Issue 1 2024

ARUP

The Arup Journal

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Sydney Modern Project, Australia
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A different route to pioneering cancer care

The first healthcare project in Alberta to use a design-build procurement model

Authors Ariane Camaclang, Mike Durtnall, Ross Griffiths, Marcus Jennings, Jack Johnson, Ashok Natarajan, Thilo Willems, Frances Yang

The Arthur J.E. Child Comprehensive Cancer Centre in Calgary is a landmark in Canadian healthcare. At 127,000m^2, it is the country's largest comprehensive cancer treatment and research facility, and the second largest in North America. Rising up to 13 storeys above Calgary's Foothills Medical Centre, it is also the first hospital in the province of Alberta to achieve a LEED Gold rating.

The scope of this flagship building is all-encompassing: from applied research, to cancer prevention and screening, to treatment, counselling, rehabilitation and end-of-life care. The facility includes 100 patient examination rooms, 160 inpatient unit beds, more than 90 chemotherapy chairs, multidisciplinary wet and dry research labs and 13 radiation vaults. Two of these vaults house magnetic resonance linear accelerators (MR-Linacs), making the hospital one of the first in Canada to adopt this groundbreaking technology. The ambition is that this complex, integrated facility will have a transformational effect on health outcomes in Calgary and the wider region – where cancer rates are predicted to rise by 30% in the decade to 2030.

But the project is not just a landmark in terms of what has been provided. It

1: The Comprehensive Cancer Centre is Canada's largest cancer treatment and research facility, and the second largest in North America

2: The facilities include 100 patient examination rooms, 160 inpatient unit beds and multidisciplinary wet and dry research laboratories

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was also trailblazing in terms of how it was delivered. This was the first healthcare project in Alberta to use a design-build model. With an immensely complex programme, the building was planned, designed and constructed over a 10-year period.

Arup has played an instrumental role in the design and delivery of this project. The clients – the provincial infrastructure delivery body Alberta Infrastructure and end user Alberta Health Services (AHS) – drew on the firm's global experience to develop a rigorous, highly technical but performance-based design-build contract from scratch. Over the subsequent years, Arup has continued in a trusted adviser role; overseeing the contract delivery, managing any changes to the specification and ensuring compliance with the 1,200-page Statement of Requirements (SoR). In recognition of the scope and complexity of the project, Arup's team received an Award of Excellence at the 2023 Canadian Consulting Engineering Awards.

Developing the contract

The project began life in 2013 under a different guise. At that stage, the intention was to deliver the project as a public-private partnership (P3), the dominant procurement mechanism in healthcare in Ontario and British Columbia over the past 25 years. Alberta Infrastructure had identified two potential sites at the Foothills Medical Centre for a state-of-the-art, one-stop care and research centre serving the city and wider region. Arup was appointed prime consultant and technical adviser, providing expertise on all engineering disciplines, masterplanning, architecture, traffic and transport, IT, medical equipment and technical specialities.

The Arup team, comprising local staff from Calgary, healthcare experts from across North America and specialists from the UK, developed a masterplan for one of the sites and an indicative design to schematic stage. At this stage, the proposal was for an 80-90,000m^2 centre with wide-ranging research labs and inpatient and outpatient facilities, including a bone marrow transplant unit and radiation vaults.

In early 2016, after the procurement strategy was revised, Arup was reappointed as the bridging consultant, acting as the client's prime representative, developing the requirements documents and providing technical and contract administration services in the design-build phase.

The move away from P3 was partly driven by a desire to maintain public control of the facility's operation, but it was also intended to foster a more design-led approach. The hope was that the change in procurement route would lead to a break with this template. By giving the designers more freedom and working more collaboratively throughout the initial bidding and design process, Alberta Infrastructure and AHS hoped to generate new ideas from evidence-based design and, eventually, deliver a more inspiring, healing environment.

3: In the SoR, each hospital space was defined in terms of the required lighting, equipment and other variables

4: The hospital is the first in Canada to house magnetic resonance linear accelerators

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This brought a number of potential risks, particularly in a complex, highly serviced sector such as healthcare, where half of the construction cost is typically taken up by engineering systems. For the client, design-build has the advantage of establishing a fixed price at the start of the contract, thereby reducing their financial risk.

Statement of Requirements

With this in mind, it was essential to include a detailed and exacting specification in the Request for Proposals (RFP). The challenge was to make this document broad enough to allow innovation, but specific enough to capture the vast range of clinical and non-clinical requirements such a project entails, so that it could be used as the benchmark against which all aspects of design and construction could be checked.

As the bridging consultant, this SoR was to be Arup's first major deliverable on the relaunched project. The team had already written partially complete requirements for the P3 project, requiring a very detailed description of all clinical and non-clinical components. But these now needed to be converted into a set of design and construction provisions, developed in close collaboration with departmental staff, the client teams and other stakeholders, as well as multidisciplinary Arup experts from around the world.

The SoR is an all-encompassing document that captures the scale and technical complexity of the project. There are separate sections for design objectives and for technical, clinical, furniture and equipment needs. There are also detailed specifications for 63 different clinical and non-clinical functions, from the MRI vaults to facilities management.

Each space had to be defined in terms of the required lighting, temperature, furniture and equipment, medical gas supplies, air changes and other variables. The Arup team had to consider how many people would be working there,

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5: A number of Arup's specialist project managers moved across to the client PMO to act as workstream leads on key project areas

6: The courtyard's form and orientation maximise the sunlight drawn into the building

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7: The courtyard helps with wayfinding and instils a calm environment throughout the circulation areas

8: The internal environment is enhanced by art inspired by the local landscape

9: The facility has 6,200m² of outdoor accessible space

when they would be there and what links were needed with other parts of the building. These adjacency requirements were illustrated with bubble diagrams indicating the relative importance of the proximity of different functions.

Towards approval

By late 2016, the client was ready to issue an RFP. Arup continued to help implement the design-build strategy, which had a number of innovative elements. Bidders were given the SoR and an otherwise blank canvas. The evaluation was also weighted towards a creative solution, with 45% of selection criteria design-led.

Proponents were invited to develop their proposals over a 6-month process, an initiative intended to encourage collaboration between the client and the bidders. Arup's role included advising in meetings with the RFP proponents, providing responses to technical queries and drafting addenda to the SoR, as well as meeting with the City of Calgary's planning department. The aim was for each bidder to arrive at a compliant proposal and fixed price by the end of this period.

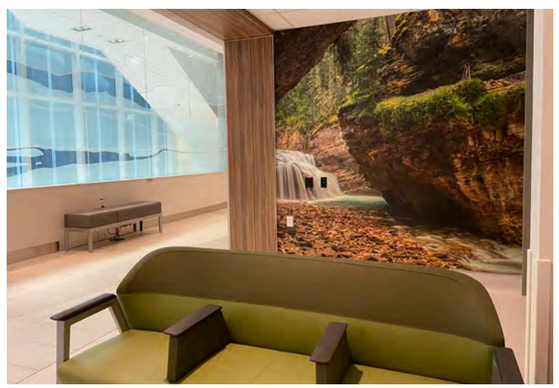
After proposals were submitted, Arup carried out a risk assessment of the schedules and a full compliance report based on the SoR. The firm did not participate in the evaluation, but remained available to respond to questions. Arup's report then formed a critical element in securing final approval to award the contract at provincial ministerial level. The contract was signed with PCL Construction in June 2017. Work began in earnest on design and construction the following month.

Managing the design process

Arup provided full multidisciplinary services to the Government of Alberta throughout design and construction. While also administering the whole stakeholder review process, the Arup team reviewed the design at contract milestones – schematic design, 50%, 75% and 100% completion – to ensure compliance with the SoR.

This required a huge amount of coordination. Arup created trackers that enabled the team to record and respond to comments from various stakeholders, including Alberta Infrastructure and AHS, as well as Arup teams in the US, the UK and the Netherlands, who were involved in checking everything from acoustics to vertical transportation. During construction, the team migrated this process to the contractor's SharePoint-based platform, to streamline it and ensure the programme remained on schedule.

The scale of the documentation involved was immense. Arup had to carry out compliance checks on data sheets for each room in the hospital. There are more than 7,000 separate spaces in the building, and even though some of these had repeated specifications, the paperwork comprised approximately 5,000 documents. The design team needed a fast turnaround to maintain their schedule, but Arup calculated that a manual compliance process would take several months.



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Based on the resources available at the time, Arup devised an automated solution. This process extracted all the data from the designs and the technical requirements from the SoR, inputting them both into a spreadsheet and running a script that would flag up any discrepancies, which enabled manual intervention. This reduced the task from months to less than seven days.

Another crucial aspect of Arup's bridging consultant role was change management. Technology advances quickly in healthcare, and the combination of a 6-year design and construction programme and a hospital that needed to be equipped with state-of-the-art technology meant that changes to the design were always likely to be needed and would have to be successfully negotiated.

An example was the two 'innovation vaults' that had been left as a slightly open element of the original brief. This gave AHS time to decide whether these two additional radiation vaults would be installed with MR-Linacs (which deliver targeted radiation while simultaneously obtaining high-contrast and high-resolution magnetic resonance imaging), or Gamma Knife radiation (which uses very precise gamma rays to treat tumours). Either would involve highly specialised design including high-precision structural requirements, mechanical and electrical services and finishes. When the decision was taken to procure MR-Linacs, Arup reviewed the contract estimates and coordinated with the user groups and design-build team, and a change order was agreed. When AHS later changed to a different MR-Linac vendor, Arup again drafted a change order and negotiated any changes to the vault design and associated costs.

The firm's trusted adviser role expanded as the project progressed. A number of specialist project managers moved across to the client project management office (PMO) to act as workstream leads on key areas such as health technology systems, furniture and equipment, and signage and graphics.

Filling the canvas

In meeting the design objectives in the SoR, the design itself benefited from the freedom granted by the 'blank canvas' design-build route. PCL's team took a different approach from the P3 indicative design from the outset, integrating a power plant into the main building that had initially been allocated to the front of the site. This had the advantage of expanding the building footprint and providing 30% more usable space, without impinging on the green outdoor areas that are so integral to the project.

The building is made up of two gently curving L-shape forms that wrap around a courtyard, one of six storeys and the other a 13-storey tower that hangs over the podium at either end in a 9m cantilever. This dramatic overhang immediately announces the building as something out of the ordinary and is an example of the design-build team exploiting the freedom to innovate and harness its own supply chain – the

10: Supplies will be transported by a self-guided vehicle system following a preset path through the building

11: The HVAC strategy includes high-efficiency condensing boilers

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12.

intricate formwork system needed to cast the concrete cantilever was procured from Germany, as this type of construction is not commonly used in North America.

Other design strategies are more understated. The courtyard is at the heart of a sophisticated approach to patient-centred design focused on daylight and nature. In all, there is 6,200m^2 of outdoor accessible space, and the building has been organised to provide as many opportunities as possible to enjoy these landscaped spaces from the inside. Its form and orientation maximise the sunlight drawn into the courtyard, and this in turn filters deep into areas that usually rely on artificial light – a factor that can exacerbate stress and anxiety in patients and visitors. The radiation therapy suite, for example, needs to be underground due to the heavy concrete walls (between 1m and 2m thick) used in its construction, but lightwells and clerestory windows draw daylight and greenery directly from the courtyard into the waiting areas.

The courtyard also acts as a strong visual landmark, helping with wayfinding and instilling a calm environment throughout the circulation areas. The shallow plan generated by the two interlocking volumes (described by the architect as a 'hug' around the courtyard) means that most spaces can be navigated in relation to external space. These connections to the natural environment are enhanced by the use of elements such as wood-grain panels and art inspired by the local landscape. Many patient bedrooms and treatment areas have views of the Rockies, the Bow Valley or the city skyline, and the patient-led approach also extends to mechanical design, with manual room controls for temperature, light, sound, ventilation and window glare.

Although the human experience is paramount, the building is also notable for its integration of automated technologies. Two robotic intravenous (IV) systems – the first to be installed in Canada – will prepare medications for syringes and IV bags in a sterile environment, improving patient safety by ensuring accuracy and reducing possible contamination. The biomedical engineering department is equipped with metal, polymer and carbon-fibre 3D printers that can create an array of patient-specific devices. Supplies will be transported by a self-guided vehicle system, following a preset path through the building.

A connected design

Another important aspect of the project is the Connector, a covered, elevated 400m pathway that links with other buildings at the Foothills Medical Centre. The Arthur Child is not a self-contained building: it relies on a connection to the main hospital for the movement of supplies and staff, and to better integrate the site's research and care facilities. Patients and visitors, too, need to be able to access different areas of the site. Of the two sites initially earmarked for the building, the one chosen for eventual development was further from the main hospital building, and therefore posed the greater logistical challenge.

The successful delivery of the Connector required buy-in from the various buildings and departments to establish contact points along the route, as well as complex analysis of the different flows, all of which were detailed in the SoR. For example, the reprocessing and sterilisation facilities are based in the main hospital, requiring isolation between flows of clean and dirty surgical equipment in the corridors. The frequency and quantity of these deliveries also had to be recorded and assessed to make sure that the Connector could accommodate peak flows. The public route, meanwhile, had to address issues around privacy and dignity while also providing amenities such as seating and coffee machines.

The resulting Connector is by necessity a structure of many parts. Paths run side by side, or one on top of the other, at different points in the route.

12: The building has achieved LEED Gold rating

13: As many as 1,650 people were on site each day during the construction work

14: The facility operates 26% more efficiently than a similar-sized commercial building

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A single storey bridge as it leaves level three of the main hospital, it crosses above the emergency department roof before becoming a 4-level, then 2-level structure, finally entering the Arthur Child on level two. From there, it is a short and direct route to the central courtyard, public lifts, and a stairway descending to the main entrance lobby.

