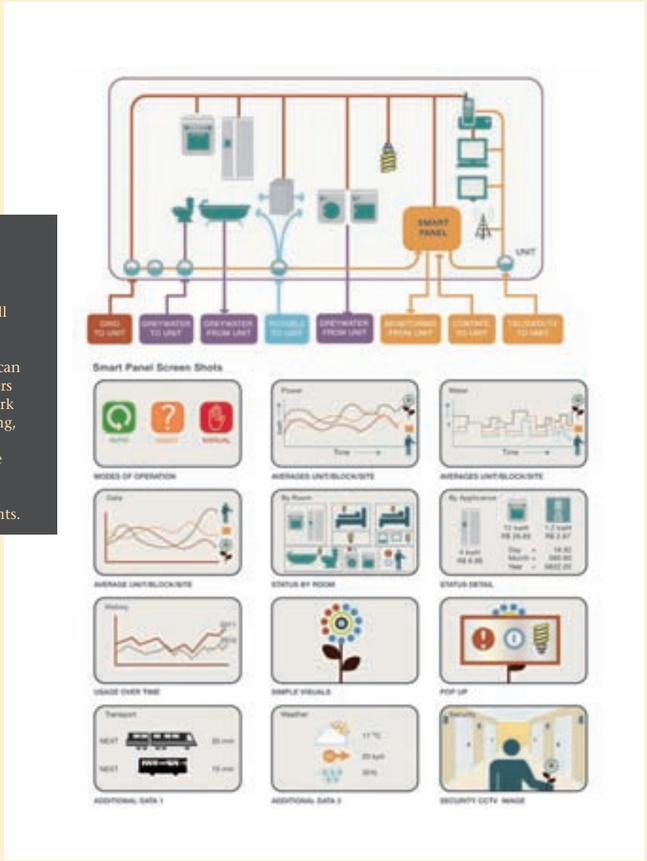
Pedra Branca is a local firm which has a good relationship with the local waste management company, but clear opportunities were being missed, such as using waste to generate energy for the development. With Arup's help, Pedra Branca started to think bigger, factoring in the waste from the neighbouring favela and approaching suppliers to identify available local technology. It started to come up with some more ambitious – and more sustainable – ideas. Bigger waste management systems could deliver economies of scale, while the by-products could be used to create energy locally.

These new approaches also raised new challenges. The favela is the same size as the new Downtown, but is less densely developed. Most of its waste is organic and is simply dumped in the neighbouring streets. In Brazil, as in many other countries, the waste industry provides low-paid employment for many people. Its catadores – litter pickers who may work individually or collectively – depend on waste to make a living and support their families, picking over dry recyclable waste for items to sell for a few centavos. They form an integral – if informal – part of Brazil's recycling effort. Only 2% of waste is selectively collected by local authorities, yet, in 2006, 77% of Brazil's used cardboard and 96% of alumninium cans were recycled.

Climate+
Pedra Branca is one of 16 global projects to be selected as part of the Climate+ programme from former US President Bill Clinton's Clinton Foundation. Climate+ supports the development of large-scale urban projects, demonstrating that cities can grow in a climate-positive way. Developers and local government have agreed to work together on clean energy, outdoor lighting, transportation and water management. The project receives no funding from the Clinton Foundation, but the link means that good practice in Pedra Branca will influence other global urban developments.

Consequently, any new waste management system could have a high social cost, especially if it means local people have to look further away to work, or are put out of work entirely. So the options outlined in Arup's waste strategy include relatively labour-intensive collection and sorting of waste that is destined to be sold as recyclables. Instead of residents sorting their own rubbish, a cleaning crew will pick up daily waste and transport it to a recycling room in each building. It is fed into a gravity chute system to the basement, where it is sorted manually. From the basement, the larger wheelie bins are transferred to a lift system, taken to pavement level and transported by truck to the on-site waste management facility. Here, recyclables are compacted down and bulked into bales, which are sold to a third party. Organic waste would join sludge from the area's existing wastewater treatment plant to be treated by a technologically-advanced anaerobic digester. This waste would be transformed into energy to sell back to the grid.

03



The team looked at a local supplier of treatment solutions for pig waste, whose anaerobic digestion processes could be used on the site. Arup also brought new ideas from elsewhere, such as community-based management models from India, to help developers work with community groups, and set up a commercial organisation to manage waste on the community's behalf and sell recyclables on the open market.

In this Brazilian development, the ultimate goal is to send no more than 5-10% of residual waste to landfill. When you compare this with London's 50%, Los Angeles' 34% and even trailblazing San Francisco's 27%, this is quite an achievement. With no intention of resting on its laurels, the developer wants Arup to help it to tackle greenhouse gas emissions next.

Climate Change Resilience for Water Infrastructure

Client
Asian Development Bank

Location
Wuhan, China

Water futures

A new 'guidebook' from Arup – with a methodology for assessing a city's vulnerability to climate change – is helping Wuhan in China prepare its water infrastructure for the future.

Known as the 'thoroughfare of nine provinces', Wuhan sits right at the centre of China, where the Yangtze and Han Rivers mingle. A rail, road and river traffic hub, it was created by consolidating the three riverside towns of Wuchang (providing the 'Wu'), Hankou and Hanyang (the 'han'). The three former cities face each other across the rivers and are interlinked by bridges.

Landlocked Wuhan does not have the water scarcity issues of some northern Chinese cities. Its strong riverfront identity and ever-growing and affluent population mean that the water impacts of climate change will be keenly felt however. In 2008, for example, snowstorms resulted in the city's water pipes bursting, leaving severe damage and the population without water for days. The city's infrastructure must meet the demands of its industry and increasing population.

The Asian Development Bank (ADB) commissioned Arup to produce a guide to how the city could adapt its water infrastructure to anticipate climate change. The ADB has been investing in Wuhan for nearly a decade, and has seen some impressive changes. In 2004, Wuhan was only able to treat 27% of its wastewater, a figure that has risen to 80% in 2010. As one of China's rising second tier cities and leader in central China, Wuhan is an ideal blueprint for a national study on adapting water infrastructure for climate change.

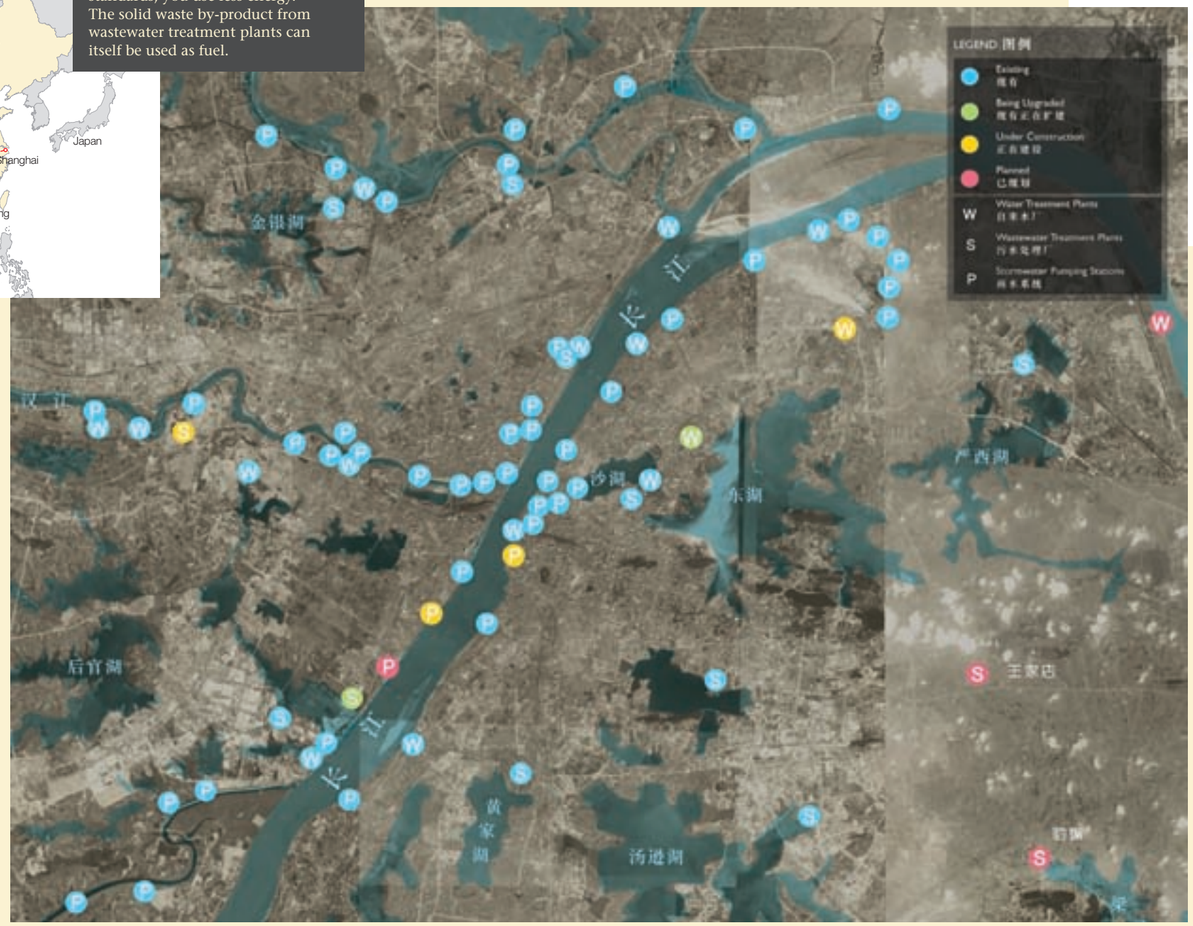
01

Arup began by getting to know the city and developing an in-depth understanding of local conditions. The city has been dealing with water-related problems for some time and had already developed a range of innovative responses. An intense programme of visits and interviews helped the team identify key issues and to develop an insight into the city's water infrastructure.

From this, a methodology was developed to assess the city's ability to combat climate change in four areas: government, water infrastructure, environment and the economy. Each area was assigned a level of vulnerability according to the city's existing state of readiness as well as its future plans. This might mean, for example, that the city is ready for a 'normal' winter, with its current population, but may not cope so well with increasingly severe winters or with a significant increase in population. The team also rated the specific climate change impacts for Wuhan in terms of frequency and severity.

By combining the vulnerability analysis with its climate change impact assessments, Arup was able to make specific water infrastructure recommendations, scaled according to cost and time needed for implementation. Alongside each recommendation, the team provided information about how such initiatives had been achieved elsewhere.

Water + energy
Arup's integrated approach paid off given the inherent relationship between energy and water. It takes lots of energy to treat water, so if you have better wastewater standards, you use less energy. The solid waste by-product from wastewater treatment plants can itself be used as fuel.



02

01 **Wuhan is a transportation hub located where the Yangtze and Hanshui rivers merge**

02 **Distribution of urban water infrastructure in Wuhan**

03 **Stakeholders in Wuhan's water infrastructure**

03

Arup's recommendations focused on two areas. The 'hard' infrastructure such as water capture and storage, flood control management and buildings was one aspect. The other area was 'soft' infrastructure, encompassing education, risk assessment and building the capacity to deal with future climate change.

The city's vulnerability to climate change can be reduced with improved strategies. Arup's methodology enabled the team to target its recommendations at those aspects that Wuhan could do something about. The team balanced less costly, long-term measures, such as education, against more expensive 'quick wins' like building a dyke to prevent flooding. For this, Arup came up with a matrix to help the city to manage and learn about risk.

Arup's early stakeholder engagement and site visits meant that it had started to build a relationship with the city and developed an excellent understanding of the local issues. The firm's global experience was also invaluable locally, providing best practice case studies to support its recommendations.

The report was not a standard one, but instead took the form of a 'guidebook', which set out clearly the recommended strategy, its benefits, how other cities have achieved it, and how Wuhan could follow suit. It introduced some complex engineering recommendations and high-level strategic policy recommendations in a user-friendly and accessible way.

15% Reduction in Carbon From Construction Processes by 2012

Client
Strategic Forum for Construction and Carbon Trust

Location
UK

Transforming construction

Arup has been instrumental in providing a road map for the UK construction industry to achieve its ambitious target to reduce carbon emissions from construction processes by 15% by 2012, measured against 2008 levels. The action plan offers quick win solutions for the industry.

In 2008, the UK Government in partnership with the Strategic Forum for Construction published the Strategy for Sustainable Construction. The construction industry set itself the ambitious target to reduce carbon emissions from construction processes and associated transport by 15%, measured against 2008 levels.

To support the industry in meeting this target, Arup was commissioned to work with the Strategic Forum and Carbon Trust to create an action plan for the industry, particularly contractors. The action plan has been shaped by stakeholders across many industry associations, individual companies and policy makers; Arup has been instrumental in facilitating this process.

An initial study has set a precedent by analysing carbon from construction processes across the sector. Arup developed a carbon accounting methodology to measure construction emissions and to work out the 2008 baseline carbon footprint for the industry. This new methodology can be used to repeat calculations year-on-year, helping to track performance in the future.

With the deadline for the reductions approaching rapidly, the action plan needed to focus on measures that would make the biggest difference in the shortest timeframe. The industry operates on slim profit margins, so the most practicable measures are those that offer financial benefits quickly, without large capital costs. These are most likely to be adopted straight away.

Eleven areas for action have been identified to tackle the key contributors to carbon emissions. Arup has provided clear guidance on how long these will take to implement, how much carbon will be saved, and the fuel cost savings available to the industry. Fuel-efficient driving and operation of plant on site, as well as the replacement of portable buildings with green cabins have been identified as straightforward changes that will make a big difference to emissions.

If the industry's voluntary 15% reduction target is to be achieved, the diverse community of construction professionals must collaborate. The action plan is channelling the industry's carbon reduction efforts into a focused and coordinated response. The plan raises all-important awareness about carbon in construction processes, and gives clear direction about the measures now available that offer benefits both for the industry and the environment.

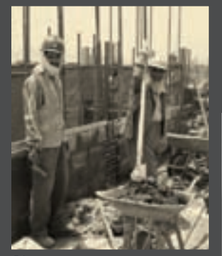
Sadar-e-Kabuli Girls School

Client
United Nations Office for Project Services (UNOPS)

Location
Kabul, Afghanistan

A legacy of knowledge

As Afghanistan continues its rebuilding efforts, a new school design in Kabul could provide a framework through which others in the region can be built. In this earthquake-prone area, a simple but robust approach to construction is key to providing safe schools for the future.



01

02

03

When Arup, working collaboratively with UNOPS, set about designing a 3,000-pupil girls school in Kabul, making the building earthquake-resistant was one of the most important design considerations. If an earthquake strikes, its inhabitants must have the best chance of exiting safely, and the engineering team went to great lengths to show how and why the design offered an appropriate solution.

Ensuring the design met rigorous international standards informed the team's detailed decisions. At each stage of the design process their thinking was shared with the client and accompanied by in-depth explanations. This meant that the principles behind the design process could be repeated locally in the future.

Although a map of Afghanistan's earthquake hazards already existed, Arup was able to help the client interpret the seismic levels and work out the appropriate code building loads for the school design. Similarly, the hazard map enabled modifications to the building design to be made in response to different levels of seismic risk around the country.

The final design for the Sadar-e-Kabuli school consists of five three-storey blocks with uniformly reinforced walls for both the façade and the internal walls. This eliminates the need for complex movement joints in the internal and external walls and simplifies the building's foundation design by spreading the loads uniformly. This made it straightforward for the local workforce to build. The design also satisfies International Building Code (IBC 2006), delivering a structurally-sound solution that goes beyond all local requirements.

Concepts and technologies used in this school design are already being applied to many other projects in Afghanistan, promoting safer construction and having a far wider impact than envisaged at the outset of the project.

01 **Construction of concrete masonry unit walls**

02 **Afghan schoolgirls**

03 **Detail of concrete masonry unit wall at column**

Arup Interactive Reports

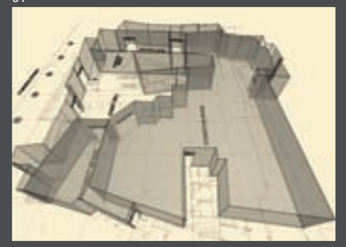
Location
Global

01 **A navigable 3D project model of fire safety interventions**

02 **Interactive 3D model shows planned engineering work by discipline**

02

01



Information innovations

Time constraints and information overload mean that many valuable reports risk being overlooked in clients' decision-making. Arup is changing this by using new technology to present complex and technical information in a visually-rich and accessible way.

Arup is making full use of the latest digital technology in its client communications. By introducing technology at the start of a project, the influence of engineering decisions on feasibility and options can be made easily accessible, even if the information is technically complex.

Digital technology, used appropriately, can support communication throughout the life of a project, offering a smarter way of sharing information. The client is emailed an interactive report in PDF file format, with a 3D project model embedded in the content.

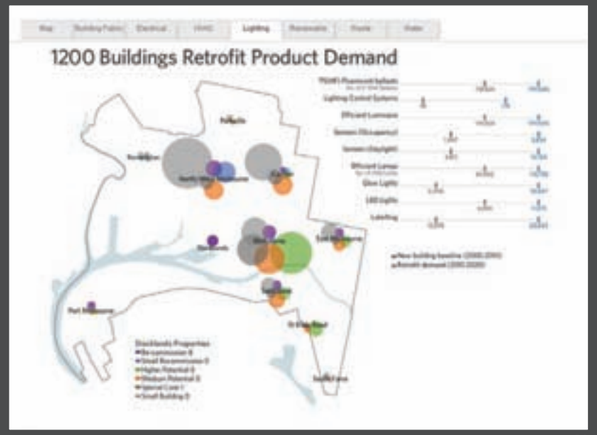
A 3D project model – for instance, of a building – helps stakeholders clearly visualise Arup's proposals – be they fire safety measures or engineering interventions. A 3D model removes much of the guesswork about where the proposed measures take place within the building.

Supporting text makes clear Arup's recommendations and the client has the ability to drill down into deeper levels of detail as they wish. This approach offers information that is far more immediate and meaningful than a traditional report can covey.

1200 Buildings Retrofitting Project Stimulus

Client
Department of Innovation, Industry and Regional Development, Victoria

Location
Melbourne, Australia



01

01 **Analysis of predicted activity, clustered by level of retrofit opportunity**

Data made simple

Arup has developed an interactive visualisation tool that makes large amounts of complex data easy to understand.

The City of Melbourne's large-scale 10-year building retrofit programme should significantly stimulate the State's manufacturing sector, but the challenge for government and industry was finding a way to clearly quantify this impact.
Arup was able to help by developing a way to model demand for the products and materials required to carry out the retrofit of buildings within the city, while also creating an interactive visualisation tool to present the findings.

A multi-step technical analysis was first done to model the anticipated product demand for the retrofit programme by product type, coupled with a targeted audit of Victoria's manufacturing capability. This model expanded on an earlier study by Arup which segmented the city's office property stock according to its retrofit potential, based principally on the age and size of each property listed in the Council's rates database.

With such a large variety of products used to retrofit buildings, the study resulted in lengthy Excel spreadsheets containing data for each scenario, with the results embedded in a detailed and complex report. The use of a scenario model meant that Arup would need to run variations to the base case on the client's behalf, limiting the exploration of different conditions.

An interactive visualisation tool from Arup changed this by presenting the results of the detailed analysis in an appealing and clearly accessible way. The tool, which is accessed via the internet, is dynamic and gives control to the client, who can change the model without the need for intervention. A simple slider can be used to adjust the number of buildings in the programme, with the impact of a new scenario instantly clear.

The beauty of the tool is that it condenses all the findings for each product type into just one screen, and a simple tab system allows the user to switch between products. It simplifies the report's findings, giving a firm basis for further investigations into market opportunities.

Arup's visual solution grabs the viewer's attention and provides a conceptual and holistic view of the programme. This encourages consideration of the more detailed written report and makes it that much more easily digestible. It also gives the government a tool to aid future discussions with industry.

Decentralised Energy Master Plan (DEMaP)

Client
London Development Agency

Location
London, UK

Low-carbon London

If the Mayor of London is to meet his targets of reducing London's carbon emissions by 60% and decarbonising 25% of its energy supply by 2025, a radical shift in the way electricity and heat are generated and delivered is needed. The Decentralised Energy Master Planning (DEMaP) programme is helping to create and accelerate this shift.

Decentralised energy is the generation of electricity close to the point of use, enabling heat released during the power generation process to be captured, distributed and used locally via a District Heating (DH) network. A mayoral initiative, led by the London Development Agency (LDA) is underway to increase London's use of decentralised energy and the potential positive impact of this programme is enormous, with almost half of all CO_2 emissions in the UK arising from heat used in homes, business and industry. Changes in this area are therefore critical to achieving the Mayor of London's targets.

Arup has been heavily involved in formulating the LDA's DEMaP programme – with Arup staff seconded to run the Programme Management Office. The firm has also been instrumental in bringing forward a number of decentralised energy projects on behalf of the LDA, across all phases of the development cycle.