LEED Gold

The environmental strategy formed an important component of the SoR, and this heavily influenced both the procurement process and the ensuing design and construction. Arup's specification placed a contractual duty on delivering a low-energy building, 34% below the benchmark in ASHRAE 90.1 and 37% below the National Energy Code of Canada for Buildings 2011. Alberta Infrastructure also mandated LEED Silver certification.

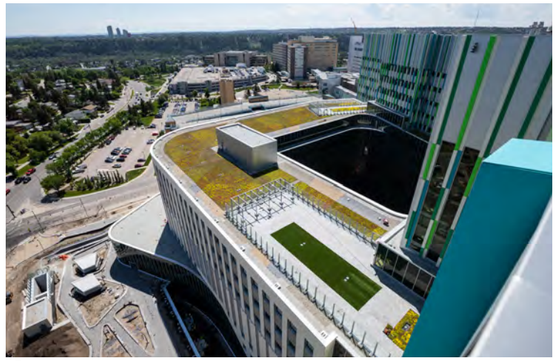
Driven by the SoR, the design included a raft of innovative energy-efficiency measures intended to allow the facility to operate 26% more efficiently than a similar-sized commercial building, despite its high servicing requirements. Dynamic glass on external windows controls solar and heat gain by changing tint on a pre-programmed schedule or via manual controls. HVAC strategies include ventilation heat recovery, high-efficiency condensing boilers, a high-efficiency magnetic bearing water cooled centrifugal chiller, and premium efficiency pumps and fans with variable speed control. LEDs and occupancy and daylight sensors are installed throughout, and it is anticipated that more than 34 million litres of water will be saved each year through the use of water-efficient fixtures such as low-flow showers, toilets, urinals, lavatories and kitchen sinks. Close attention has also been paid to indoor air quality. High efficiency filtration removes particulates and other debris from the air, and the HVAC system is designed to use 100% fresh air, ensuring that air within the facility is not recycled and reducing the risk of airborne transmissible diseases. At main entrances, innovative flooring has been installed to capture dirt and particulates.

The project has achieved LEED Gold, exceeding the standard mandated requirement. This was the highest rating that the building could achieve without making operational changes elsewhere across the site, which was outside the scope of the project.

Construction and COVID-19

Construction work began in mid-2017. It has been a monumental build, with as many as 1,650 workers on site during the peak of construction. By the end of 2022, it was calculated that they had completed more than eight million hours.

Arup continued as bridging consultant throughout construction.



15: More than 100 Arup specialists worked on this project over the course of a decade

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A key part of the firm's role was contract administration and schedule management. This involved monitoring the site, checking compliance with the design and SoR, and certifying payments at the end of each month. Again, the scale of the project required innovative ways of working, including the use of tablets to conduct site reviews – an initiative that was subsequently adopted by the Alberta Infrastructure and AHS teams.

This proved particularly valuable during the COVID-19 pandemic. Although the project was deemed essential infrastructure, allowing work to continue, Arup's policy was to restrict site visits to a minimum. It was also, of course, impossible for international members of the team to carry out planned inspections. For example, Arup's vertical transportation specialist team was based in London, so was unable to be on site when the lift installations were completed. However, in close collaboration with PCL's site team, Arup was able to send sufficiently detailed photographic and video material to enable the inspection report to be completed.

The firm also worked closely with PCL to maintain the schedule throughout this period. In the final phase ahead of opening, Arup is continuing to support the client in post-construction and occupancy activities including closeout, annual energy target assessment, warranty administration and seasonal commissioning.

More than 100 Arup specialists from across North America and Europe have worked on this mammoth project over the course of a decade. Its impact on Calgary – both in terms of health outcomes and job creation – is likely to prove transformational.

Authors

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Jack Johnson was the client's clinical and furniture and equipment workstreams lead. He is an Associate in the Calgary office.

Ashok Natarajan was the client's healthcare technology systems workstream lead. He is a senior consultant in the Toronto office.

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Project credits

Clients Alberta Infrastructure / Alberta Health Services
Construction consortium PCL Construction | DIALOG + Stantec
Arup team architects Metafor (formerly Marshall Tittemore Architects), HKS, Ground Cubed (Landscape)
Other Arup subconsultant disciplines: DB specialist, scheduling, payment certification, art consultant, infection prevention and control specialist, SharePoint development, healthcare planning, F&E consultant, land surveying, medium voltage specialist, value management.
Acoustics, AV, BIM, cost consulting, civil engineering, electrical, energy, fire, geotechnical, ICAT, landscape, LEED, logistics, mechanical, project management, structural, transport consulting, scheduling, systems integration, vertical transportation Arup:
Rezvan Ahmed, Panos Bakos, Alan Beadle, Catherine Belanger, Flavio Bertolo, Callum Brown, Matthew Browning, Thomas Bukovac, Ariane Camaclang, Luke Chang, John Co, Karima Dharssi, Mike Durtnall, Anni Feng, Derek Ferguson, Adam Foxwell, Giuliana Galante Casazza, Bettine Gommer, Tristan Green, Natasha Greenwood, Ross Griffiths, Luke Healy, Alex Hucal, Annika Hui, Marcus Jennings, Jack Johnson, Diane Kim, Courtney King, Helen Kwan, Leonora Lang, Alba Losada Amor, Zoran Markovic, Keith McCall, Lisa McMillan, Ashok Natarajan, Cherilyn Ng, Sheri Oghbaie, Edward Poon, Rebecca Rogers, Meron Semaw, Ken Sissakis, Brian Smith, Andrew Sorrie, Mark Summers, Theodore Tasic, Justin Trevan, Svetan Veliov, Christine Wang, Thilo Willems, Edmund Wong, Katie Wood, Frances Yang, Daniel Yoon.

Image credits

1, 5: David Watt Photography
2, 3, 9-13: Ross Griffiths/Arup
4, 6, 7, 14, 15: PCL Construction
8: Arup

1.

Planning for Southern Auckland's sustainable economic success

Innovative economic masterplanning to drive growth

Authors Gaurav Ahuja, Greer Oliver

1: The masterplan sets out a vision for how Southern Auckland can be developed sustainably, boosting growth and creating thousands of jobs

Southern Auckland, on New Zealand's North Island, is a strategic corridor that connects the nation's largest city, Tāmaki Makaurau-Auckland, with the fourth largest, Kirikiriroa-Hamilton. Proximity to these prosperous cities and the wealth of land available for development make the area a desirable place to live and do business, and it is already home to over 350,000 people. The location was initially projected to grow rapidly over the next 30 years to accommodate 22,000 new houses and more than 12,000 jobs. But Southern Auckland needed a new vision and significant investment from the public and private sectors to, at a minimum, accommodate this expansion, connect the suburbs with new industries, create employment opportunities and foster economic growth.

Tātaki Auckland Unlimited (TAU) is Auckland's economic and cultural agency. It drives investment and innovation in the region to help deliver a coordinated, region-wide programme to maximise cultural, social and economic benefits for residents and visitors. TAU commissioned Arup to develop an economic masterplan for Southern Auckland. Based on NZ$2.8bn

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2: Southern Auckland is a strategic corridor that connects Auckland and Hamilton

3: Proximity to Auckland, New Zealand's largest city, is one of the factors that make the area so attractive

4: There is a wealth of land available for development

4.

investment from the private and public sector over the next decade, the resulting plan will see the transformation of the town of Opāheke-Drury – and the surrounding areas – around five economic hubs; health, construction, food and beverage, wool and textiles, and the circular economy. In total, this development could be worth NZ$44.3bn to national gross domestic product (GDP) and exceed the initial employment target to create more than 50,000 jobs.

Arup's activities encompassed strategic economic positioning, environmental consulting, town planning, masterplanning and urban design, landscape architecture and civil engineering. The result was a masterplan that provides a roadmap for investment to drive sustainable growth for business, housing, employment and infrastructure, creating opportunities for businesses and residents alike.

A new approach

It was essential that the plan should align with the New Zealand Government's economic and social objectives and the changes it has promised to implement in the country; improving household incomes and housing affordability, creating new jobs with higher-value skills and capabilities, and helping New Zealand move up the value chain in terms of the industries it attracts.

Masterplanning has historically been dominated by governments and has operated using the principles of town planning, based around roads, buildings, transport infrastructure, and commercial and residential property. But in Southern Auckland, the economic planning came first: the Arup team began with an analysis of what the area would need to thrive and to attract private investment from industry, before moving on to what would be built and where.

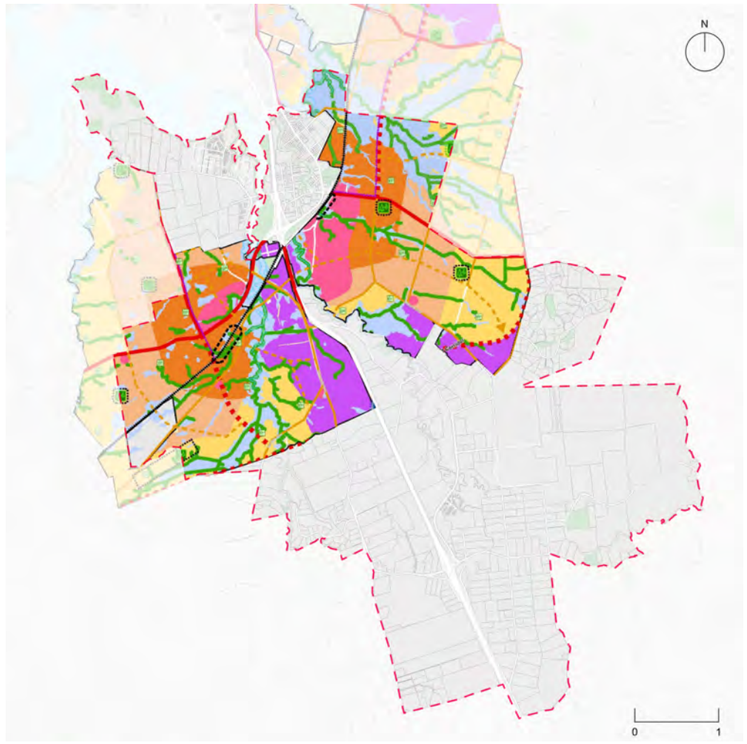
Sectors analysed as part of the research included health, construction, and food and beverage. These sectors were analysed in terms of how they compared to other major economies, how much they were worth to New Zealand now and how much they could potentially bring to GDP through the Southern Auckland development. By far the two biggest industries considered were health, which could be worth an additional NZ$23.6bn, and construction, which could be worth NZ$17bn. Between them, they could potentially create nearly 40,000 jobs.

A major opportunity identified in the planned development is a potential new hospital, which would not only serve the area's growing population but also support other health sector activities relating to education, training, research and the production of healthcare goods and technologies. This will develop skills that are already in high demand and support productive businesses in the health and biotech sectors. The plan envisages that the hospital will be between 55,000m^2 and 100,000m^2 in size. The masterplan also proposes the creation of hubs for advanced industry, biotech and the circular economy. One early adopter is global kitchen appliance manufacturer Fisher & Paykel, which is planning a 105ha campus for research on the site.

Smaller target sectors identified by Arup's research were food and beverage manufacturing, worth NZ$3.7bn, and wool and textiles, worth NZ$200m, which could create 1,446 and 60 new jobs respectively. The site's proximity to the coast was also seen as having great potential for the fisheries industry, which would both enrich the immediate area and be an asset to the consumer market and food security in New Zealand as a whole.

A blank canvas

While having a relatively blank canvas to work on had benefits for both economic and physical planning, it also created challenges. Cities like New York, London, Paris and Tokyo have taken centuries to become thriving urban centres; they have organic ecosystems that have developed over time. In Southern Auckland, the attempt is to create an ecosystem, albeit at smaller



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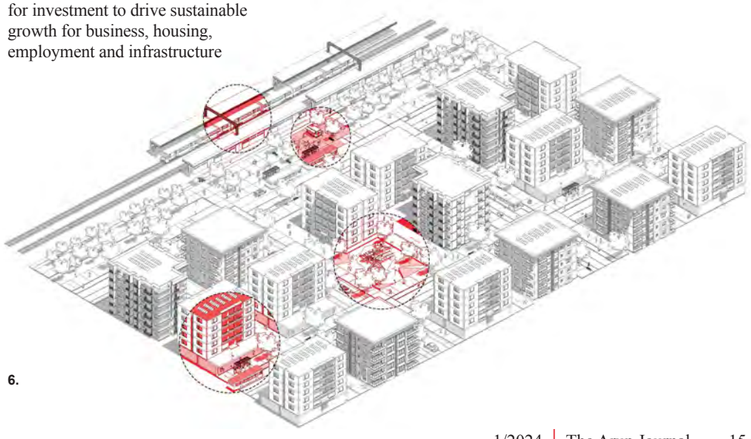
5: The plan aligns with the New Zealand Government's objectives around improving household incomes and housing affordability, and creating new jobs with higher-value skills

6: The plan provides a roadmap for investment to drive sustainable growth for business, housing, employment and infrastructure



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scale, in a highly accelerated timeframe; in just 10 to 15 years, Drury is expected to become a thriving centre.

Another challenge was that the client, TAU, does not own the land identified for development. As such, Arup was tasked early on with engaging multiple stakeholders from the public and private sector to promote the planned development. This was one aspect where the front-loading of the economic strategy helped, as did the fact that central government supported the project. It meant that stakeholders were able to see early on that the project would have significant political and economic backing and understand how, by aligning interests across multiple parties and sectors, there could be mutually beneficial outcomes for all.

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Māori partnership

As with all major projects in New Zealand in the past decade or so, the Southern Auckland project involved *mana whenua*, the indigenous Māori people who have historic and territorial rights over the land. The area of the masterplan fell into the jurisdiction of three *iwi* (tribal authorities) in Tāmaki Makaurau-Auckland.

The masterplanning process was used as an opportunity to enhance cultural, economic, social and environmental outcomes for the Māori people. Economic development in Southern Auckland can play a significant role in improving these outcomes, including employment, housing and education, by using the framework of five *pou* (pillars) of *mana whenua* aspirations: governance, culture, natural environment, economy and wellbeing.

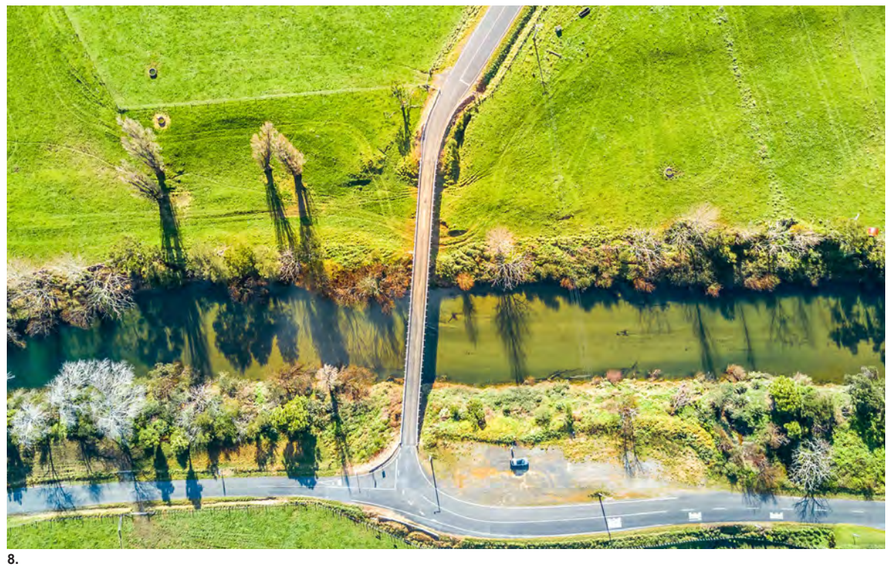
Māori businesses have been considered at the earliest stages of economic planning: these businesses are already growing, with the majority of growth coming from the food and fibre sectors, and the *Rautaki mo te Taurikura* action plan (a collaboration between government and the Māori Primary Sector Forum) will provide investment into these sectors.

The project team was guided and inspired by the long-term thinking that is so ingrained in Māori culture, where it is typical to think of development in terms of the previous seven generations and the next seven generations. Using that timeline (approximately 150 years), Arup was able to consider the impact of the project far into the future, rather than the usual time horizon of up to ten years that is typical of the planning processes.

The development plan was set out in three stages; zero to five years, five to ten years and ten years plus. The first stage will initiate innovative economic development through the establishment of a health campus and resources hub around Ngākōroa Station. The focus for stage two is the establishment of an innovation campus and industrial and advanced manufacturing activities. The final, long-term stage unlocks land at the southern end of the area identified for development, including the establishment of a logistics hub to provide for regional, national and international exchange of goods and materials.

Building a community

Central to the project was the fact that the economic strategy and the urban planning were carried out simultaneously. Rather than architects and engineers drawing up a masterplan and leaving it to a funder or a developer to calculate how to pay for it, the financing and design ideation were being carried out in tandem. How the project could pay for itself was front of mind throughout the process.



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The team looked at existing transport infrastructure and buildings, as well as geography, including rivers and other natural barriers that could constrict development. They were tasked with ensuring that the development would function as its own community, as well as being part of the Auckland Region. The Arup team worked collaboratively to understand the spatial requirements of the identified economic opportunities and mapped these throughout the region with a land-use plan. Ideas were tested, feedback gained and stakeholder buy-in obtained on the opportunities presented. By using an iterative process, the plan seeks to balance economic, placemaking and community interests.

The masterplan creates easily adoptable and sustainable investment opportunities by ranking each opportunity by 'development readiness' and sorting them into work packages. This approach gives the public and private sectors guidance to work together to create sustainable growth, and the confidence to plan future public and private investment decisions.

A dual approach

In a first for economic masterplanning in New Zealand, this project brought together perspectives from a diverse group of stakeholders, including government, the private sector, landowners and *iwi*, to drive investment and policy alignment. In planning this ambitious development, Arup took a similarly innovative approach, viewing every element simultaneously through two different lenses – economics and urban planning – in a way that will inform future masterplanning projects.

The firm expects this dual approach to be at the forefront of future projects, enabling economic, commercial and financial thinking to be embedded into technical analysis early on. The process followed in the creation of the Southern Auckland Economic Masterplan can be replicated across other regions in New Zealand and elsewhere, helping to unlock potential and ensuring that future generations can live, work, play and thrive.

7: The development plan was set out in three 5-year stages

8: The plan considered rivers and other natural barriers that could constrict development

9: The plan centres on five economic hubs: health, construction, food and beverage, wool and textiles, and the circular economy

9.

Authors

Gaurav Ahuja is Arup's Australasia finance and economics leader and a Principal in the Melbourne office.

Greer Oliver was the lead strategic planner and Project Manager. She is an Associate in the Auckland office.

Project credits

Client Tātaki Auckland Unlimited
Town planning, urban economic planning, masterplanning and urban design, landscape architecture, transport planning Arup: Gaurav Ahuja, Yostina Badawi, Auryl Bernhardt, Phil Carter, Kate Hardwick, Paige Herbst, Victoria Liu, Eloise Mitchell, Malcolm Smith, Jamie Stronge.

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1.

A new model for urban stormwater resilience

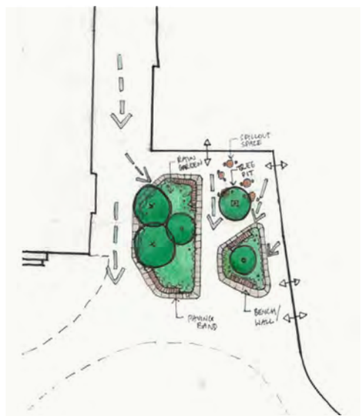
Using nature-based drainage systems to make a town more spongy

Authors Peter Holt, Zac Tudor

Urbanisation, population growth and increasingly frequent incidences of severe weather brought on by climate change have exposed towns and cities to major risks of flooding and watercourse pollution. These pressures on drainage infrastructure are reducing the resilience of these urban areas. In the UK, overloaded combined sewer overflows (CSOs) frequently discharge untreated wastewater into watercourses or coastal waters, resulting in poor water quality that negatively effects health and wildlife.

Spearheading a more enlightened, nature-positive approach to urban drainage, Arup worked with water company Severn Trent Water and UK water regulator Ofwat to design and implement a first-of-its-kind flood resilience scheme. The £76m initiative plans to turn the town of Mansfield, in Nottinghamshire in the UK, into the equivalent of a giant sponge, using hundreds of nature-based interventions on roads and in public spaces to capture tens of thousands of cubic metres of stormwater, freeing up capacity in the existing sewers. As the largest sustainable drainage project in the country, it will help reduce flood risk for 110,000 people. It also demonstrates how nature-based flood resilience can be designed at a town- or catchment-level scale, and at a rapid pace, with the entire scheme due to be completed in just four years.

Arup provided sustainable infrastructure design, water engineering and flood risk management services, and the firm's digital innovation and technology expertise was critical to the delivery of the project. The firm also inputted into research on recycled functional sustainable drainage systems (SuDS) soils and on urban greening approaches that, together, can deliver reduced maintenance requirements for the client. Arup's expertise, combined with sophisticated machine learning and data analysis, was employed to develop the initial masterplan study, which was used to secure funding from Ofwat.



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1: The flood resilience scheme in Mansfield will improve water quality, biodiversity, and even human health and wellbeing

2: Hundreds of nature-based interventions on roads and in public spaces will capture tens of thousands of cubic metres of stormwater

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Moreover, the work to decide what types of infrastructure to install in Mansfield resulted in the development of a digital tool capable of accurately locating and quantifying the volume of nature-based solutions that can be retrofitted in towns and cities.

Sustainable drainage

Climate change is having a dramatic impact on rainfall in the UK. Even if pledges to limit temperature increase to 1.5ºC are met, locations in South-East England, North-East England and South Wales are set to experience significantly increased flooding in the years ahead.

As green spaces in towns and cities are increasingly built on and paved over, areas of permeable land that can soak up rainwater are lost and existing drainage systems become overloaded, causing flooding and other issues. SuDS, alongside natural flood management measures such as bioswales, rain gardens and basins, provide a nature-based alternative that can not only cut the volume of water entering sewers and waterways to mitigate flooding, but also improve water quality, biodiversity, and even human health and wellbeing. These 'blue-green' interventions replace traditional 'grey' drainage systems made from concrete, which are carbon-intensive to produce and install.

Numerous SuDS schemes have been implemented worldwide, but Mansfield's is the first to be delivered at such an ambitious scale and rapid pace, with close to 500 interventions planned to be constructed across the town from a standing start in spring 2021 to full handover in April 2025. This Mansfield Sustainable Flood Resilience project was created in response to a challenge set by Ofwat, the UK Department for Environment, Food & Rural Affairs, the Environment Agency, the Drinking Water Inspectorate and the Consumer Council for Water, asking water companies to put forward ideas on how to promote green economic recovery after the COVID-19 pandemic.

Arup was initially appointed by Severn Trent Water as key consultant to develop the blue-green masterplan concept. Mansfield was considered an ideal location due to local flooding risk and CSOs, and because the catchment was of sufficient size to further the understanding of how to deliver blue-green flood resilience schemes at scale.

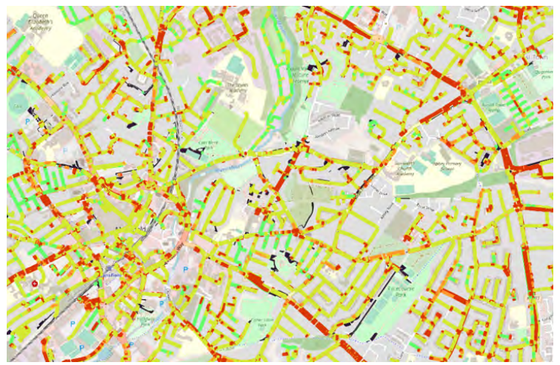
Land use and multiple benefits analysis

Arup has a strong track record in delivering sustainable solutions to help developers, local authorities, government agencies and infrastructure operators understand and manage flood risk. The firm drafted guidance for the Construction Industry Research and Information Association on flood resilience of critical infrastructure systems, has worked closely with the Environment Agency for many years, has supported flood management authorities such as the Regional Water Management Boards in Poland, and developed the Shanghai urban drainage masterplan for the Shanghai Water Authority.

3: Arup designed the town centre rain gardens

4: Analysis revealed 14 different land typologies in Mansfield

5: The Digital Strategy Tool can analyse an entire town to quantify potential volumes and types of intervention, street by street



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6: Arup developed a new digital tool to identify and quantify the volume of different retrofitted blue-green interventions

7: The tool used detailed mapping and algorithms to assess the entire town and calculate water storage volumes street by street

In Mansfield, the firm deployed Terrain, an Arup-developed land use analysis mapping tool, to quantify the typologies for the masterplan study. Terrain uses data analytics, machine learning and automation to digest large quantities of data and satellite imagery and determine how land is being used in far greater detail than has ever been possible before. The system sifts through this information to identify patterns, producing detailed land use maps and accurately calculating a study area's percentage coverage of different land types, such as grass, trees, industrial or commercial districts, and different types of residential areas. Approximately five times faster than manual analysis, it can analyse 20,000m² of land data per second and can even distinguish between visually similar elements, such as a tree nursery and a forest.

Rapid analysis revealed 14 different land typologies in Mansfield. Arup's stormwater management experts then used these to assess each typology's ability to accommodate different nature-based mitigations for stormwater flood risks, to quantify the potential volume available. With the types and quantities identified, the team were able to undertake a cost-benefit analysis of potential scenarios, including wider benefits associated with nature-based solutions, revealing that a £6m investment to establish a green wastewater management solution would result in over £22m of wider benefits.

Apart from improved flood resilience, the team found that there would be health benefits for citizens, due to improvements to the living environment; increased local government and business revenues, thanks to greater local economic activity; and upskilling in green economy jobs. The improvements to local amenities were also expected to benefit human health and happiness. This analysis supported Severn Trent Water in developing the business case for the pilot, which was subsequently awarded the £76m in funding by Ofwat.

Digital innovation

With the funding in place, Arup assembled a multidisciplinary team to deliver both outline and detailed designs. Collaboration was key, as the plans required the involvement of multiple consultancies and contractors and approval by two local authorities; Mansfield District Council and Nottinghamshire County Council.

Digital innovation again came to the fore when scoping out a comprehensive town-wide strategy, optimised to the tight 4-year timeline. Working with CADA Consulting, Arup developed a new Digital Strategy Tool to quickly identify and quantify the volume of different retrofitted blue-green interventions along every highway and road in the study area. The tool used detailed mapping and algorithms to assess the entire town and calculate water storage volumes across all drainage areas – evidence that was needed to inform delivery strategies, to cost-plan more effectively and to consider future scenarios. A total storage volume of 34,000m³ was identified along highways in the study area. The tool also displays data and insights in a user-friendly dashboard. This was accessible to Severn Trent Water and other stakeholders so that they could review

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strategy scenarios and recommendations across the whole town or focus in on a smaller area.