To succeed, the programme relies on the London Boroughs to implement it, and a support programme has been developed to enable them to deliver energy masterplanning in their local area. The support programme effectively carries out enough work to bring viable opportunities to market, developing schemes to the point where the private sector can invest and deliver them, if appropriate, with confidence. Over three-quarters of London Boroughs are already actively engaged in the programme, and it is hoped that more will become active over the next twelve months.

One of the key resources for the London Boroughs is the London Heat Map. This plots supply and demand for heat by accumulating heat loads into clusters, producing a viable heat load profile for Combined Heat and Power (CHP) and DH network opportunities. As such, the map provides an evidence base for the networks to be installed. Arup is now custodian of the Heat Map, and is collating local-level data to fully populate it. Once key opportunities have been identified and prioritised for decentralised energy projects, land can be identified and safeguarded for the energy centre and more detailed development work can begin.

The Heat Map also highlights opportunities for developers and boroughs to work together, by taking advantage of their proximity to networks, as regional planning policy in London requires any new building development to link to either an existing heating network, or one that is planned. To help deliver district energy projects, local planning policy is being reinforced to make the process more effective.

Part of Arup's role is to assess the technical feasibility and financial viability of decentralised energy projects and to develop plans for implementation. This is a complex process. It involves engaging stakeholders, identifying infrastructure routes and constraints, testing alternative supply plant and operational scenarios and understanding the economic and commercial implications of different options.

Infrastructure projects of this nature often carry large up-front costs, and attracting investors is key. Arup's work is helping to show that the risk for certain projects is at an acceptable level by demonstrating financial viability through secure revenue streams. Procurement and funding options and strategies for future expansion are all identified to help instill investor confidence.

Following the development of community scale projects in the Royal Docks area, the wider London Thames Gateway Heat Network (LTGHN) was developed. This flagship scheme has the potential to connect up to 120,000 homes and many public and private buildings through 67km of pipework, saving almost 100,000 tonnes of CO_2 emissions each year. The LTGHN 'Vision Map' created by Arup has helped to communicate the ambition for this project and the overall programme.

With several schemes now close to being delivered, and suppliers, funders and customers negotiating contracts, London will soon see more community energy projects appear in the market. By developing self-sustaining programmes and ensuring that solutions are market-tested and proven commercially, Arup is supporting delivery of the Mayor's initiatives. In doing so, it is helping to pave the way for the creation of a new heat industry, with jobs and skills to support it. All of this will help London's endeavour to reduce carbon emissions and meet its 2025 targets.

01

02

01 **The London Heat Map**

02 **London Thames Gateway Heat Network Vision Map**

03 **The British Library, a potential participant in the Euston Road District Energy Scheme**

04 **Combined Heat and Power plant**

03

04

Why decentralised energy?

A decentralised energy system removes the need for homes and other buildings to produce their own heat energy (using a boiler or electricity) by using hot water that is produced centrally within a community by either a gas fired Combined Heat and Power (CHP) plant, or from other low and zero carbon sources, such as locally produced biomass. This hot water is delivered to the community via a network of pipes. Individual and collective users can then connect to this central hot water distribution network.

Industry-Based Sustainability Reporting on Key Issues

Client
Initiative for Responsible Investment, Harvard University

Location
USA

automobiles
real estate investment trusts
banks airlines paper
conventional electricity

Materiality matters

Measuring and reporting of sustainability-related performance is still in its infancy, but a white paper from Arup and Harvard puts forward a new methodology that could transform the way companies report on green issues. It provides a simple and cost-effective way of reporting, and allows US companies to focus on what matters most.

The landmark decision by the US Securities and Exchange Commission (SEC) to consider extending the concept of materiality from financial to non-financial issues – such as climate change – has forced many US-listed companies to consider the relevance of sustainability reporting, and what impact a mandatory reporting scheme might have on their organisation.

Currently, a lack of clear guidance – together with a reporting system that is voluntary, time-consuming and highly complex – has resulted in a situation where only a few US companies are reporting on their sustainable performance. Of those that do, many report on a wide range of issues in response to stakeholder requests without prioritising those that are critical to their organisation and sector. Compounding the matter, companies can report on any timeframe or indicators they choose, making it very difficult for the market to benchmark sustainable performance across companies within a sector.

A white paper authored by Arup and its partners could change all that. It sets out a new framework for reporting which makes it easier for companies to identify the areas that are most material to their sector and operations. This is an approach that could be easily adopted by the SEC and provides an alternative to existing broad disclosure frameworks.

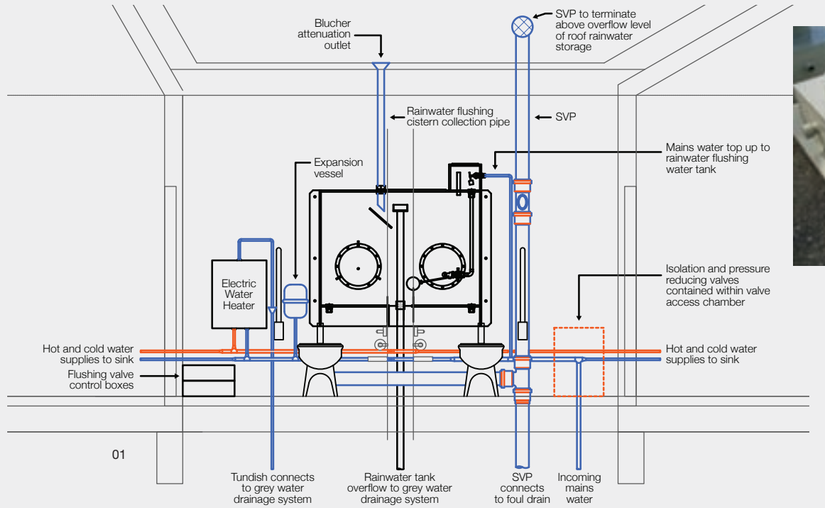
The paper proposes a new six-step approach based upon three principles – simplicity, materiality and transparency – and establishes a baseline for sustainable performance within each sector. Six industries were tested (airlines, automobiles, diversified real estate investment trusts, conventional electricity, paper and banks), and clear key performance indicators developed for each, which also resulted in a common set of issues that spanned them all.

The methodology builds on existing broad disclosure frameworks such as Global Reporting Initiative G3, while seeking to address some of the drawbacks of these approaches relating to time and cost. Most importantly, it enables companies to identify areas of opportunity, risk and competitive advantage while also allowing the financial markets, investors and stakeholders to compare and benchmark sustainability performance, a crucial element which had been missing from existing reporting guidance.

Rainwater Harvesting Flushing Tank

Client
Arup

Location
Bristol, UK



02

01 **System diagram**

02 **Final product ready for installation**

Product to market

Arup is at the forefront of 'retrovation' – applying traditional techniques to modern buildings for a more sustainable approach. The firm's latest product design, a rainwater harvesting flushing tank is a case in point.

From the Australian outback to the African bush, the concept of a toilet flushed by rainwater collected on the roof is commonplace. In the developed world, designers hardly ever specify a gravity-flushed toilet, despite its low-carbon credentials and negligible running cost. When Arup wanted one for a Bristol building, the firm found that there was no such product and had to design it from scratch. Why?

The answer lies in the manufacturing and design process. Manufacturers produce what they know they can sell – standard products to fit the average building. High-pressure water appliances have become the plumbing industry norm. They are specified by building designers and expected by consumers, who like their power showers. If mains pressure is insufficient, an electrical pump is fitted to support the product. Where building designers select a particular boiler for a development, for example, they design the pipework to suit. Designers are likely to specify and design for an established product, constrained by what is on the market.

Commercial reality can also put the brakes on innovation. The industry response to an increasing demand for rainwater harvesting systems, for example, has been to rebadge petrol interceptor tanks as 'underground rainwater storage tanks'. These require energy-hungry electrical pumps to transport the water to where it is needed.

Taking a new product idea to market, therefore, can be difficult. Once Arup had designed its rainwater harvesting flushing tank, it needed a manufacturer open to innovation in order to enter the market. Pipex's core business is the design and manufacture of pipe systems across a range of markets. Together, Arup and Pipex developed the concept into a prototype and a product, with the makings of a patent. The UK's patent office is currently examining the application and will decide on its merits in late 2010.

Such product creation may appear a long way from Arup's core business. However, bringing a low-carbon rainwater harvesting system and flushing tank to market, will expand the available range of options for building designers.

Since the system can be fitted into existing buildings as well as new ones, it offers a significant contribution to water conservation. It also eliminates the need for an underground tank, extensive pipework and energy-hungry pumping equipment. The only essential requirements are gravity and rainwater.

How it works

Most toilets in commercial buildings are placed in front of a blank wall, which conceals a void, normally equivalent to the width of the toilet. In the middle sits a small cistern for each toilet. The rest is wasted space.

Arup's system replaces the small cistern with a rainwater tank that fills the entire space behind the toilet(s). It is filled by rainwater that trickles down from the roof, via an outlet that incorporates a filter.

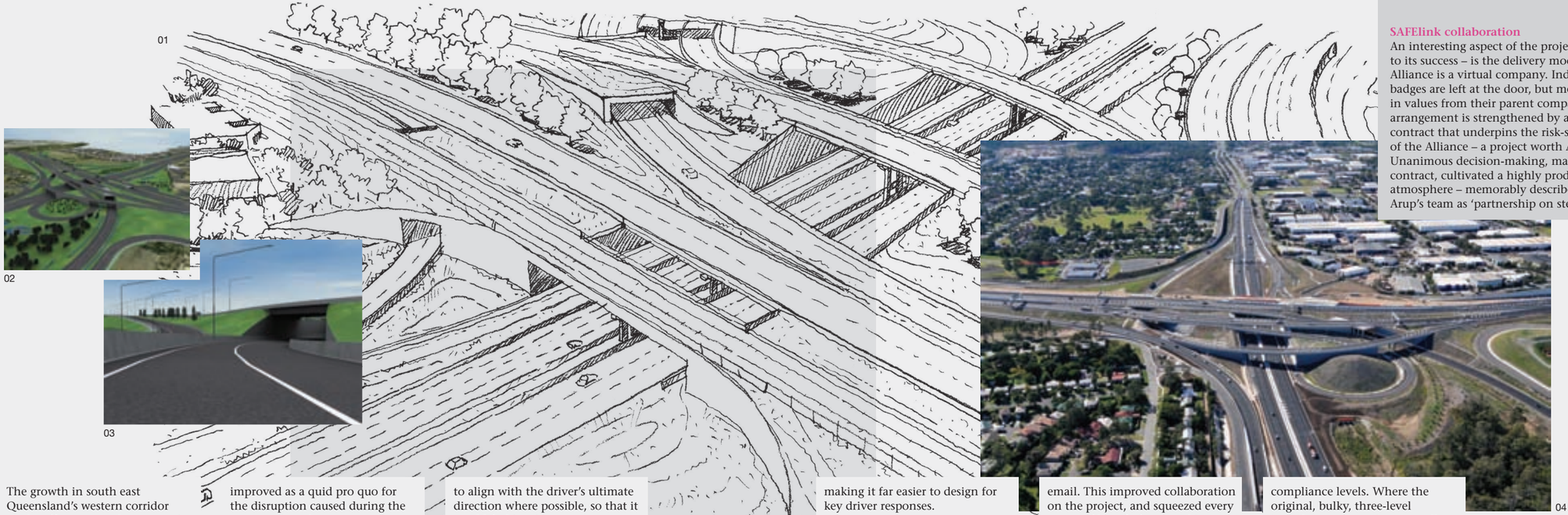
The team adapted technology from the food processing industry to flush the right amount of water into the WC pan, supplementing it from the water mains if necessary. The concept is flexible enough to be used in almost every type of development.