The tool can analyse an entire town or catchment area in advance of design to quantify potential volume and types of blue-green intervention at a reasonable level of detail. This is revolutionary, because design is traditionally completed before volumes can be calculated, restricting assessment to much smaller geographic areas.

Blue-green interventions

The valuable information from the Digital Strategy Tool guided Severn Trent Water to establish the overall project strategy, and to help the company steer procurement and works needed to deliver the scheme. The project's initial objective was to create up to 15ha of blue-green interventions, able to store around 58m litres of stormwater. This is equivalent to 60% of the future network storage required up to 2050, or approximately 23 Olympic-sized swimming pools.

The several hundred interventions will include up to 6.5ha of green spaces and 2.5ha of permeable surfaces. Together, these will reduce the impact of extreme storm events by catching water runoff from roads and roofs and slowing the flow of stormwater into the ground or existing sewers. The filtration through soils helps to filter out pollutants from rainwater runoff, which is particularly important if the water is released back to a river.

Solutions include detention basins – larger storage areas in open spaces that are mainly dry when it has not been raining. These have been installed in public parks across Mansfield and in a school playing field. Other solutions include smaller landscaped surface depressions, known as bioswales, that are placed in land alongside roads and incorporate planting; and rain gardens immediately adjacent to roads that provide shallow depressions that runoff drains into before filtering down through the plants and soils. In addition, some streets will be made of permeable paving materials that absorb water and store it before releasing it slowly. Other installations include bioretention tree pits with appropriate species, located in streets and public areas; and rainwater downpipe planters located below building downpipes that take rainwater from roofs and provide raised areas of planting.

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8: Rain gardens provide a nature-based alternative to grey infrastructure

9: Arup led and part funded research to assess the efficiency of different designs of surface inlets to capture surface water and direct it into rain gardens

10: A typical constructed bioswale showing timber checkdams

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Research

Arup has built a strong working relationship with the University of Sheffield through previous projects, and the firm was able to introduce the institution to the client for its expertise to feed into the development of SuDS for Mansfield. Studies were carried out, in partnership with Severn Trent Water, to understand soil structures and water dynamics in blue-green infrastructure, and how they interrelate as part of a holistic system, and to quantify the benefits.

Arup also led and part-funded research that assessed the efficiency of different designs of surface inlets to capture surface water and direct it into rain gardens. Working with the University of Sheffield and Severn Trent Water, the aim was to assess the impacts of different variables on performance, rank them in importance, and carry out a cost-benefit analysis to see if designing bespoke inlets aimed at maximising water capture would provide value for money. Results from physical modelling and experiments with specially constructed test rigs are currently being written up in a scientific paper that is due to be published later this year. This data-led approach is expected to inform SuDS best practice and industry standards.

Insights from the research also led to new SuDS product designs. For example, the team engaged with the client and a manufacturer to develop a prefabricated orifice chamber fitted with a non-return valve which, in the event of heavy rainfall, prevents combined sewage from backing up into a rain garden and causing pollution.

Three pilot schemes with a range of biodiverse interventions were completed in August 2023 in the town centre, adjacent to Mansfield Town Hall, and different interventions are currently being constructed across the whole town, with completion due in April 2025.

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11: The scheme shows that it is possible to create fresher, greener places to live for residents and communities

Lessons learned

A key motivation behind the Mansfield project was to track the lessons learned, to help guide the industry towards more sustainable approaches to flood resilience. The scheme revealed the challenges of upskilling the workforce to deliver blue-green infrastructure at scale and pace, including contractors responsible for highways improvement works or flood resilience in general.

One key positive outcome was the successful merging of Arup's technical excellence with digital technology. The use of digital tools has helped remove much of the 'heavy lifting' related to repetitive tasks, freeing up designers and engineers to focus on more creative and interesting aspects of design and delivery. The multidisciplinary nature of the work provided the conditions to break down traditional silos between professional teams, enhancing understanding of different perspectives and the challenges and opportunities involved.

Flooding and combined sewer overflow spills threaten many towns and cities worldwide, and Arup's work in Mansfield demonstrates how a nature-based approach can mitigate the phenomenon across a whole town in a way that is easier to understand and predict. In recognition of these achievements, the project won Natural Capital Initiative of the Year at the Water Industry Awards 2023, while the groundbreaking work with the Blue-Green Digital Strategy Tool was nominated for Digital Initiative of the Year at the British Construction Industry Awards 2023.

More than just a blueprint for how municipalities can better manage stormwater in the future, the Mansfield scheme shows that it is possible to create fresher, greener places to live for residents and communities, as well as giving a much-needed boost to biodiversity and improving water quality.

Authors

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Image credits

1, 2, 4-11: Arup
3: Giles Rocholl Photography

First-class expansion

Critical infrastructure modernisation on the busiest commuter rail line in the US

Authors Peter Guest, John Mastera

The Long Island Rail Road (LIRR) Main Line is the central artery of the New York area's Metropolitan Transportation Authority (MTA) commuter rail system in Queens, Nassau and Suffolk counties. The 120-mile line extends from Montauk at the eastern end of Long Island to Manhattan (Grand Central Madison and Penn Station) and is the busiest commuter line in the US, serving 87 million customers each year.

The LIRR Expansion Project (LIRR EP) modernised a critical 9.8-mile (15.8km) segment of the LIRR Main Line from Floral Park to Hicksville stations where, previously, four tracks narrowed into two. This section of the network carries 41% of the LIRR's daily passenger numbers and is where five branches converge. The upgrade of this segment of the network was a strategic component of a larger plan to transform New York's regional transportation infrastructure.

The US$2.6bn design-build LIRR EP provided a new third track for this segment, increasing rail capacity by 40% when coupled with the new Grand Central Madison service, allowing for more frequent and robust services during peak periods. The other elements of this major infrastructure upgrade included the reconstruction of five stations, seven bridge replacements, six new pedestrian bridges, three bridge expansions, the elimination of eight level crossings, and the upgrade of all rail infrastructure and systems, along with improving station accessibility.

Arup brought its technical experience from its contribution to the MTA's Enhanced Station Initiative, which saw the modernisation of 20 stations, Fulton Street Station and the Second Avenue Subway. On this latest project, the Arup-led joint venture with Jacobs (AJJV) served as the Project Management Consultant (PMC) for the MTA's Construction & Development division (MTA C&D), overseeing the design-builder. The PMC was responsible for commercial, risk, public outreach, rail operations, digital information management, and compliance oversight of design, construction, quality, environmental, safety and security. This was the first time a design-build delivery method had been used by the MTA. The AJJV, with MTA C&D, LIRR, and New York State Department of Transportation staff, formed the integrated Project Management Team (PMT), co-located with the design-builder and project designer at a project office established along the project corridor.

Upgrade in a dense urban environment

The LIRR EP passes through a dense urban environment. The PMT ensured all communities had a voice in the plans to deliver the project and minimised impacts to the surrounding communities through an extensive public outreach campaign. The project was accomplished without acquiring any residential property, and rail services were maintained throughout construction, outside of planned outages. There were 51 double-track weekend outages that fully shut down the Main Line branch of the LIRR, with seamless returns to weekday morning services on each occasion after the weekend works were completed. While LIRR previously conducted one or two double-track outages a year, they implemented more than 15 per year for this project, with 39 of the 51 double-track outages being

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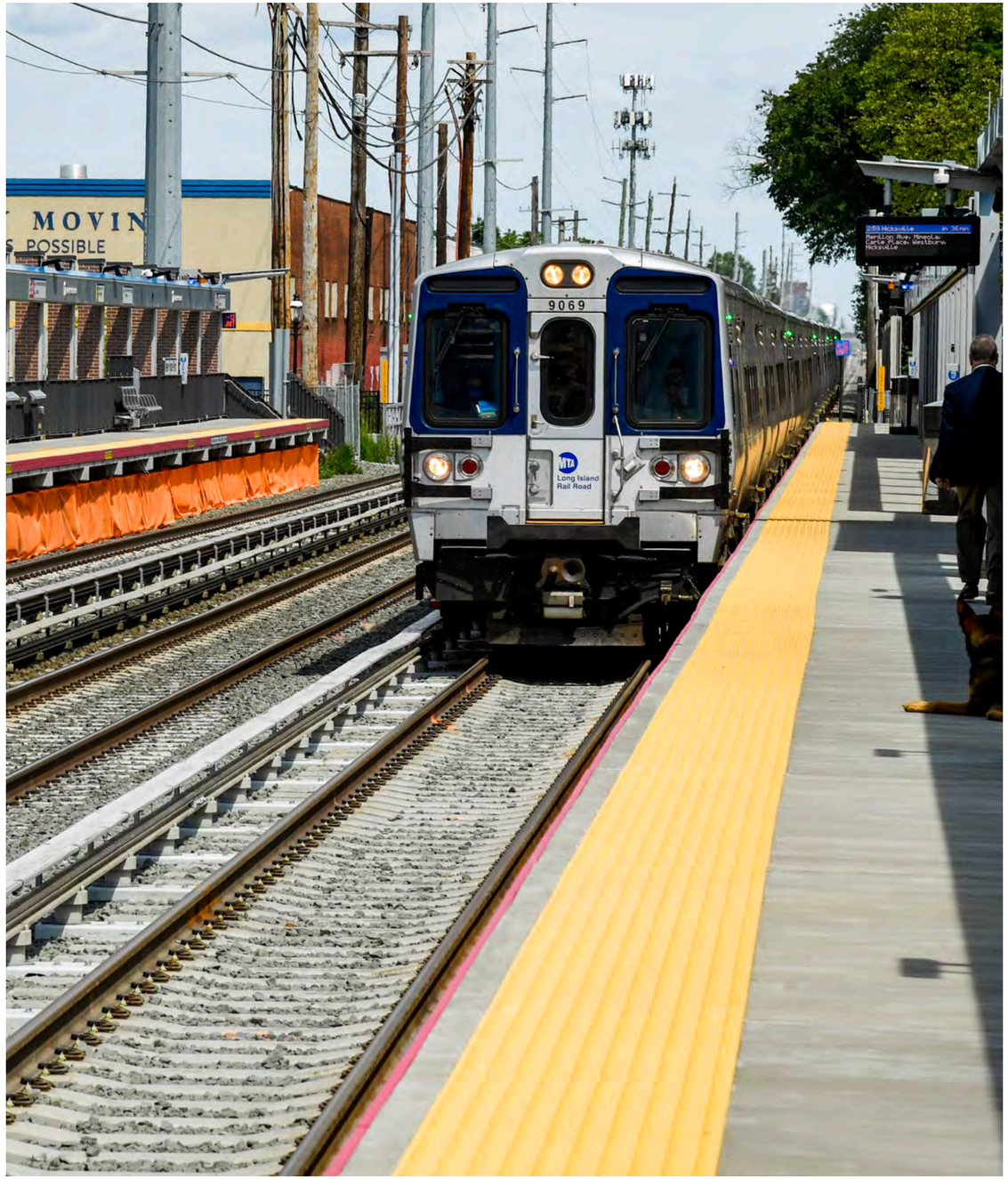
1: The LIRR extends 120 miles from Montauk to Manhattan and serves 87 million customers each year

2: Eight level crossings were removed as part of the project, improving safety and reliability

3: New Hyde Park Station was one of five stations that were reconstructed



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implemented on consecutive weekends. The AJJV helped develop 15-minute work plans to ensure the weekend outages went smoothly.

An initial section of two blocks of the LIRR EP opened in August 2022, with the final block opening in October 2022. The completed project was a key component in enabling Grand Central Madison, the new LIRR terminal in midtown Manhattan, to open with full capacity in early 2023.

Creative construction methods

In the US, level crossings are one of the major causes of death, injury and property damage resulting from improper interactions between rail and non-rail assets. Eight level crossings were eliminated as part of the project, including an accelerated programme for the School Street crossing where, prior to the works, there was a fatal accident in 2019. The removal of these crossings had both an immediate and a long-term positive impact on LIRR, and on pedestrians, cyclists and motorists looking to cross the LIRR Main Line tracks. Previously, as trains approached stations, the crossing gates were in the down position about 30% of the time during morning and evening peak periods.

Six of the crossings required major re-profiling by creating depressed roadways beneath newly constructed bridge structures. Traditional construction methods would have necessitated numerous track outages, resulting in impacts on the travelling public as well as overall LIRR operations. To overcome this, a 'box-jacking' construction method was used, with the entire bridge's steel structure and concrete foundations fully constructed in a pit adjacent to the tracks. This innovative methodology utilised a proprietary system not previously used in the United States, and enabled trains to run unrestricted while the bridges were being built. Once complete, each bridge was installed over the course of a single weekend double-track outage.

To accommodate the new third track, four bridge superstructures were replaced and the existing substructures – some of which were nearly 60 years old – were modified, all while maintaining train operations. Several of the bridge replacements increased the clearance height below, enabling large vehicles to pass underneath more safely. This eliminated a long-standing vulnerability that caused safety concerns and delays from over-height trucks. Between 2016 and 2018 there were an average of 76 truck versus bridge accidents across the LIRR system per year, each of which led to widespread, often system-wide LIRR delays, and disruption to local vehicular traffic.

A self-propelled modular transporter (SPMT) was used for four of the bridge replacements. The weekend process for this construction element included taking the tracks out of service on the Friday night; disconnecting the existing steel bridge from the abutments and rolling it out of place using the SPMT; performing modifications to the substructure in preparation for the new bridge installation; installing the new off-site constructed bridge in place using the SPMT; and backfilling so the tracks could be re-installed and prepared for train service by Monday morning.