Client
Department of Transport and Main Roads

Location
Queensland, Australia

Clear road ahead

Queenslanders benefited from shorter journey times during the construction works needed to upgrade a key motorway and build the state's biggest transport interchange. Now that construction is complete, journey times have become quicker, and accident rates have fallen, thanks to thoughtful design.



01

02

03

04

The growth in south east Queensland's western corridor road traffic prompted a progressive upgrade of the Ipswich motorway, including the 5km section between Wacol and Darra. One challenge was that around 100,000 vehicles a day had to be kept moving throughout the construction works.

Safety was at the top of the agenda for the SAFElink Alliance, a collaboration between the Department of Transport and Main Roads Queensland, Leighton Contractors, BMD Constructions, AECOM and Arup, brought together into a 'virtual company' by a common contract. Historically, this particular traffic interchange has had a high accident rate and, for the Alliance, creating a safer highway was crucial. It also wanted the upgrade to be done as sustainably as possible, improving on existing best practice. Finally, it was keen that local residents' lives were improved as a quid pro quo for the disruption caused during the construction phase.

All over the world, safety in road design is codified, with designers working to at least meet relevant standards. The team wanted to do more. Arup took the view that intelligent design should consider non-codified elements that also help to enhance the finished project.

Any interchange is, by its nature, complex and slightly stressful to drive through. Arup stripped back the design to reduce visual clutter and help drivers to concentrate on road signage and line markings. There are a few key decision points for drivers, and these are, as far as possible, simple binary choices. Where a road splits in two at a junction, for example, a driver might take the left branch but subsequently need to access a road in the opposite direction. The team wanted the traffic exit point to align with the driver's ultimate direction where possible, so that it would feel intuitive.

The design minimises visual distractions such as roads crossing each other. In several cases it was necessary to design ramps to climb up and over roads, requiring tweaks to the angle of a curve to prevent drivers from heading into the sun and missing road markings. Arup used road design software that visualised information on issues such as road camber and curves to help inform its judgements.

Many different elements of the design contributed to the overall improvement of the user experience. To help quantify such a subjective measurement, Arup asked an independent group to come in and test the planned routing and quantitatively measured people's reactions. The team developed a 3D programme to allow a virtual 'drive through', making it far easier to design for key driver responses.

Technology was a key contributor to the project. Arup modelled all aspects of the interchange and road upgrades in 3D, complete with GPS control so that managers could sit in the project office and see the progress of the construction phase. Arup's own building information modelling (BIM) techniques were adapted, using 4D (adding in the element of time) and 5D (adding in cost too) technology, applying it for the first time to an infrastructure project in Australia.

During the project design phase in 2006/7, Arup had around 130 people on the project, working from different offices including Brisbane, Sydney, Hong Kong and mainland China. The team used Arup's global tool, ProjectWise, to manage data and ensure consistent drafting standards, helping to bypass the use of file transfers and email. This improved collaboration on the project, and squeezed every ounce of benefit from working across different time zones. Project managers would arrive in the morning to find files that had been updated overnight, with version control and a full audit trail.

The technology also proved invaluable for communicating with other stakeholders, such as owners of existing structures. The team programmed highly-accurate 3D models within their construction model. This allowed SAFElink to help agencies visualise the project. This was unprecedented in Australia and significantly smoothed negotiations on the project.

The road opened in April 2010 to widespread acclaim. Roads are an essential part of Australia's freight transport infrastructure, and the project's environmental impact has been minimised and offset wherever possible, far surpassing compliance levels. Where the original, bulky, three-level interchange was noisy, generally intrusive and blocked light, the replacement two-and-a-half-level interchange is 8m lower. This makes it far less intrusive to the surrounding landscape, and noise mitigation techniques have reduced the traffic noise impact considerably.

Had it been developed on a completely fresh site, the new interchange would already have been an impressive achievement. But as a replacement interchange, smaller and less intrusive than the original, with a construction process that actually improved commuter times and reduced accidents, the SAFElink project is a unique achievement. The project has set new standards in Australia, thanks to the collective determination and design collaboration of the Alliance.

SAFElink collaboration
An interesting aspect of the project – and key to its success – is the delivery model. SAFElink Alliance is a virtual company. Individual company badges are left at the door, but members bring in values from their parent companies. The arrangement is strengthened by a 50-page contract that underpins the risk-sharing nature of the Alliance – a project worth AUS$824m. Unanimous decision-making, mandated by the contract, cultivated a highly productive working atmosphere – memorably described by one of Arup's team as 'partnership on steroids'.

01 **Early sketch of the interchange**

02 **CAD modelling of the interchange**

03 **The 'virtual drive through' provided by visualisation programmes**

04 **The completed interchange**

Dubai Towers

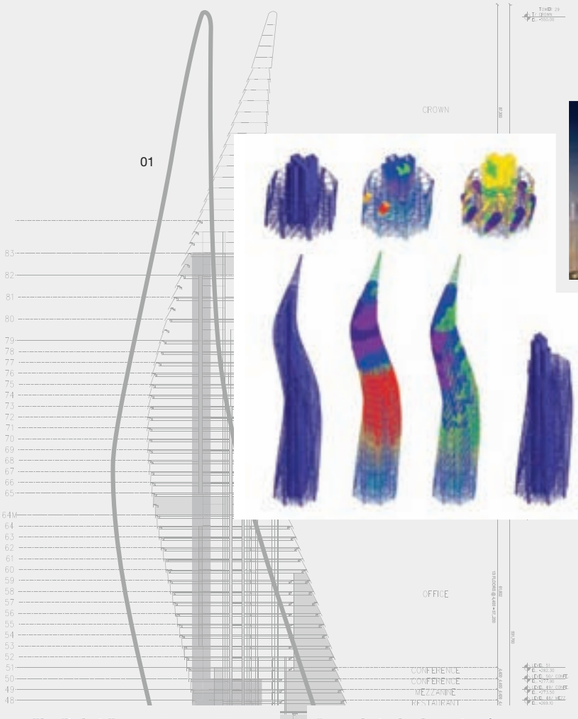
Client
tvsdesign

Location
Dubai, UAE

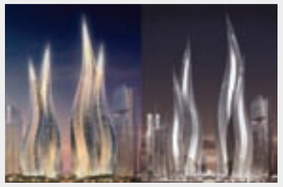
01 **Revised geometry**

02 **Rendering of the Dubai Towers before (left) and after adjustments**

03 **Construction sequence analysis**



01



02

03

Refine and reduce

With a vision more sculptural than architectural, the design of these four towers presented quite an engineering challenge. To remain true to the architect's vision, Arup found a way to optimise the geometry, devising a structural solution that would be efficient, economical and buildable.

The Dubai Towers taper, rotate and curve until they reach their peaks, which range from 365m to 550m. The engineering challenge was to find a structurally efficient form and detailed geometry within this complex aesthetic concept. By working with the principle of the tower appearance and making minor adjustments, Arup was able to make positive technical interventions.

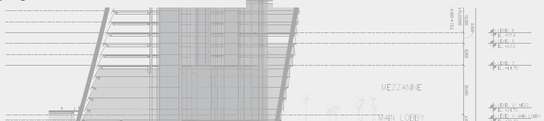
Beginning with a process of 'form finding', Arup explored multiple configurations for the towers, evaluating the performance and cost of each. By using Arup optimisation software, the process could be streamlined. The geometry was fed into the scripted software which then generated models of the entire structure and loads, providing results for each proposed modification.

In a relatively short timeframe, the team was able to evaluate a number of different design strategies. Each iteration was assessed based on the balance of the tower, reduction in internal shears, and aesthetics. The team adjusted the geometry by degrees to find a workable solution as close to the original architect's intent as possible.

The geometry proposed by Arup ensures the towers would be balanced and stable. Conceptually, the goal was to create a vertical building with a flowing perimeter that could 'hang' from it. The central core would therefore do the primary structural work of the building. As a result, the layout was revised to increase the loads carried by the vertical core, and stability was further enhanced by reducing the slope of the columns towards the bottom of the tower to help decrease cumulative horizontal loads.

The geometry created other structural challenges. The rotation of the tower itself created torsion, and without structural intervention the tower would literally try to 'untwist' itself. This was overcome by introducing a perimeter diagrid brace that sloped in the opposite direction to the columns.

These engineering strategies led to a dramatic reduction in the sizes of the perimeter braces and columns, as well as greatly reducing the amount of concrete needed for the foundations. The revised design would save 95,000 tonnes of steel and 96,000m^3 of concrete – a reduction of 40% in the materials originally proposed – with a cost saving estimated at US$600m.



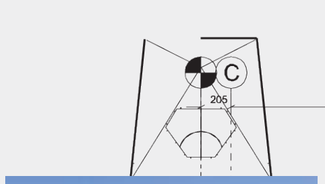
Upton Square

Client
Mansell Construction

Location
Northampton, UK

Code 6 living

An eco-development in Northamptonshire shows zero-carbon residential design in practice with the UK's highest sustainable home rating, Code 6. More than a theoretical example, Upton Square's terrace of eco-homes are occupied and fully functioning.



Upton Square gives us a glimpse into the near future. Recently shortlisted for a prestigious British Construction Industry award, the six terraced homes, by architect Bill Dunster/ZEDfactory, are the first commercially-available residential Code 6 properties. They are forerunners to the design of all new-build homes in 2016, when the UK Government has determined that all new dwellings will be zero carbon.

Upton Village is an extension to an existing town and has an overall target of achieving a 60% carbon reduction. Six properties within the eco-development were set the challenge of achieving zero-carbon status by incorporating the latest thinking in sustainable design.

As well as providing multidisciplinary engineering services, Arup was appointed as the code assessor for the project, working closely with the Building Research Establishment (BRE) Group to meet exemplary Code 6 status. An ongoing collaborative relationship helped speed up the design process and make the high sustainability rating achievable.

The energy strategy was crucial to Code 6 achievement, and Arup looked at a number of electricity generation schemes to find the most efficient solution for domestic use. Photovoltaic (PV) panels were selected and each home has twenty panels that satisfy most of the annual electricity demands. As a consequence, residents benefit from much reduced energy costs, and extra energy generated can be fed back to the grid. Introduction of 'feed-in tariffs', which came in after Upton Square was built, have made PV generation on new schemes increasingly attractive, by reducing payback periods.

As a result of this Metropolitan Housing Partnership development, the broader community has an increased awareness of sustainability-related issues which helps to promote a low-carbon lifestyle. It also demonstrates to the construction industry that a zero-carbon – and Code 6 – solution is possible using current and readily-available technology. Such developments will steadily become more affordable through government incentive, new suppliers to the market, and greater production to meet demand and combat the issue of increasing fossil fuel energy costs.

Some of the measures introduced to achieve the high sustainability rating:

A community-scale centralised wood bio-fuel plant and local distribution system eliminates the need for gas supplies to the properties, provides all required heating, and allows an efficiently sized system to serve a local cluster of several homes.

300mm mineral wool insulation was installed throughout the walls, floor and roof of the building – much thicker than that found in a standard house, this minimises energy usage.

Air-tightness, three times the mandatory requirement, greatly enhances heat retention and ensures very little warm air escapes from homes.

A south-facing 'sunspace' creates a modern living area. Highly functional, it provides passive solar heating.

Passive natural ventilation is incorporated on the roof and heat from extracted air is used to pre-warm incoming fresh air.

Water conservation, rainwater harvesting, green roofs and a drainage system incorporating wetland landscape and runoff channels, allows a natural surface drainage strategy and limits outflow to sewers.

Natural Terrain Hazard Mitigation Works

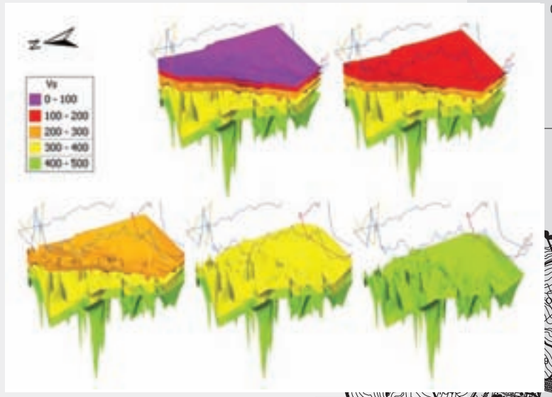
Client
Geotechnical Engineering Office, Hong Kong SAR Government

Location
West Lantau Island, Hong Kong, China

Pilot Seismic Microzonation Study

Client
Geotechnical Engineering Office, Hong Kong SAR Government

Location
North-West New Territories, Hong Kong, China



01

01 **3D image of soil conditions for assessing seismic motion amplification**

02 **Examining landslip debris**

03 **Clusters of landslips from June 2008**

Understanding the risks

Hong Kong is one of the world's most densely populated areas, with seven million people living in just 25% of its landmass. Much of its urban development lies on relatively flat land in the lee of hills and mountains. So when heavy rains fall or earthquakes strike, landslips are a major problem. The Hong Kong Government is working to reduce the risk of landslip on urban development in the future, even as it protects the most vulnerable areas in the present.

In just 24 hours in June 2008, Hong Kong suffered several thousand rain-induced landslides following torrential rain. Debris hit houses, blocked vital roads and left villages at the bottom of natural hill slopes isolated and without power for over a week.

In the aftermath, Arup was challenged by the Hong Kong Government to develop a way of quantifying the risk of rain-induced landslides in an 18.5km² area of West Lantau Island, which alone experienced over 500 landslips in June 2008. Working with a local joint venture partner, the team devised a new approach to analysing available data and mapping a risk profile for the area.

The team developed a methodology that examined the physical conditions and processes evident within the site, such as soil type and condition, and its distribution. For example, if soil does not 'match' its immediate surroundings, it may have been moved there by previous landslides and may indicate a higher risk of possible future movement. The next step was to interpret the areas' geological conditions and geomorphology (how the hills are formed) and record all findings on digital maps using a Geographical Information System (GIS) database. The GIS database incorporates the location and extent of all previous landslides within the study area, documenting over 5,000 landslides that had been identified using nearly 50 years of aerial photograph records. By examining the geomorphological conditions in association with the landslide data, the team was able to understand how the frequency and type of landslides were related to various different parts of the hillsides within the study area. This allowed it to define zones of differing levels of landslide hazard.

Next, the team prioritised and ranked the hillside catchments according to risk; a challenging piece of analysis. The catchments were divided into two sets – those affecting villages and those affecting infrastructure – and the 30 areas with the highest risk profile were studied further. A densely developed area sitting on the valley floor, for example, would be particularly vulnerable, as the debris 'fan' – rather like a flood plain at a river mouth – indicates notable accumulation of past landslide material. Arup assigned a hazard and consequence value to each hillside catchment in order to create a matrix of risk. The result is a valuable planning tool.

Arup's peer-reviewed, world-class study extends the science and practice of risk assessment in urban planning, as well as providing Hong Kong's Government with the means of identifying those areas where mitigation work is most likely to save lives. Hong Kong's deaths from landslides have been dropping steadily, thanks to Arup's previous work on a comprehensive risk assessment framework for manmade slopes. This project does the same for the natural terrain, making Hong Kong a world leader in risk assessment in this area.

03

Seismic motion mapping

Hong Kong has no seismic code of its own, partly because of its relatively central location on the Eurasian Plate, but since 1997 the China seismic code has classified Hong Kong as being in a moderately active seismic region. Now, in a groundbreaking new study, Arup's seismic engineers are working with Chinese seismologists on zoning and developing a dedicated seismic risk profile for Hong Kong's natural terrain.

The first part of the study is an area-specific microzonation assessment, which means dividing the area into zones based on how they would amplify seismic energy. This takes into account local geology, topography and ground responses. Employing rich data on Hong Kong's geology, Arup is coordinating specialist ground investigations and input from Chinese methodologies.

In this project seismic engineering and geology is being combined to formulate seismic risk assessment, with the team developing new techniques in the process. Arup is working with seismologists from the Guangdong Engineer Earthquake Resistance Research Institute to combine approaches that have been successfully developed around the world with those used throughout the Chinese mainland.

The second part of the study takes the team to the forefront of landslide hazard research. Arup is developing a hazard methodology for slopes – something still in its early stages in other parts of the world that have extensive earthquake-induced landslide problems such as Japan, Taiwan and the US. Methods for identifying the areas that are potentially most at risk is little understood and there is no existing local data to draw on. The team is using site investigations, GIS techniques and 3D modelling skills to process and present the information.

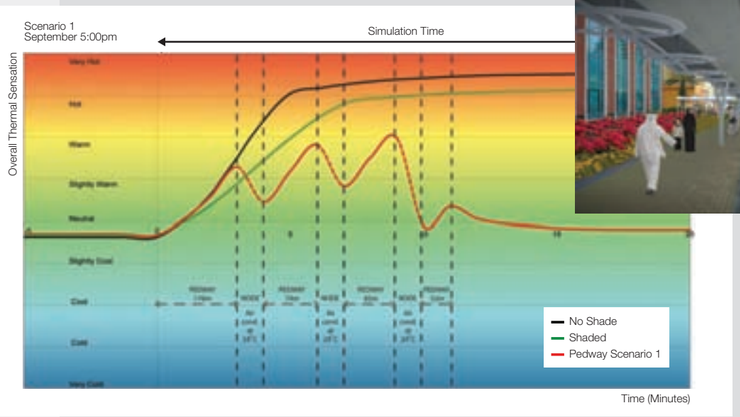
The study will provide the Hong Kong Government with a set of 3D maps, which are zoned according to seismic motion at ground level and that show areas of slopes likely to move in the event of tremors. These provide a methodology for future seismic microzonation studies. They also inform the Government's new town planning and help it to quantify the risk of developments in different areas.

Dubai Pedway Development Strategy

Client
Strategic Planning Department,
Roads and Transport Authority (RTA)

Location
Dubai, UAE

01



02

01 **Analysis shows how pedestrians move in comfort in a low energy pedway (in red) as compared with walking in direct sunlight (in black) and in the shade (in green)**

02 **Naturally ventilated section with fans and canopy roof**

Cooler walking

A new study is exploring the feasibility of a system of city walkways to extend the catchment of the public transport network, including the recently opened Dubai Metro.

Dubai's blue skies and warm weather have made it a popular magnet for tourists. But getting around this sprawling city during the hot and humid summers can be a challenge. Air-conditioned cars prevail as the most comfortable option for many in the heat of summer. Pedestrians face a number of difficulties, including poor continuity of footpaths, the dominance of traffic and the fact that whole communities are intersected by 12-lane highways.

Dubai's new metro system has so far exceeded its targets. However, the local climate means that, unless people live within a few paces of a bus or metro stop, they face an uncomfortable walk in the heat. Keen to build on the metro's initial success, Dubai RTA asked Arup to develop proposals to extend the walking catchments, with particular emphasis on low energy options. One answer is a pedestrian walkway – 'pedway' for short – that provides a quick and convenient means of moving between public transport and residences, offices, shopping malls and community facilities, while protecting pedestrians both from the traffic that dominates the city and from the aggressive heat.

Dubai's air-conditioned buildings are regularly set at temperatures of around 18ºC, which means that people experience thermal shock when they walk out into temperatures that can exceed 45ºC in the summer months. Arup's approach is to 'split the difference' between these two extremes and develop a range of options that mitigate the problem. One of these is a naturally-ventilated pedway that increases pedestrian safety and mobility without the need for extensive energy-hungry air conditioning.

The team looked at pedway precedents in other cities, including Mumbai, Hong Kong, Toronto, and Chicago. They proposed a shaded structure with high thermal mass as the best way to avoid the problem of solar gain, while capitalising on the heat retention of the structure itself to keep cool, with fans to create airflow. Arup's microclimate experts modelled thermal comfort and sensations over time. They started from a benchmark of walking in the winter sun to define a comfortable transient sensation level. They analysed transient comfort, considering walking speed, metabolic rate and walking distances. This led to the proposal that the pedway would need air conditioning at regular intervals to bring thermal sensation back down between naturally ventilated sections.

The team provided three case studies to illustrate the proposition: one tunnel, one low-energy open structure, and one that is enclosed and AC cooled. The study created a flexible framework for pedway development and implementation that could be developed organically, connecting more and more commercial and leisure buildings to become a vital part of the city's transport infrastructure. It also explored funding and revenue models that would offset the capital costs.