A new three-track interlocking installation took place on the route, with signal apparatus put in place to prevent

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4: An accelerated programme was used for the removal of the School Street level crossing where, prior to the works, there was a fatal accident in 2019

5, 6: Box-jacking was used for the level crossing removals, with the entire bridge's steel structure and concrete foundations fully constructed in a pit adjacent to the track

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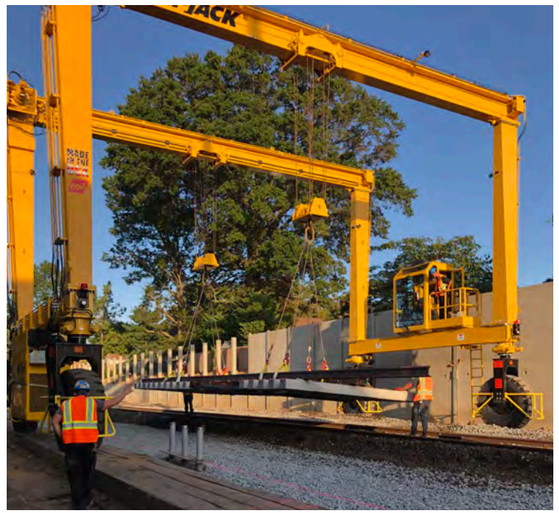
conflicting movements on the track. This was part of a major systems upgrade which included the installation of 55 miles (88km) of new fibre backbone for the communications and control systems. Work also involved installation of seven new substations, six new battery huts, eight new signal cases, 17 master location signal huts (each with battery cases), and a positive train control system.

The corridor where the interlocking was installed was directly adjacent to commercial buildings on the north side of the railway, with residential homes on the south side for nearly three-quarters of a mile (1.2km), resulting in limited construction access. For this work, a steerable rolling gantry crane was used that could follow a wheel path within the narrow right of way (ROW) to receive the track materials, and deliver and install them at the correct location. In addition to allowing for material delivery in a constricted area, the gantry crane was able to maintain its position in the ROW during the times when works were not occurring and allow trains to pass beneath it.

Timetable and temporary platforms

As the LIRR EP was constructed under live operating conditions, one of the PMT's central roles was to ensure that safe, reliable rail services were maintained during construction. As such, they co-rewrote timetables to accommodate and coordinate LIRR EP construction activities with other LIRR projects, as well as coordinating and implementing service plans, outages, work trains, and roadway worker protection for the design-builder and LIRR workers on or near the LIRR ROW.

7-9: An SPMT (7), a steerable rolling gantry crane (8) and temporary platforms (9) were deployed to ensure continuous operation of the railway during works



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The PMT also planned for station infrastructure and platform work by having temporary platforms installed and using gangways to ensure the safe boarding and alighting of trains. These temporary platforms allowed the design-builder to perform all the necessary construction work at the stations, while protecting the public and avoiding disruption of train operations.

Digital strategy

The project team developed and implemented an innovative digital strategy to help manage various aspects of the project in both the design and construction phases. This included the development of a web application for design and construction oversight, and the development and hosting of a cloud-based electronic data management system. Tools were used for workflow automation and electronic document controls, and for oversight of asset management and GIS data submissions by the design-builder to facilitate monitoring construction and support reporting functions.

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The web application for construction oversight included a mobile mapping solution that was deployed on tablets and smartphones for logging daily and weekly construction activity observations, and quality, environmental and safety observations. This enabled the project's field engineers to directly contribute structured and complete data in a cloud database, rather than recording observations by hand and later transcribing unstructured information. The results were not only notes that were organised and searchable, but also photos, videos and audio recordings that could be linked to construction observations and geotagged to the location of the worksite. This extensive data ensured the design-builder's compliance with contract requirements, while also creating a permanent project record.

Community outreach

As with many large-scale infrastructure projects, the LIRR EP had the potential for creating construction-related impacts and disruptions to residents and business owners along the project corridor. To mitigate potential hazards or disruptions, the PMT managed a robust stakeholder and community engagement programme along with the design-builder. Hundreds of meetings with elected officials, community leaders, homeowners and other stakeholders along the project corridor were held. A community information centre with project-related documentation and materials was set up at the Mineola LIRR station.

A community benefits fund (CBF) was included in the design-builder's contract, with the purpose of providing funds for the affected communities to maintain their quality of life during the project's construction. The PMC managed and tracked the CBF, which allowed for qualified costs incurred by affected communities to become eligible for reimbursement by MTA C&D and LIRR (e.g. landscaping efforts to offset visual construction impacts). The team created a community scorecard, used by the affected communities on a quarterly basis to rate the design-builder's commitment to fulfilling its contractual environmental and community commitments.

In addition to a CBF, the PMC administered the Design-Builder 'Incentive Program'. This element was designed to encourage the design-builder to meet or exceed the community safety and quality-of-life commitments. These two programmes resulted in a highly effective method to exceed the community, town and village expectations. They kept all parties in communication with each other and helped the project to complete the required work with a minimum of disruption to the surrounding communities.

Performance and reliability

In addition to the increased capacity, the additional track allows for true bidirectional intra-island commuting for the first time. The LIRR can now run an east- and west-bound local service, while at the same time running an increased number of express trains that will get commuters to Manhattan and back to points further east with greater frequency and speed. The LIRR now also has the ability to circumvent potential service disruptions by working around any disabled trains or other unforeseen situations. A positive train control system was put in place to prevent train-to-train collisions, over-speed derailments, incursions into established work zones, and movements of trains through switches left in the wrong position.

Critical to the project's success was providing commuters with completely rehabilitated stations that have many of the modern elements passengers have come to expect, such as platform Wi-Fi and phone charging, video messaging boards and comfortable station houses to wait in for the next train. The fully rehabilitated stations were built with increased platform widths and lengths to facilitate access to the 12-carriage trains, allowing for easier, more efficient entering and exiting of trains, which in turn enables those trains to spend less time in the stations and thus stay on schedule. To comply with the Americans with Disabilities Act, new ramps were installed at five stations, with 11 lifts either replaced or newly installed, allowing all passengers to easily traverse station entrances and exits and to safely use overpasses to reach platforms.

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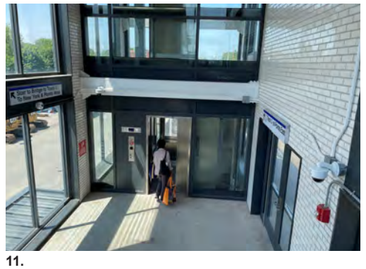

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10: The rehabilitated stations have wider and longer platforms than before

11: To improve accessibility, 11 lifts were either replaced or newly installed as part of the project

12: The lifts enable all passengers to safely use overpasses to reach platforms

13: The upgrades to the nation's busiest commuter rail line will benefit Long Island communities for years to come

Benefiting local communities

The LIRR EP was completed within a corridor that, for most of its length, was only 66 feet (20m) wide, surrounded by both major commercial properties and residential homes. State-of-the-art construction methods were implemented as part of the project, including accelerated bridge construction and an advanced level crossing elimination technology, and advanced digital technologies were developed for project management.

The elimination of eight level crossings along nearly 10 miles of busy Main Line LIRR track constitutes a tremendous boost to the safe operation and reliability of the country's most-used commuter rail network. The project achieved heavy construction completion after four years of work on schedule and under budget, completing a project that will benefit Long Island communities for generations to come.

13.

Authors

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Project credits

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Specialist consultants A G Consulting Engineering PC, Stellar Services, Patriot Design & Consulting, Alpha Graphics, Calladium Group LLC, JCMS Inc, Management Concepts Systems & Services, Onpointe 3d Technologies LLC and SI Engineering PC
Civil structures, civil engineering, geotechnical, lighting, track, rail operations, structural engineering, programme project and commercial management, safety and security, digital, quality management, and risk management (with JV partners Jacobs) Arup:
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Image credits

1, 3, 7, 10, 13: Marc A. Hermann/MTA
2, 4, 5: MTA
6, 8, 9, 11, 12: Arup

1.

A fusion of art, architecture, heritage and landscape

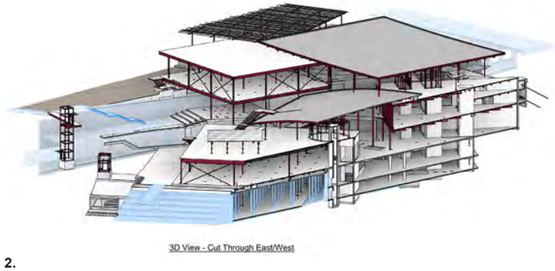
Blending heritage and modern design to create an expanded home for Sydney's flagship art museum

Authors Michaela Brown, Jake Cherniayeff, Andrew Johnson, Alistair Morrison, Andrew Phillips, Karen Seeto, Yuanyuan Song, Harvey Yang

Strategically located near Sydney Harbour, the Art Gallery of New South Wales (AGNSW) is one of Australia's flagship art museums, founded in 1871. The Sydney Modern Project expansion of the Art Gallery has created a new cultural landmark and has increased the exhibition space by 7,000m^2 and the entire building by 17,000m^2 – almost doubling both measures. The redevelopment enhances the city's eastern cultural precinct and creates a unique indoor-outdoor art space for the public.

The light and expansive design for the building includes a new, prominent destination for Aboriginal and Torres Strait Islander art, and education facilities catering for community and student activities. With the increased space, the gallery can now showcase more of its outstanding collection and attract more of the best national and international exhibitions to Sydney. The development has created a new, collaborative and immersive landscape for the public to experience and enjoy art in all its forms.

Arup's work on the project began in 2015 when the firm partnered with Japanese architects Kazuyo Sejima + Ryue Nishizawa | SANAA during the development of their submission for the Art Gallery's international design competition. Arup then led the engineering design to bring the competition scheme to life, providing integrated design services across disciplines including structural, civil, acoustics, audio visual, fire engineering, hydraulic and fire services engineering, security, lighting, traffic, pedestrian planning and more. Arup completed the final design and



2.

1: Aerial view of the Art Gallery of New South Wales' new SANAA-designed building

2: The expansion consists of a series of exhibition pavilions of different scales

3.

3: Interior view of the new building, featuring works by (lower wall, left to right) Lindy Lee and Stanley Whitney and (upper wall) Lisa Reihana

4: Yayoi Kusama, *Flowers that Bloom in the Cosmos*, commissioned for the Sydney Modern Project with funds provided by the AGNSW Foundation and the Gandel Foundation

5: Francis Upritchard, *Here Comes Everybody*, commissioned for the Sydney Modern Project with funds provided by Peter Weiss AO, the Droga Family in memory of Vibeke Droga, the Hadley Family, and the AGNSW Foundation

construction phase services for multiple disciplines under novation to Richard Crookes Constructions (RCC), and for the remaining disciplines carried out peer review works for Infrastructure NSW (INSW) – the state agency that delivered the project on behalf of the New South Wales Government.

Additionally, the firm provided engineering services to the gallery for several of the artworks commissioned for the project. This work included the structural support for the striking flower sculpture by Yayoi Kusama, the skeletons and construction engineering for the three large bronze sculptures by artist Francis Upritchard delicately installed under the undulating glass canopy of the Welcome Plaza, and the gantry frames for *The End of Imagination* by Adrián Villar Rojas. With Upritchard based in the UK, Arup's London office worked with the artist's team to design the internal frames, collaborating with the Arup team in Sydney, who designed the concealed foundations. The outdoor art garden features a living artwork called *bíal gwiyúŋo* (*the fire is not yet lighted*) by local Aboriginal artist Jonathan Jones, due for completion in 2024.

Adapted to the locality

The expansion is located to the north of the Art Gallery's original 19th-century sandstone building. The new building includes an entry plaza, exhibition spaces, retail, food and beverage facilities, visitor amenities, education spaces, multipurpose spaces, publicly accessible terraces and landscaping.

It is designed to suit the natural topography of the site, with a series of exhibition pavilions of different scales intertwined and stacked over five levels. Each pavilion connects with the outdoors – roof terraces, courtyards, public walkways and a 24/7 accessible art garden. Design constraints that added to the complexity of the project included its location on a steep escarpment between The Domain public park and Woolloomooloo Bay. Approximately 75% of the new gallery was constructed on existing structures, including on the subterranean decommissioned

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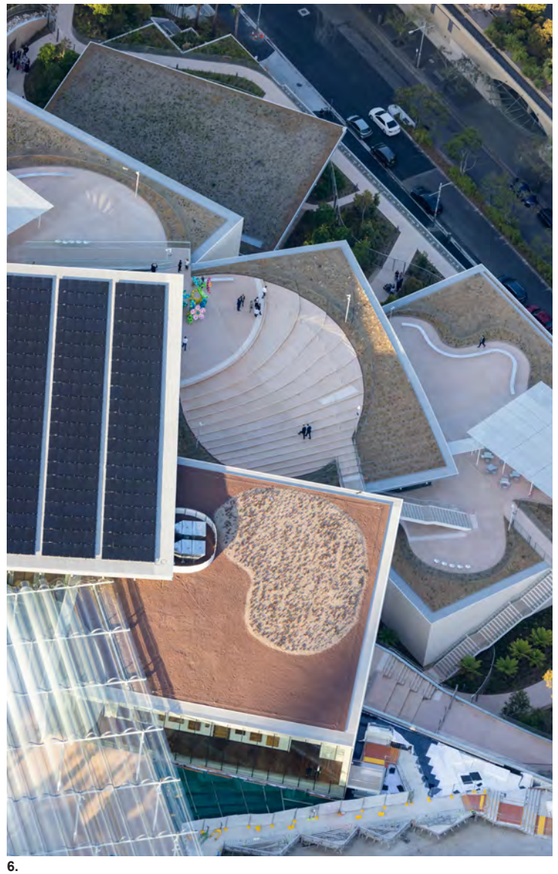


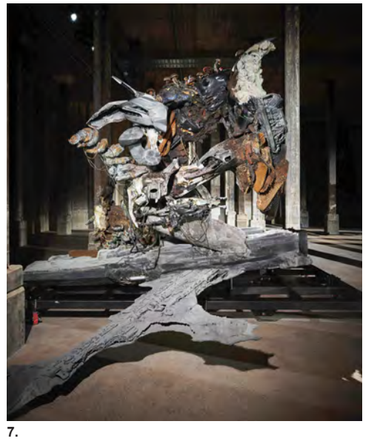
6.