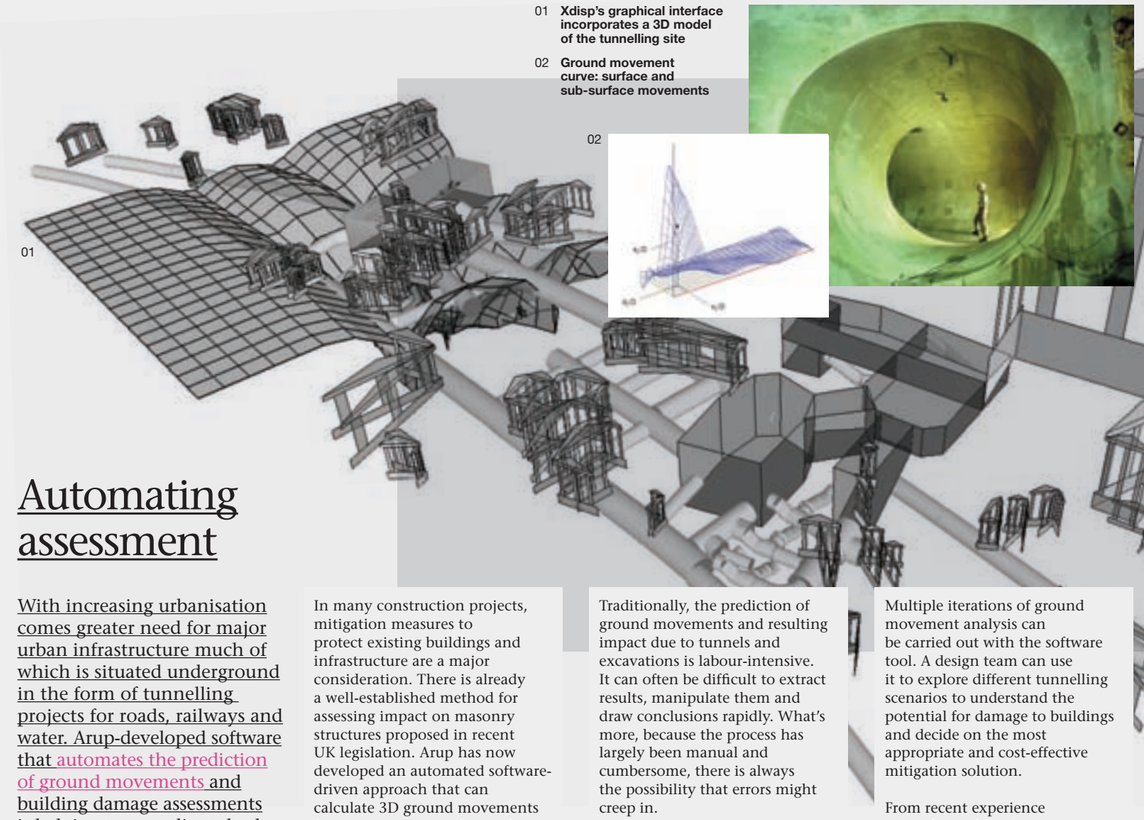
Arup's feasibility study shows how a Dubai pedway could be developed, increasing access to public transport and bringing with it commercial sponsorship opportunities such as retail kiosks and advertising space. It also sets out guidelines and mechanisms for a flexible system of connected walkways that could continue to develop and grow, alongside the city itself.

Xdisp – Building Damage Assessment Tool

Location
Global

01 **Xdisp's graphical interface incorporates a 3D model of the tunnelling site**

02 **Ground movement curve: surface and sub-surface movements**



Automating assessment

With increasing urbanisation comes greater need for major urban infrastructure much of which is situated underground in the form of tunnelling projects for roads, railways and water. Arup-developed software that automates the prediction of ground movements and building damage assessments is helping to save clients both time and money.

In many construction projects, mitigation measures to protect existing buildings and infrastructure are a major consideration. There is already a well-established method for assessing impact on masonry structures proposed in recent UK legislation. Arup has now developed an automated software-driven approach that can calculate 3D ground movements from excavations and tunnels. It can automate the process of determining building damage assessments in an integrated and dynamic way.

To put building damage assessment into context, the mitigation measures on the 1990s London Underground Jubilee Line extension accounted for one sixth of the total civil engineering spend, at more than £100m. So any improvements in the assessment process influence an important and expensive aspect of such major works.

Traditionally, the prediction of ground movements and resulting impact due to tunnels and excavations is labour-intensive. It can often be difficult to extract results, manipulate them and draw conclusions rapidly. What's more, because the process has largely been manual and cumbersome, there is always the possibility that errors might creep in.

Working alongside colleagues in Oasys (Arup's software house), the firm's engineers have developed Xdisp – short for Excavation Displacement – which automates the calculations necessary to carry out building impact assessments.

Xdisp's graphical interface incorporates a 3D model of the proposed tunnelling site and provides clear visualisation of the relationships between tunnels, excavations and buildings, making it a useful communication tool for both designers and clients.

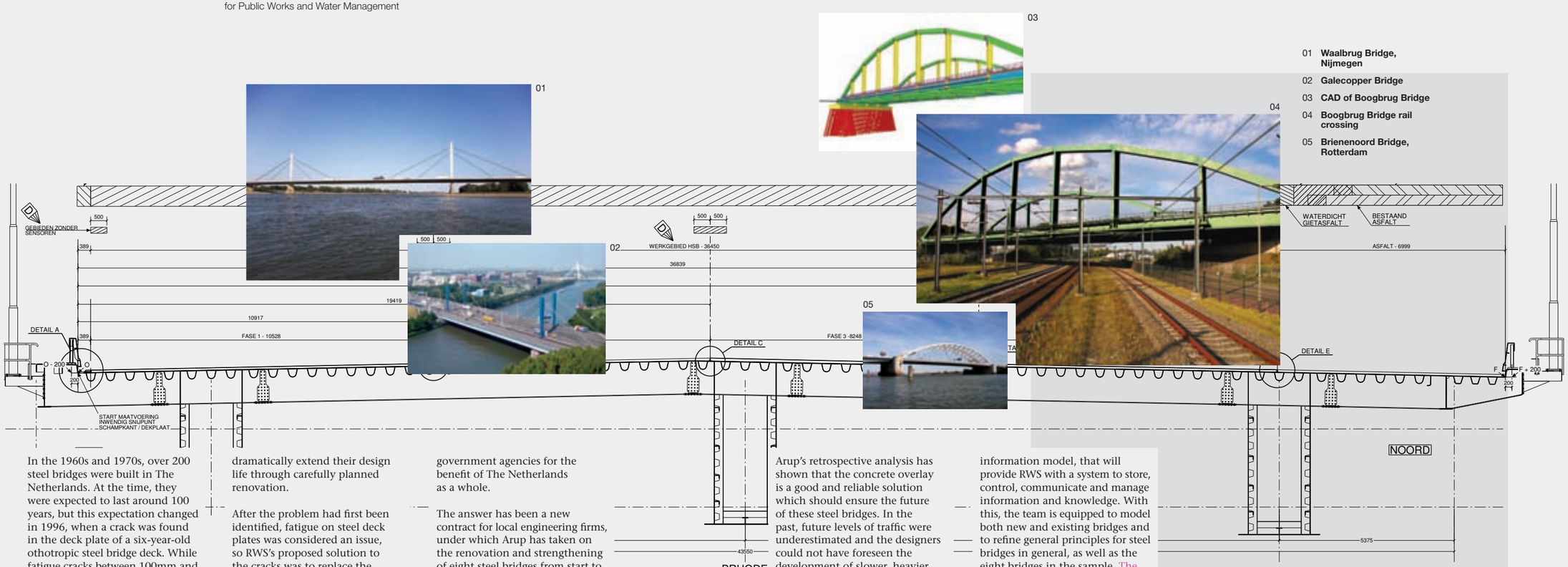
Multiple iterations of ground movement analysis can be carried out with the software tool. A design team can use it to explore different tunnelling scenarios to understand the potential for damage to buildings and decide on the most appropriate and cost-effective mitigation solution.

From recent experience using the tool on Arup projects, the automation of building damage assessment calculations saves a significant sum per iteration. This gives clients a cost advantage, especially on medium- to large-scale projects. Given the important role and proportionately high cost of building damage assessment calculations in underground infrastructure projects, a tool that improves their efficiency is invaluable.

Renovation of Eight Steel Bridges

Client
Rijkswaterstaat, Dutch Directorate-General for Public Works and Water Management

Location
The Netherlands



01 **Waalbrug Bridge, Nijmegen**
02 **Galecopper Bridge**
03 **CAD of Boogbrug Bridge**
04 **Boogbrug Bridge rail crossing**
05 **Brienenoord Bridge, Rotterdam**

Take 8 bridges

Due to higher traffic loads several of The Netherlands' most important steel bridges are showing signs of fatigue damage. Arup – working closely with the country's transport agency – is helping to build a nuanced and detailed understanding of how these bridges behave and how their design life can be extended.

In the 1960s and 1970s, over 200 steel bridges were built in The Netherlands. At the time, they were expected to last around 100 years, but this expectation changed in 1996, when a crack was found in the deck plate of a six-year-old othotropic steel bridge deck. While fatigue cracks between 100mm and almost 1.5m long have since been found in many Dutch bridges, this was the youngest bridge to show such damage. Still structurally safe, even with cracks on the deck plate as large as this, the findings have nevertheless prompted urgent investigations.

Arup together with a Dutch joint venture partner Royal Haskoning won the tender for the investigation of eight of the most crucial bridges in the highways network, which is overseen by national agency, Rijkswaterstaat (RWS), Directorate-General for Public Works and Water Management, part of the Ministry of Transport, Public Works and Water Management. Arup is applying its bridge design expertise from all over the world to analyse these bridges and dramatically extend their design life through carefully planned renovation.

After the problem had first been identified, fatigue on steel deck plates was considered an issue, so RWS's proposed solution to the cracks was to replace the asphalt layer with a concrete overlay of the same thickness. Although this slightly increased the weight, this was not expected to be a problem. The idea was studied tested in two pilot projects and appeared to work. By doing this RWS ensured a steep learning curve for themselves and the market. Eventually, a development partnership with contractors was able to come up with a reasonable and acceptable means of extending the remaining life of the two pilot bridges.

In 2000, RWS consciously decided to leave a bigger part of the design work to agencies in the private sector. This left them with the challenge of ensuring that expertise and understanding of steel bridge design exists outside government agencies for the benefit of The Netherlands as a whole.