8.

6: The exhibition pavilions are intertwined and stacked over five levels

7: Installation view of Adrián Villar Rojas, *The End of Imagination 2022*, in the Tank at the Art Gallery

8: Each gallery pavilion connects with the outdoors – terraces, courtyards, public walkways and a 24/7 accessible art garden



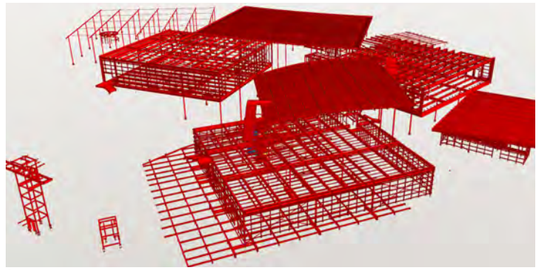
7.

World War II naval fuel tanks and the land bridge over the Eastern Distributor motorway. The tanks were built on and transformed into an immersive art space and back-of-house spaces.

Framing the structure

With the gallery's unique location, the design of the steel-framed pavilions required creative thinking and smart structural solutions to support SANAA's architectural vision. Arup used non-linear response history analysis for the seismic design, a specialised structural analysis method not normally used for seismic design in Australia. This enabled the seismic risks to the new building, existing land bridge and heritage fuel tank structures to be predicted to a greater level of detail than conventional techniques. The direct result of this analysis approach, in combination with a targeted testing regime for the existing materials and construction, was optimisation of the design to maximise the reuse of the existing structures with minimal intervention, while complying with contemporary building code requirements. Significant quantities of reinforcement required in new structures and in retrofitting existing structures were predicted initially using more conventional response spectrum and equivalent static methods. These were alleviated in the final design – saving significant cost, carbon and time while enhancing the building's function and aesthetic. In addition, the analysis provided dynamic simulation of the performance of the delicate sway frames and slender columns of the pavilions, demonstrating their safety in design seismic events.

Following discussions with the Art Gallery about future acquisitions of large-scale artworks after the planning envelope was set, the design required alteration to deliver a clear span gallery with the removal of the interior columns. A 38m spanning trafficable roof structure was designed within a similar depth to that of the typical gallery pavilions in order to maintain the gallery clear height below. A series of parallel steel portal frames composite with the lightweight concrete roof slab were integrated into the design and tied through the gallery floor structure below.



9.

9: The design of the steel-framed pavilions required creative thinking and smart structural solutions

10: Parallel 38m spanning steel portal frames form the clear span gallery

11: Arup took over 90 recordings and measurements to document the sonic part of the tank's heritage

Building on the land bridge

Arup integrated into the building the land bridge, built in 2000, that spans over the Eastern Distributor motorway, along with the underground heritage tank structures. Based on an assessment of the as-built drawings, construction records and known construction sequence, Arup developed a capacity diagram that was used to develop the massing of the new building, the landscaping, and tree and sculpture allowances, and then to plan and review the construction loading. Through careful modelling, the structural engineering team determined the appropriate place for the structural 'touch points' over the reinforced and pre-tensioned concrete land bridge. This approach saved time and cost by eliminating the need for any strengthening works or disruptive major road closures.

The Entrance Pavilion and gallery floors placed over the land bridge were constructed of lightweight concrete (1,880kg/m^3 density) on lightweight concrete distribution walls, designed to optimally distribute the loads across the bridge and maximise the imposed load capacity for the gallery floors. These floors were connected integrally with the global gallery structure, and base isolated laterally from the land bridge structure using sliding bearings. This allows the building to move independently from the land bridge during a seismic event, protecting both structures and avoiding the requirement for any retrofitting.

Fuel tank redevelopment

During World War II, two large fuel tanks were built on the site in a former sandstone quarry to provide fuel for the naval fleet at nearby Garden Island. The tanks were decommissioned in 1983 but kept in place below ground. To accommodate a state-of-the-art loading dock and back-of-house functions for the new building, the roof slab of the northern tank was substantially demolished but with much of the existing walls and the large raft foundation retained. The southern tank, meanwhile, was transformed with minimal physical intervention into a new art space. The only spatial interventions were a new floor slab to allow a drainage layer over the existing floor, openings cut into the walls for egress, and a circular penetration in the roof slab for a new spiral steel stair from which visitors can now enter this unique space. The scale, structure and acoustics of the 2,200m^2 area are remarkable, and the creative reuse of this underground treasure is one of the gallery's highlights.

The initial assessment of the tank structure informed the design and construction, with the research including the review of the original design documentation and photographs, visual condition assessments, physical testing of concrete elements, and reinforcement scanning. Parametric studies were used to review the load sharing and load paths to maximise the use of existing elements, with advanced seismic analysis and sympathetic remedial detailing to achieve a minimal intervention aesthetic.

The original tank structure comprised a reinforced raft slab directly on rock, thick, lightly reinforced concrete perimeter and dividing walls, slender precast concrete columns over 7m tall with in situ pedestals and capitals, and a reinforced concrete flat roof slab. The vast majority of the original tank columns were retained to support multiple new levels of galleries and trafficable roofs. The new floor of the gallery immediately above was set above the tank roof slab, to allow a zone for a new steel grillage to distribute loading from the new gallery floors and roofs above. This maximised the retention of existing columns and fully utilised their existing load capacity. The optimised design only required the replacement of ten of the existing 125 columns to accommodate the increased loading from the new building above. In these locations, high-strength (100MPa) concrete columns and pedestals were constructed and profiled to closely match the form of the existing columns. Where egress openings needed to be cut in the walls, the concrete over the openings was strengthened with concealed grouted dowels, allowing the wall to arch over the openings without the visual impact of lintels.

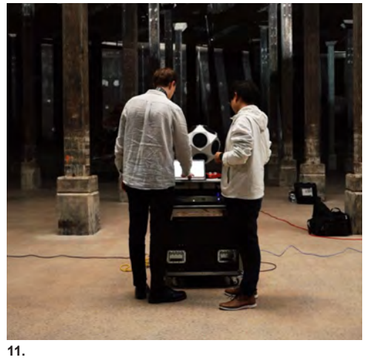
10.

The new structure over the tank was stitched into the existing walls to take advantage of their inherent capacity, reducing the quantity of new shear walls required at the lower levels. For the new concrete structures, concrete mixes were designed to achieve an average of 34% reduction in portland cement relative to a standard mix. Grade 400MPa steel was used to minimise steel weights in the plate-welded girders in both the transfer structures over the fuel tanks and the roof structure over Gallery 2. Adaptive reuse of the tanks alone saved over 2,500m^3 of concrete and 250 tonnes of reinforcement, equating to over 3,000 tonnes of CO_2.

Below-ground sound

Transforming the large empty tank space, with its smooth concrete surfaces and 7m clear height, into a contemporary art experience required careful and creative acoustic treatment. Working with the Art Gallery, SANAA, Architectus and INSW, Arup's acoustics team took on the challenge of converting this area.

Initially the team documented the acoustic signature of the existing space, as its unique acoustic environment would change once construction started to convert it into a publicly accessible exhibition area. Using specialised audio equipment, Arup took over 90 recordings and measurements to document this sonic part of the tank's heritage before repurposing started.



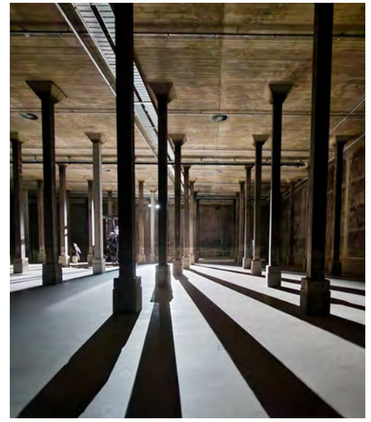
11.

The team created a detailed measurement plan to guide every step of the recording day in precise 15-minute blocks, using microphones with different directivity, including ambisonic and dummy head binaural microphones. The recordings also included members of the Arup team playing a duet with a French horn and a flute, weaving ambient harmonies together inside the tank.

Having captured the acoustic signature, the team turned their attention to creating a 3D digital twin acoustic model of the space. This allowed the testing of different scenarios and configurations to inform the final design of the tank, as well as the Art Gallery's operational considerations. Key to this process was the use of auralisations, or 'visualisations for the ear', in Arup's SoundLab. The SoundLab enables users to hear existing and future spaces and to test the sound of different designs. It enabled the team to design acoustic solutions in finer subjective detail, beyond decibel charts or acoustic maps.

Art museums are a hive of activity, with sounds including quiet exhibition viewing, time-based artworks with sound, school groups, community events, music performance and keynote speeches. As a result, the tank space required flexibility to cater for a range of artists, exhibitions and audiences. Using the SoundLab, Arup's acoustics team simulated the experience of the space in five different operational situations: a conversation, a static exhibition, an event with over 800 people, a formal speech and a music performance. The model was also used to test various time-based artworks from the Art Gallery's

12.



13.

14.

12: A circular penetration was made in the tank roof slab for a new spiral steel stair

13: 115 of the existing 125 columns in the tank space were retained

14: Interior view of the Art Gallery of New South Wales' new SANAA-designed building

collection to help inform curatorial thinking about works that could be exhibited in the space.

Each of these situations was simulated with three acoustic treatment options: acoustic curtains around the perimeter of the space, acoustic panels on the walls, and acoustic baffles hung from the ceiling. The latter option was of particular interest, as the baffles preserved the raw state of the tank as much as was practical, while providing customised acoustic flexibility for exhibitions and events.

The SoundLab provided the Art Gallery with an accessible and human-centric view of the tank prior to construction commencing, helping the gallery to think about the future potential of the space based on the acoustic outcomes experienced aurally. This process also provided valuable information to the gallery on its future operational considerations in the space.

Design innovation

SANAA selected a Japanese metal deck profile, usually used for roofing purposes, for the exposed soffits of the lightweight concrete roof slabs. Arup engineered the design to make this deck work compositely with the steel roof beams. Longitudinal shear testing to the local steel code (AS4100) was undertaken to verify the capacity of the shear studs within the metal deck profile in combination with the concrete. This validated the analytically estimated composite behaviour, enabling the decking and concrete slab to be used as part of a composite structure with the steel beams, optimising the beams' capacities and minimising steel tonnage.

15: Lee Mingwei, *Spirit House 2022*, commissioned for the Sydney Modern Project with funds provided by The Chen Yet-Sen Family Foundation in honour of Daisy Chen, and the AGNSW Foundation

16: The Sydney Modern Project opened in December 2022

15.

More than 250m of cement-stabilised rammed earth walls curve through the building over two levels. Arup worked with contractor RCC and specialist subcontractor Rammed Earth Constructions to develop reinforcement, jointing and support details for the 300mm thick and 6m high walls. A similar collaborative approach was used for the Spirit House, a small but unique artwork comprising a rammed earth dome embedded into the hillside, housing a single sculpture by artist Lee Mingwei.

Fire strategy

Performance-based fire safety engineering design was key to unlocking the architectural aspirations for the gallery's open and connected levels with reduced environmental impact. The design by the Arup fire engineering team made use of the terraced levels to provide direct egress to outside, using phased evacuation validated with pedestrian and smoke modelling to avoid additional fire stairs and mechanical smoke exhaust systems required by the prescriptive code requirements. This also helped reduce ongoing maintenance and reduce fluctuations in the tight environmental conditions for the artworks by avoiding the introduction of outside air when such systems are tested.

To protect the sensitive gallery spaces and art storage areas, Arup developed performance-based fire protection systems, ensuring robust life safety and property protection without the risk of water damage to collection pieces. The Arup fire and structural engineers collaborated closely to optimise the structural fire protection, enabling slender structural elements and reduced applied fire protection (particularly at the interfaces of primary and secondary steel members), and omitting the requirement for fire protection for the steelwork in the transfer deck above the tank. This resulted in significant savings in materials and costs across the project, as well as reducing future maintenance requirements. Intumescent paint was only required to provide fire protection to architecturally exposed steelwork, or where there was insufficient space to apply other protection such as vermiculite.

16.

Sustainability first

Reducing water use and protecting precious artworks were key considerations for Arup's hydraulic and fire engineering design teams. They developed a digital water balance calculation tool to assess and optimise onsite rainwater harvesting. The building rainwater system collects water from all roof and trafficable terrace areas for reuse in the gallery's cooling towers and landscape irrigation system. A combined stormwater tank for retention (260m^3) and detention (340m^3) was integrated into the basement of the new building, providing the opportunity for on-site stormwater reuse while limiting site discharge to pre-development conditions.

Maximising usable and publicly accessible gallery floor area influenced the placement of the water tank in the basement level. This introduced the requirement for pumped discharge in regular operating conditions, with a gravity overflow in place for major storm events. The downstream boundary conditions are subject to local flooding and the proximity to the harbour required consideration for potential sea level rise caused by climate change. The gravity overflow required resilience to flood waters entering the tank and basement, while balancing the required discharge flow rate in major storm events. This was achieved through a large 3.5m x 2.65m surcharge pit integrated within the external landscaping, with an internal overflow weir set to achieve flood protection. This approach reduces water use and protects the gallery and the stormwater network from flooding. The tool was a contributing factor to the gallery being awarded a 6 Star Green Star design rating from the Green Building Council, the first art gallery in Australia to achieve this.

The collaborative effort of the overall project team and of Arup's different disciplines and Sydney, Tokyo and London offices has created a stunning building, one that embraces the constraints of a complex site and turns them to its advantage. The Sydney Modern Project opened its doors in December 2022 and this unique two-building art museum is free for everyone to visit, allowing the community and visitors to Sydney to experience the Art Gallery's broad collection in a generous, uplifting and sustainable space.

Authors

Michaela Brown managed the design of the structural steelwork for the Arup team. She is an Associate in the Sydney office.

Jake Cherniayeff led the hydraulic and fire services design. He is an Associate in the Sydney office.

Andrew Johnson was Arup's Technical Director for the project. He is a Principal in the Sydney office.

Alistair Morrison led the fire safety engineering design throughout the project. He is a Principal in the Sydney office.

Andrew Phillips managed the structural engineering team and was the multidisciplinary team Project Manager. He is an Associate in the Sydney office.

Karen Seeto led the civil engineering design. She is an Associate in the Sydney office.

Yuanyuan Song worked on the fire engineering design. She is an Associate in the Sydney office.

Harvey Yang led the acoustic design. He is a senior acoustic engineer in the Sydney office.

Project credits

Project sponsor Infrastructure NSW
End client Art Gallery of New South Wales
Architect Kazuyo Sejima + Ryue Nishizawa | SANAA
Executive architect Architectus
Geotechnical engineering Coffey
Mechanical & electrical engineering Steensen Varming
Landscape architects GGN and McGregor Coxall
Main contractor Richard Crookes Constructions
Structural engineering, civil engineering, fire engineering, hydraulic and fire services engineering, acoustic consulting, audio visual, specialist lighting, design, pedestrian modelling, security consulting, traffic engineering Arup:
Mitchell Allen, Rafid Alnashi, Victor Andrade, Allen Ang, Hashan Aponsu, Francis Archer, Lew Arnold, Vince Bombardiere, Edward Bond, Nick Boulter, Tom Brickhill, Michaela Brown, Zoe Brown, Rebecca Cadorin, Vicky Callaghan, Valentina Caoduro, Tim Carr, Polly Cen, Dom Chan, Michelle Chan, Jake Cherniayeff, Bryce Collins, Katelyn Commerford, Ricardo Costa, James Cruz, Ellie Dean, Jethro Dickens, Leah Dodt, Josh Eaton, Pearl Elgindy, Jessica Enever, Travis Finger, Matthew Finn, Joni Foster, Kathy Franklin, Odisho Gabrial, Matt Galbraith, Robert Galluccio, Ethan Gear, Julian Gherda, Oliver Gibson, Thomas Graham-Murdoch, Darren Hansen, Guy Hopkins, Eve Hoskins, Nick Howard, Geoffrey Hsu, Emma Huang, Andrew Hulse, Navya Jayawardena, Dane Johns, Andrew Johnson, Caitlyn Johnson, Kim Jones, Lisa Kaluzni, Mitsuhiro Kanada, Michael Kelleher, Vanessa Khuu, Carrie Kingsford, Ben Kirkwood, Braeden Krecichwost, Win Kyaw, Manuel Lawrence, Rebecca Lawson, Carter Leung, Cheng-Guo Li, Jingsha Liu, Elena Longo, Carlo Loreto, Codee Ludbey, Song Luo, Peter Macdonald, Joyce Man, Anthony Mastromauro, Niall McDermott, Callum McGregor, Louise Millward, Chris Monk, Alistair Morrison, Mitchell Mulvey, Owen Myers, Eddy Ng, Shane Norton, Chris Nugroho, Xavier Nuttall, Ngaire O'Leary, Kimberley Pepperell, Andrew Phillips, Michael Rumbold, Katy Samonova, Tristan Samson, Jack Schroeder, Jamie Scott-Toms, Andy Sedgewick, Karen Seeto, Lauren Shapiro, Carol Shi, Christopher Sims, Paul Sloman, Rachel Smith, Yuanyuan Song, Peter Suryadi, Gerard Taig, Kengo Takamatsu, George Target, Will Thickett, Harley Trappitt, Tom Urquhart, Vivian van Deursen, Matt Walden, Tim Watson, Andy Wong, Simon Xiang-Hui Wu, Harvey Yang, Nina Yiu, Berna Zaragoza Solis.

Image credits

1, 3, 6, 14, 16: Iwan Baan
2, 9, 10, 12: Arup
4: Art Gallery of New South Wales/Zen Wimberley
5: Art Gallery of New South Wales/Christopher Snee
7: Jörg Baumann
8, 13: Alistair Morrison/Arup
11: Daniel Weiss/Arup
15: Art Gallery of New South Wales/Diana Panuccio

1.

Managing coastal risk

Improving coastal flood resilience and boosting local regeneration

Authors Robin Campbell, Rosheena Jugdhurry

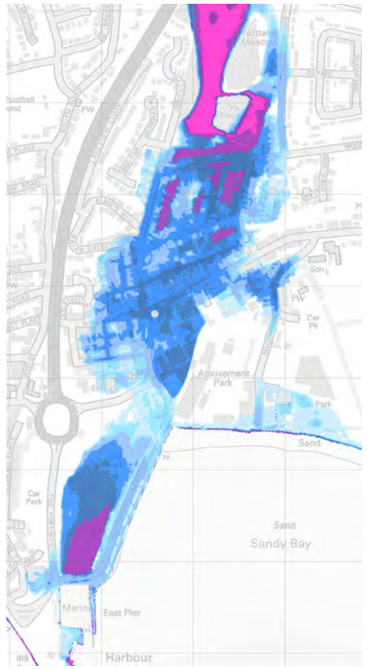
In the face of increasing coastal flood risk from climate change, exacerbated by often ageing waterfront assets, communities worldwide are turning to innovative solutions to safeguard their coastal regions. Among these, the Porthcawl Sandy Bay Coastal Scheme in Wales, spearheaded by Arup for client Bridgend County Borough Council, stands as a testament to proactive planning, collaborative effort and resourceful engineering. This transformative project mitigates the threat of flooding and sets a precedent for sustainable coastal management.

In recent years, severe flooding and adverse weather conditions have affected communities across Wales. Porthcawl, a picturesque seaside town on the Welsh south coast that attracts over a million visitors annually, faced increasing vulnerability to coastal flooding, posing a significant threat to both infrastructure and the local economy. The existing historic coastal defences were inadequate to withstand the intensifying impacts of rising sea levels and extreme weather events. In addition to the threat to homes and businesses, the combination of ageing infrastructure and flood risk has constrained development opportunities in the town.

Recognising the urgency of the situation, Bridgend County Borough Council commissioned Arup to develop a business case for investment to reduce long-term coastal flood risk. The bay is surrounded by more than 100 acres of land identified for regionally significant regeneration. The firm developed a phased approach to the scheme so that works within the council's control could be funded without the delay and risk of awaiting future development.

As part of the evidence for the business case, flood inundation modelling, informed by asset condition assessments and wave modelling, showed that 110 homes and 70 businesses were at risk of flooding. However, if the Western Breakwater were to fail, this increased to more than 530 homes and 175 businesses. Thanks to Arup's business case, the council secured an additional £1.2m of funding from the Welsh Government to regenerate the flood defences. The firm was appointed to deliver design development and detailed design, including asset condition assessments, wave modelling, environmental impact assessment, stakeholder engagement, and consenting.

The project was jointly funded by the Welsh Government and the local authority as part of the Coastal Risk Management Programme. During the works, construction firm Knights Brown revived the promenade area, developing an accessible space with new planters and amenity terraced seating that can contain wave overtopping as flood defences between Porthcawl Marina and Coney Beach. The scheme also provides locals and tourists with improved amenities, as well as acting as a mechanism to unlock further regional regeneration.



2.

Context and challenges

Sandy Bay has four distinct but connected frontages; the Western Breakwater, the Eastern Promenade, the relict sand dunes and Rhych Point headland. Porthcawl's 182m-long Western Breakwater is 200 years old and Grade II heritage listed. It forms part of the coastal infrastructure that protects the harbour and Sandy Bay from extreme wave impacts. To protect its legacy and initiate substantial repairs to maintain its structural integrity, Arup consulted closely with Cadw, the Welsh Government's historic environment service, as well as Bridgend County Borough Council's heritage specialists.

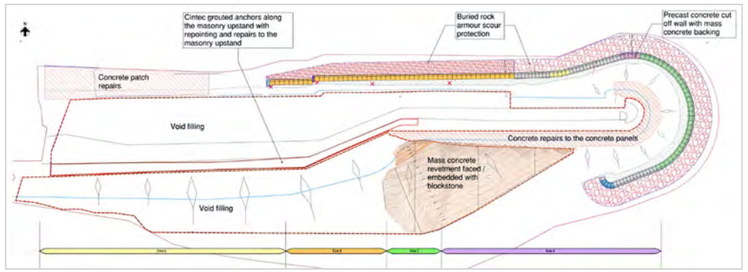
The firm developed the design of repair and strengthening works to the listed breakwater, carried out the environmental assessment and oversaw stakeholder engagement activity. The Arup design included repairs to masonry and concrete, raising parapets, installation of a precast concrete cut-off wall and new rock armour for the Western Breakwater. Early engagement with the contractors was

3.

1: Sandy Bay has four distinct but connected frontages

2: Modelling indicated that a failure of the Western Breakwater would put more than 530 homes and 175 businesses at risk of flooding

3: Rising sea levels and extreme weather events threaten Porthcawl's coastal defences



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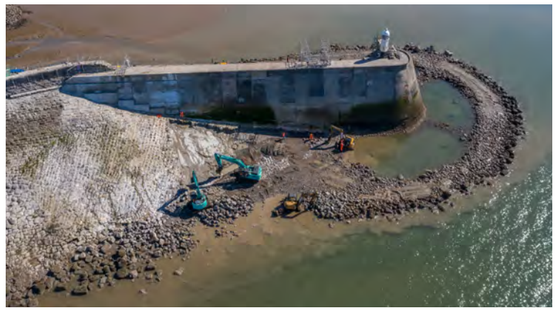

5.

4: The works to the Western Breakwater included repairs to masonry and concrete, raising parapets, installation of the cut-off wall and new rock armour

5: The works were designed to be safely implemented during periods of low tide and in challenging coastal working conditions

key; it ensured that the team's designs could be safely implemented during periods of low tide and in challenging coastal working conditions.

As well as repairing and improving the listed breakwater, Arup's work extended to the Eastern Promenade, located on the west side of the popular Sandy Bay beach. Initially, a secondary wall to stop waves overtopping the promenade was planned, but Arup's placemaking design sought to ensure the promenade will be attractive for visitors and residents in years to come, and overtopping studies showed that the wall could be replaced with multifunctional planters. This added more green space, integrated terraced seating and minimised service diversions and disruption to the public.

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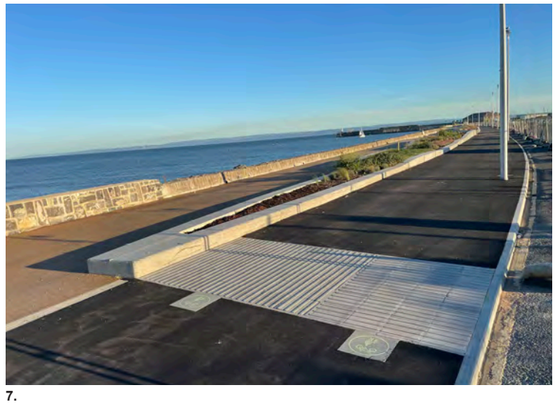

7.

6: A planned secondary wall to stop waves overtopping the Eastern Promenade was replaced with planters to add more green space

7: The team also improved cycling and walking routes along the promenade

The Western Breakwater

- 182m long
- Grade II listed
- Constructed in the 1820s, extended in the 1860s
- 166 Cintec anchors used in parapet
- 550 tonnes of grout used during the upgrade
- 227 hexagonal panels deployed at the foot of the breakwater
- 10 different patterns and panels installed

The team also improved cycling and walking routes, ensuring the promenade was more functional and appealing for visitors and locals.

Preserving the dunes

Where previous proposals would have seen the sand dune habitat protected by concrete terraced defences, Arup's study into coastal processes showed that the dunes could be preserved and restored using nature-based solutions, minimising costs and carbon emissions. For the restoration of the dunes to create a natural buffer, the team proposed 285m of low-level fencing to encourage the build-up of new dunes. These simple measures, combined with a growth and stability monitoring plan, will help maintain the coastal pathway. This approach has enhanced coastal resilience and revitalised the beach ecosystem, benefiting both residents and tourists.