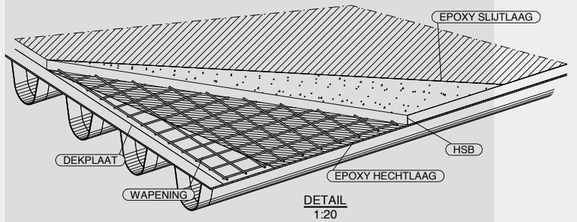
The answer has been a new contract for local engineering firms, under which Arup has taken on the renovation and strengthening of eight steel bridges from start to finish, including responsibility for managing the contractors together with joint venture partner Royal Haskoning. Arup is drawing on its global expertise and developing a nuanced understanding of the eight landmark bridges, which range from 100m to more than 300m in span, and over 1km in length. All are strategically important to the Dutch highway network and carry heavy loads. In developing a methodology to suit these eight bridges, Arup will be producing a blueprint for renovating the rest of the country's steel bridges and perhaps others further afield.

The team is assessing the bridges with a view to strengthening them and extending their useful life by at least 30 years.

Arup's retrospective analysis has shown that the concrete overlay is a good and reliable solution which should ensure the future of these steel bridges. In the past, future levels of traffic were underestimated and the designers could not have foreseen the development of slower, heavier freight trucks (with 'super single tyres' for juggernauts which load the vehicle weight onto a smaller wheel surface) becoming standard within just 10 years. The Netherlands is one of the most congested countries in Europe and also provides key access to the continent. It is in this context that the lives of the country's steel bridges must be extended.

Arup is working closely with RWS consolidating expertise in steel bridge design, much of which is neither regulated nor written down. The firm's programmers have linked sophisticated 3D bridge design modelling with static and fatigue-modelling programmes. Using the expertise of bridge experts in three of the firm's offices, Arup is developing a bridge information model, that will provide RWS with a system to store, control, communicate and manage information and knowledge. With this, the team is equipped to model both new and existing bridges and to refine general principles for steel bridges in general, as well as the eight bridges in the sample. The plan is to add 3D models showing the appropriate information for each structure that will enable clients to take a virtual walk over individual bridges.

Of course, building such expertise in bridge design and performance over time increases the global body of knowledge in this area and will be applicable elsewhere. In Germany, for example, similar problems are arising with existing pre-stressed concrete bridges. Germany has approximately 5,000 pre-stressed concrete bridges and more than 500 steel bridges. The need for the assessment of existing bridges in Europe is expected to grow and Arup's capacity to carry-out such analysis is increasing commensurately.



DETAIL
1:20

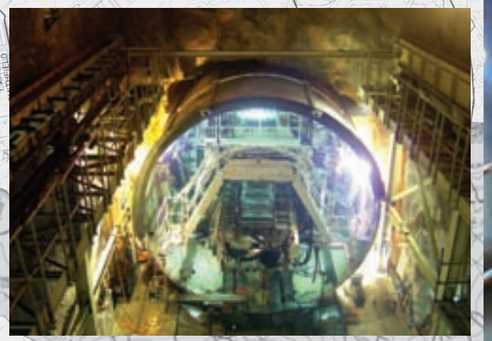
Hong Kong West Drainage Tunnel

Client
Drainage Services Department, Hong Kong SAR Government

Location
Hong Kong, China

Down to earth

Hong Kong Island's drainage system is under pressure. The rapid rate of urbanisation has caused a sharp increase in flooding, but a new drainage tunnel – Hong Kong's largest ever – will soon help protect the island's Northern districts.



Raise boring method
The raise boring method works by drilling a pilot hole from the stream intake down to the completed adit at tunnel level. A large steel frame with rock rollers is placed in the adit connected to the pilot hole. It is turned slowly and cuts the rock, which conveniently falls down into the adit for easy clearance and disposal via the main tunnel.

Vital statistics of the tunnel

- The main tunnel comprises an eastern section of 3.9km with an inside diameter of 6.25m and a western section of 6.6km with an inside diameter of 7.25m.
- The adits that connect the dropshafts with the main tunnel total just under 8km and are generally 2.3m in diameter.
- There are 32 dropshafts, with the deepest 180m deep.
- There are a total of 34 intakes, these intercept and divert the existing flows into the 32 dropshafts.
- The western portal provides an outlet to the sea at Cyberport and includes an energy dissipating stilling basin to control the velocity outflows.
- The eastern portal is the largest intake structure and includes a maintenance entry point to the tunnel.

The Hong Kong West Drainage Tunnel (HKWDT) will be the largest drainage tunnel constructed on the island. At over 10km long and with a diameter ranging from 6.25m to just over 7m, it is a major undertaking that is not made any easier by being located below dense, wealthy, urban areas. The challenge is further compounded by steep terrain, narrow streams and restricted access on sloping sites.

By putting the drainage tunnel uphill from the areas prone to flooding, including Central, the main financial business district, the tunnel will capture stormwater flows before they drain into the low-lying, flat, reclaimed commercial and residential areas. This will help to relieve floods and ensure these areas have a sustainable economic future.

The tunnel is being constructed by mechanised Tunnel Boring Machine (TBM) methods with some long drill and blast adits connecting the tunnel to the drop shafts. Blasting was the preferred option for the construction of the adits as they have to be constructed while the main tunnel works are in progress.

The whole scheme lies within and below exclusive, prime residential properties, which gives the project an exceptionally high profile, not least in the local media. From the beginning, community engagement has been pivotal to the success of the project. With extensive and exhaustive consultation, it has gained strong community buy-in. The final design's minimal visual impact helped to allay community concerns.

The construction programme runs over a four-year period and is planned to be finished in 2012, allowing sufficient clear time to carry out full testing of the system before the onset of the wet season. With this deadline in mind, Arup has worked hard to minimise any risk of delay during the construction process, and has even created an unconventional approach to tunnel blasting.

Normally, everyone underground is evacuated prior to the blasting, regardless of where they are located in the tunnel network. They would only be allowed back in after the tunnel conditions have stabilised and it was deemed to be safe to re-enter. To evacuate such a long tunnel with numerous adits and shafts deep underneath Hong Kong Island would take a significant amount of time and cause major disruption to the construction programme. Arup proposed a new approach.

Rather than carry out a full evacuation of the tunnel, a safety zone would be established around the point of detonation at a minimum safe distance from the blast. Personnel would evacuate to a safe refuge chamber located on the back of the TBM, so once the blast was complete and safety checks carried out, work could resume promptly. Importantly, the blasting need not interrupt work elsewhere on site.

Safety is of paramount importance and the proposal went through a stringent safety review by all the relevant government bodies before being authorised for implementation. This new approach offers a significant improvement to working practices not just on this project, but across the tunnel construction industry in Hong Kong.

Another significant departure from conventional tunnel construction techniques was to adopt a raise boring method for excavating the intake shafts. Conventionally, the shafts would have been sunk as machine-dug shafts, or as hand-dug caissons from ground level. These methods are inherently less safe and can put an increased burden on the local road network, as excavated material has to be removed by truck from the top of the shaft.

By contrast, the raise boring method meant less impact on local residents with reduced levels of dust, fumes and noise as well as significant energy and environmental savings for the local community and the project. Importantly, huge savings were also made in alleviating construction-related road congestion.

This method needs to be meticulously planned, since it creates a number of dependencies in the construction process. The main tunnel and adits need to be completed prior to the raise boring commencing, and blasting has to be choreographed with the main tunnel construction. With a project of this magnitude, even the movement and hire of boring machines must be carefully planned and implemented.

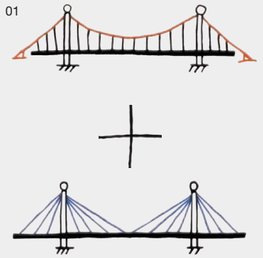
By proposing unconventional construction methods and processes, Arup is helping to ensure that the Hong Kong West Drainage Tunnel will be handed over on time, as well as delivering an effective design solution. Once complete, the drainage tunnel should ensure that the city's vital business district is effectively protected from flood risk.

Long Span Bridge Research

Client
GS Engineering &
Construction Corporation

Location
Global

01



Stability at length

Cable-stayed bridges are cheaper to build than suspension bridges, but conventional wisdom says they have a natural span limit of around 1,100m. Arup's bridge designers, drawing on experience gained on Stonecutters, aim to extend this limit with a new approach that combines elements of both bridge types.

Long span bridges fall into two types: the suspension bridge and the cable-stayed bridge. Although they look similar, they depend on different structural solutions.

Suspension bridge: how does it work?
Two large cables sag between two towers and are ground-anchored at each end. Suspended from these main cables are many smaller cables or hangers, which support the bridge deck. The main cables carry most of the load of the deck.

Cable-stayed bridge: how does it work?
The bridge deck is supported by many parallel cables. The cables pull to the sides rather than upwards, putting horizontal compression loads into the deck. Because the horizontal forces are balanced, the bridge is self-anchored rather than ground-anchored.

Partially ground-anchored cable-stayed bridge: how does it work?
For very long spans, the horizontal compression loads in the deck become too great. By anchoring some of the cables to the ground the compression is kept within the limits that the deck can bear but the anchor block is much smaller than would be required for a conventional suspension bridge.

Arup has joined forces with a Korean contractor, GS Engineering & Construction Corporation, and Professor Niels Gimsing, a renowned Danish bridge expert, to test the limits of cable-stayed bridges and design new construction techniques. These techniques could produce a longer span but still cost less to build than a suspension bridge.

The challenge is to work out the most efficient way for the bridge to reach its 'kissing point' – where the two sides meet in the middle and the load is shared out along the span and reduced (conventionally, bridges are engineered to bear the loads of the construction process, as well as the live load they must ultimately bear).

The design team tore up the rulebook and came up with a method of building the bridge from the middle of the span outwards.

An aerial cable/walkway is hung between two towers and the middle deck segments are suspended from this cable. Shown below are the two methods used to get the stay cables out to the middle segment.

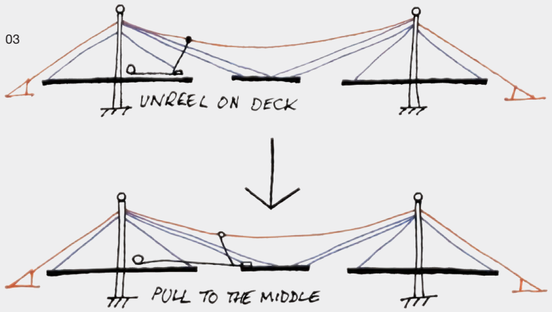
01 **Using design elements of both bridge types, the new approach to construction both increases the span and reduces the steel required**

02 **Unreel the cables at the top of the towers and feed them down the aerial cable/ walkway**

03 **Unreel the cables on the deck and then use a suspended hanger from the aerial cable/ walkway to traverse the cable to the central part in a see-saw motion**

02

03



Light Neville Street

Client
Holbeck Urban Village
Bauman Lyons Architects

Location
Leeds, UK

A dark, noisy and unwelcoming approach to the city of Leeds has been transformed by a sound and light art installation that provides a modern counterpoint to this historic city.

Light aloud

Can an underpass be uplifting? The experience of commuters in Leeds suggests that it can. Previously, you would have been hard pressed to hold a conversation under the bridge in Neville Street. People would rush 'head down' along the narrow pavements to escape this railway underpass. Neville Street in 2010 is almost unrecognisable and a completely different experience: wide footpaths take you through a quieter and subtly-lit thoroughfare, bathed in the sound and light art of two artists. It is the result of an extraordinary, cross-disciplinary effort from Arup's acoustic, lighting, structural and electrical designers, who worked closely with the architects and artists.

By realigning the road and relocating bus stops, the team widened the footpaths. Both sides of the tunnel are lined with sound-absorbent cladding, with an air gap behind to reduce noise, especially the low-frequency boom of buses and goods vehicles. The panels are designed to look good long-term, deter vandalism and provide a blank canvas for the sound and light installations. They also conceal a multiplicity of equipment, services and access for the essential maintenance of the bridge abutments, which support the railway crossing above.

The art installation on the east side, designed collaboratively by the team with international artist Hans Peter-Kuhn, features a grid of acrylic light rods, with 3,200 light-emitting diodes (LEDs), which change daily to a randomly-generated pattern. The west side panels, designed collaboratively by the team with local artist Andy Edwards, overlay a graphic design with a moiré effect, which creates animations for passersby. The team integrated essential highway lighting into the top of the cantilevered ceiling panels along with the permanent sound system and control systems.

The design team used Arup's SoundLab, a room-sized auralisation tool, to enable stakeholders to hear for themselves the benefits of the sound-absorbing cladding and the sound art, long before any work was done on site. It also allowed the team to establish that the project would improve the experience of all users of the underpass including the visually impaired.

One regular commuter commented, "It looks sleek, smooth and rather futuristic. You have a sense of something thoughtful. I will never linger in front of the installations – it's not an art gallery – but it does get my day off to a better start."

Regent's Place Pavilion

Client
British Land

Location
London, UK

The beauty of the Regent's Place Pavilion lies in its simplicity with near-impossibly slender columns that support a planar roof of minimal thickness. To create this elegant structure required creative, first-principles engineering.

Simply slender

Regent's Place Pavilion greets visitors to one of British Land's newest office developments. Both ornamental and functional, the Carmody Groarke RIBA Award winning design was conceived following an Architectural Foundation competition that looked to add life to the public space between the buildings.

258 columns together create the vertical structure of the pavilion. At 7.8m in height, but just 50mm square and with a wall thickness of only 4mm, they defy conventional codified calculation methods and rely on creative engineering.

The success of the design relied on Arup working from first principles – design calculations, methodologies and assumptions – all verified by a technical review at Imperial College, London. They also underwent thorough physical testing in a wind tunnel and at the UK's Building Research Establishment.

Understanding the wind and dynamic response of the columns was essential. The way in which the columns were to be arranged helped factor in a degree of wind-resistance to the design, with one column sheltering another from the prevailing winds. Each column was also welded to the roof plane in order to create a more rigid overall structure. And while conventional methodologies indicated that such a welded structure would have sufficient inherent damping to avoid resonant wind vibration, this did not prove to be the case in testing. It transpired that the actual structure effectively had no inherent damping and even in a slight breeze, the columns would oscillate uncontrollably.

The Arup team set about creatively solving this problem, which was key to the success of the project. After much deliberation a simple and elegant method of providing damping without compromise to the aesthetics of the pavilion design was devised. Impact damping – involving hidden rods encased in plastic and suspended within each of the columns – effectively deadens any vibrations and prevents resonance, with the physical test results proving the preliminary calculations correct.

By using impact damping, the columns could be kept at their original dimensions – slender beyond anything previously conceived – and made possible through thoughtful and creative design.

Samsung Green Tomorrow – Zero Energy and Emission House

Client
Samsung C&T Corporation

Location
Yongin, South Korea

Arup's work with Samsung on the design of a zero-energy, -carbon and -waste emissions house has delivered major advances in sustainable building design. It incorporates passive elements based on traditional Korean building design as well as state-of-the-art green technology and IT. Korea's construction industry is expanding rapidly and Green Tomorrow has set a precedent for exemplary sustainable homes, with the country's first LEED® Platinum rating.

One of the rooms recalls the prototype of a Korean summer pavilion. The south-facing façade is made up of folding windows that can be opened during the hot summer months, while during the winter time, the double skin façade of the east side of the building helps to minimise heat loss.

Radiant floor heating, a system often used in residential properties locally, is incorporated into both the Korean room and bedroom. This type of heating is typically more comfortable due to the fact that the feet and body are warmed first, so the thermostat can be set to a lower temperature, which helps to reduce energy consumption.

To keep temperatures comfortable natural ventilation is incorporated into the design, enhancing internal thermal comfort and reducing indoor cooling loads. Photovoltaic blinds provide shading as well as generating electricity, and natural daylighting and a solar hot water system both add to the efficiency of the building. Green Tomorrow also has a Direct Current Electric Power System, further improving its energy efficiency by reducing the power conversion loss from AC to DC.

To cope with seasonal temperature variations a ground source heat pump, which warms water by using the earth's natural geothermal energy, is connected to the building's air-conditioning and air-handling units. It is a system widely adopted in Korea, that offers far greater heating efficiency than a conventional boiler and far greater cooling efficiency than a standard AC unit.

What makes Green Tomorrow such a successful project is the careful integration of the building's design features – a total of 68 green strategies – that each provide an incremental improvement to the overall energy efficiency of the building. Its LEED® Platinum rating gives the project a high profile, setting a positive example to Korea's construction industry and to the wider community.

Samsung's Green Tomorrow project sets a new benchmark for sustainable residential design in East Asia. Awarded both LEED® Platinum and the highest level of Green Building Certification in Korea, it demonstrates that zero-energy, -carbon and -waste emissions targets are achievable.

At home in Korea

Renoma Retail and Office Centre

Client
Centrum Development & Investments

Location
Wrocław, Poland

The Renoma store, built in Wrocław, in 1930, is an early example of a multi-storey steel-framed building. Designed at a time when the use of structural steel sections in construction was still in its infancy, on opening it was the largest steel-framed retail centre in Europe. It was therefore necessary to investigate the existing structure, including the physical and chemical composition of the steel, at an early stage in the redevelopment of this heritage building and to plan the structural works accordingly.

So when the team began the restoration process and uncovered a steel beam with large deflection, it warranted further investigation. Findings from advanced material investigations contradicted earlier tests and demonstrated that the steel could not be welded. Indeed, if welding had been carried out as planned, it could have weakened the steel frame and rendered the structure unsafe. Bolted connections and strengthening had to be introduced instead of the welding.

A complete technical redesign was required. Arup had to find a safe and practical structural solution that would work within the existing framework, without compromising the architectural layout for the new commercial space.

When the developer was presented with the opportunity to place tenants in the building prior to completion, Arup prepared a detailed feasibility study to reassure the owner that restoring the building from the top was possible. As a result, the top three floors were to be refurbished as office space and, once occupied, the restoration works would carry on below.

This approach required the implementation of advanced load transfer systems below the occupied area as well as a continuation of all services, such as fire safety, heating and ventilation. Careful consideration of the construction sequence was also needed to control the timing of works, particularly with regard to noise, dust and vibration impacts.

By combining its design and project management skills, Arup successfully addressed the challenges as they arose to ensure this complex restoration and retrofit was completed smoothly with new tenants already in place.

The careful restoration and redevelopment of Renoma, a major department store in Poland, has preserved its original character while revitalising this historic building as a modern mixed-use office and shopping centre.

Top down restoration

Credits

All images are copyright Arup except those stated below:

Page 2-3 01-02 Transport Scotland

Page 4-5 01 Arup/Hufton+Crow
04 Arup/Hufton+Crow
05 Arup/Kingkay Architectural Photography
Background image Arup/Hufton+Crow

Page 6-7 01 NC3D
03 Jannes Linders/Benthem Crouwel Architects
04 HS2 Ltd
05 Arup/Zhou Ruogu Architecture Photography
06 UIC: International Union of Railways
07 Arup/Daniel Clements
08 MTR Corporation Ltd

Page 8 01-03 City of Cedar Rapids – Community Development Department
04 Sasaki Associates

Page 10 04 The Edge

Page 11 01-05 Arup/Nottingham Trent University

Page 12 01 ZGF Architects
03 William Wright Photography

Page 13 01-03 Grimshaw Architects

Page 14 01, 03 Brookfield Multiplex

Page 15 01 Arup/rolaesphotography.com

Page 18-19 01-04 KPF

Page 20-21 01 Marina Bay Sands Pte Ltd 2009
02 Lian Beng Construction Pte Ltd
04 Marcel Lam Photography

Page 22 01, 02, 04, 05 Ed. Züblin AG

Page 23 03 Network Rail

Page 24 02-03 Nic Lehoux_Gensler

Page 28 01-04 Arup/Morley von Sternberg

Page 32-33 01 Zina Deretsky, National Science Foundation

Page 36-37 01-05 Peter Hyatt

Page 43 02 Rachel Robb

Page 46-47 01-02 LDA

Page 50-51 01-04 SAFElink alliance
Background image SAFElink Alliance

Page 52 02 TVS International

Page 53 ZEDfactory Ltd

Page 54-55 03 GEO

Page 58-59 01-02 Rijkswaterstaat
04-05 Royal Haskoning

Page 63 Chris Sharples

Page 64 Arup/Luke Hayes

Page 65 Samsung C&T

Page 66 Juliusz Sokolowski

Mixed Sources
Product group from well-managed forests, controlled sources and recycled wood or fiber
www.fsc.org Cert no. SGS-COC-0620
© 1996 Forest Stewardship Council

Printed by Beacon Press using their *pure*print® environmental print technology. The printing inks are made from vegetable based oils, 95% of cleaning solvents are recycled for further use and no harmful industrial alcohol is used in the printing process. The electricity was generated from 100% renewable sources and on average 98% of any dry waste associated with this production will be diverted from landfill. Beacon is certificated to Environmental Management System, ISO 14001 and registered to EMAS, the Eco Management and Audit Scheme.

ISBN no: 978-0-9516602-5-6

Contact us at designyearbook@arup.com

www.arup.com