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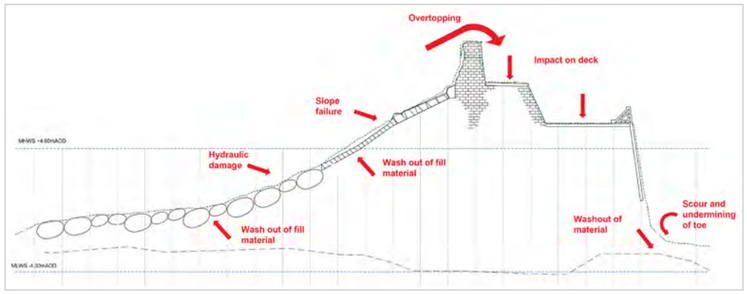


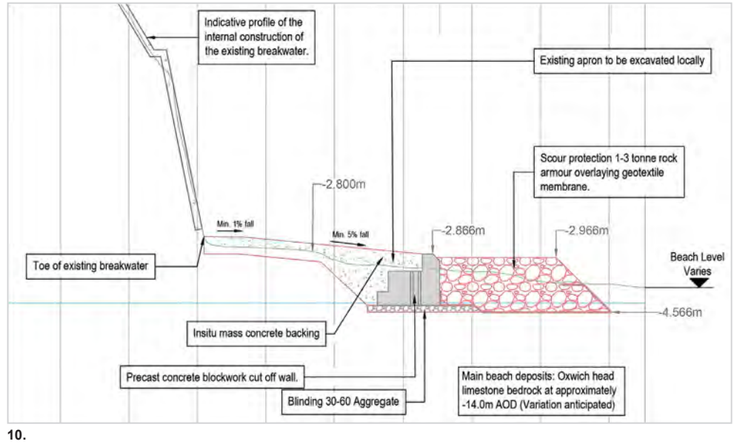
9.

Groundbreaking research

Engineers have for centuries constructed waterfront structures such as walls and breakwaters. While they are vital, it's often the case that old waterfront walls are maintained only when they show signs of severe deterioration. Many are challenging to analyse from a structural point of view; they are complex in form and there is limited historic data on their design and construction.

The first challenge with the Western Breakwater was understanding the existing structural form (as the breakwater had undergone numerous modifications over its lifetime) and the likely failure scenarios associated with that structure. It was essential for the team to uncover its chronological development since its construction in the 1820s and to identify the nature and extent of its defects. Arup combined historical research with drone, lidar, geophysical and geotechnical survey data to understand its structural weaknesses.

Surveys used non-destructive techniques such as ground-penetrating radar, supplemented by trial pits and horizontal cores. Using the information gathered, the team devised a plan to help maintain the breakwater's original character while reducing flood risk and improving its structural integrity. The design thus reduced the risk of voids and the impact of waves. Stone from the local quarry used in the original construction was sourced to replace a failed seaward-sloping wall, and the voids were grouted to prevent water leakage and corrosion. A cut-off wall was constructed to provide a protective layer to reduce scour risk and future washout of fine material.



10.

To strengthen the slender parapets without damaging the heritage-listed historic masonry, Cintec reinforcing anchors were added. This is a system that uses grout contained in a fabric sock mesh, combined with steel anchors. It helped to preserve the breakwater's original character, as well as minimising carbon impacts and overall project costs.

By repairing the existing breakwater rather than building a new one, the design reduced embodied carbon, and locally quarried materials were used to reduce transport impacts. Arup's choice of prefabricated mass concrete blocks instead of reinforced concrete for the cut-off wall will reduce future maintenance needs for the Western Breakwater. It also reduced the health and safety risks of deep-water working, as the blocks acted as permanent shuttering.

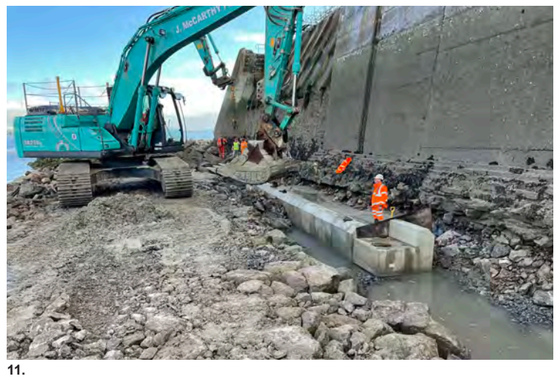
Collaboration and stakeholder engagement

Arup's emphasis on collaboration and stakeholder engagement was central to the success of the scheme. From the outset, the team worked closely with local authorities, environmental

8: 285m of low-level fencing has been added to encourage the build-up of new dunes

9: Arup reviewed the likely failure scenarios of the Western Breakwater

10: The cut-off wall was constructed to provide a protective layer to reduce scour risk and future washout of fine material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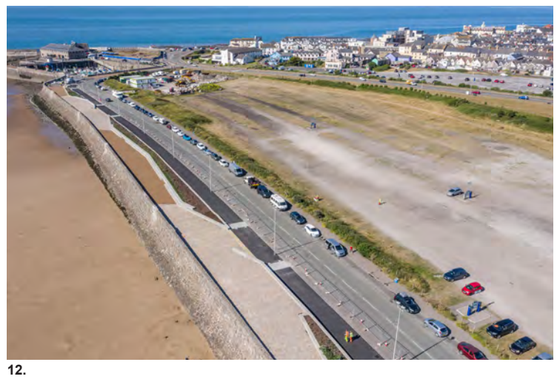
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agencies, community groups and residents to understand their needs and concerns, fostering a sense of ownership and inclusivity throughout the project lifecycle. Regular consultation sessions and public forums provided avenues for feedback and transparency, ensuring that the final scheme reflected the aspirations of the community while adhering to technical standards and regulatory requirements.

Arup engaged in activities and schemes to support local social, economic and environmental wellbeing, whether by improving the environment, building stronger communities or contributing to sustainable economic growth.

Supporting marine biodiversity

To help support marine biodiversity, the team worked with Cube X Industries Ltd/Blue Cube Marine and Swansea University to test innovative modular textured panels to form an artificial reef and rock pools. The hexagonal panels featured 13 distinct patterns made from ultra-high-performance concrete, with three different concrete mixes tested, including one incorporating local crushed cockle shells and ash. These were affixed in a beehive arrangement on the horizontal toe of the breakwater, to evaluate pattern colonisation by fauna and seaweeds under varying submergence times and wave exposures. The panels aimed to mimic natural habitats and foster marine life such as the protected honeycomb worm.

Awards

British Construction Industry Awards
Highly Commended, Environmental Project of the Year 2024

Shortlisted for the National Infrastructure Commission Design Standards Award 2024

The project, known locally as the Settlers of Porthcawl, gained community support for eco-engineering interventions. Through questionnaires, the team established the public's preferences for patterns imitating natural textures, and for a mixture of designs on the seawall. The project gained popularity among local schools and hosted over 200 students to teach them about climate change, biodiversity and sea-level rise.


13.

Safeguarding the future

Despite the impact of the COVID-19 pandemic, as well as multiple severe storms, the Porthcawl Sandy Bay Coastal Scheme was completed in the agreed timeframe and within budget by June 2023.

Beyond its primary objective of reducing flood risk, the scheme has delivered substantial economic benefits to the local community and the wider region. By safeguarding critical infrastructure, residential properties and commercial assets, the scheme protects livelihoods and preserves the vitality of the coastal economy. Moreover, the enhanced recreational opportunities and improved coastal aesthetics will attract tourists and investors, stimulating economic growth and enhancing the town's resilience to future shocks.

A major factor in the success of the project was that the Arup team was able to correctly frame the problem and devise a risk-based design. The result was a scheme to manage coastal risk by safeguarding the historic breakwater, reinvigorating the seaside promenade and restoring the sand dunes. In addition to protecting over 700 homes and businesses from coastal flooding, the scheme will help garner support for local strategic regeneration.

Arup's commitment to environmental sustainability was evident in every aspect of the scheme, from design to implementation. By prioritising nature-based solutions such as beach nourishment and habitat restoration, the scheme minimised the ecological footprint of the project while enhancing biodiversity and ecosystem services.

The Porthcawl Sandy Bay Coastal Scheme is a shining example of effective coastal risk management and sustainable development. As climate change continues to pose unprecedented challenges to coastal communities worldwide, the lessons learned from this project can provide inspiration for future endeavours in coastal adaptation and resilience.

Monitoring for a year revealed colonisation disparities across the sites due to wave exposure. This emphasised the significance of submergence and exposure. It was found that the most successful patterns to help foster colonisation were those with protruding ledges and rough microstructures, as opposed to smooth designs.

11: The choice of prefabricated mass concrete blocks for the cut-off wall will reduce maintenance needs

12: The remodelled Eastern Promenade is more appealing for locals and visitors

13: Modular textured panels were installed to support marine biodiversity

14: Sandy Bay is now better protected against extreme weather events


14.

Authors

Robin Campbell was the Project Manager. He is an Associate Director in the Cardiff office.

Rosheena Jugdhurry was the lead engineer. She is a senior engineer in the Bristol office.

Project credits

Client Bridgend County Borough Council
Contractor Knights Brown
Maritime specialist ABP Marine Environmental Research Ltd
Green infrastructure pilot Swansea University, Cubex Industries
Surveys TerraDat (UK), Azimuth Land Surveys, Glamorgan-Gwent Archaeological Trust, Tetra Tech
Maritime structural engineering sub-consultant Steve Hold Consulting
Construction supervisor WSP
Civil engineering, flood risk management, infrastructure design, masterplanning and urban design, water engineering Arup: George Batt, Robin Campbell, Stephanie Chapman, Robert Forster, Lee Galsworthy, Scott Galsworthy, Rosheena Jugdhurry, Souvith Lim, David Lynesmith, Abbie Moseley, Ben Murray, Greg Murray, Anna Ntasiou, Louise O'Brien, Henrietta Ridgeon, Juan Rodriguez Dominguez, David Short, Steve Smith, Will Turton, Jorge Vaz, Martha Villela Quiroga, Andrew Whinney.

Image credits

1, 5, 12: Knights Brown
2, 4, 6-11: Arup
3: Marcus Woodbridge/Unsplash
13: Blue Cube Marine
14: Emma Woodhouse

Letting the traffic flow

A Hong Kong first with multi-lane free-flow tolling

Authors Carmen Chu, Brad Fong, Hamlyn Kuong, Wilfred Lau

A free-flow tolling system (FFTS) allows motorists to pay tolls without having to stop their vehicles to pay at toll barriers. With multi-lane FFTS implementation, vehicles can maintain their speed without the need to stop or slow down at toll booths, thereby alleviating traffic congestion, enhancing roadway capacity, shortening journey times and improving traffic safety. By removing deceleration, acceleration and idling of vehicles approaching the toll locations, it also helps save fuel and reduce air pollution. Unlike a single-lane FFTS, where toll booths or islands are still provided to house FFTS equipment and allow some motorists to pay tolls on site, a multi-lane FFTS removes all such toll booth and plaza facilities. This frees up a large amount of valuable space in these urban areas for other types of development uses, and achieves a completely free-flow tolling experience for all traffic.

In 2019, the Hong Kong Special Administrative Region (HKSAR) Government published its HK Smart City Blueprint. One of the smart mobility initiatives in the blueprint was to implement multi-lane FFTSs at all government-owned tolled roads and tunnels. With approximately 600,000 vehicles passing through the tolled tunnels and roads daily, many of the existing tunnels had been struggling to cope with traffic demand, particularly during the peak morning and evening rush hours. The implementation of an FFTS effectively enhances the strategic roads' capacity to handle the peak demand and reduces the extent of congestion.

Arup brought together experts from several of the firm's offices around the globe and, in collaboration with the local project team, delivered the first multi-lane FFTS for Hong Kong, based on the latest best practices from advanced tolling systems implemented worldwide. This multi-lane FFTS, which is officially branded as 'HKeToll' in Hong Kong, is operated by the Transport Department (TD). It uses advanced intelligent mobility technologies to achieve high levels of automation in the toll collection process, including using a robust, image-based enforcement system to deter non-compliance, optimise revenue collection and ensure adequate levels of public acceptance to maximise account registration. The Arup team in Hong Kong capitalised on their extensive local transport planning experience to design the system with bespoke features to suit local transport industry practices and user needs.

1.

2.

1, 2: The initiative to implement multi-lane FFTSs at all government-owned tolled roads and tunnels was part of the HK Smart City Blueprint

3, 4: The HKeToll system means that vehicles no longer need to stop or slow down at toll booths

3.

Key functional design features

First used in Canada in 1997 and Australia in 2000, FFTSs have emerged as a proven method of charging for road use that permits highly automated operations with minimal impact on traffic. Previously, Arup worked with Transport Infrastructure Ireland on the multi-lane FFTS on the M50 motorway in Dublin, which processes over 50 million vehicles annually. Ireland was the first European country to implement multi-lane FFTS for all vehicle classes.

In 2019, Arup was initially appointed by the HKSAR Government's Civil

4.

5: ANPR cameras capture front and rear vehicle number plates

6: The TKO-LTT was originally planned to implement the first FFTS in Hong Kong and designed without a toll plaza

5.

Engineering and Development Department to undertake the design and construction of the first multi-lane FFTS in Hong Kong. The system was originally intended to be implemented at the 2.2km-long Tseung Kwan O-Lam Tin Tunnel (TKO-LTT) that connects Tseung Kwan O to East Kowloon, and was the first government tolled tunnel to be designed without the provision of a toll plaza. Although the TKO-LTT was subsequently commissioned as a toll-free tunnel, Arup's project scope then expanded substantially to include the design and construction of a single backend system (BES) for the FFTS to cover all government toll roads and tunnels in Hong Kong.

Arup's commission included conducting an international market sounding exercise to understand the up-to-date technologies and capabilities in the market. The firm designed the system architecture and workflow for the FFTS and the functional and performance specifications for its implementation, including the infrastructure design. Cost estimates and the promotion plan were also developed and tender documentation prepared. Arup provided supervision and contract administration of the works contracts, including testing and commissioning, as well as the final system handover to the TD as the end client.

6.

The modular-based BES handles the validation processes of all the tolling transactions, hosts the account management services, payment gateways and enforcement database, and monitors the system performance of the FFTS at the back-end site. At the front-end level, the data acquisition system (DAS) consists of the local on-site infrastructure which captures the detailed vehicular information for tolling purposes at each tolling site. The Toll Tag, a self-adhesive radio frequency identification (RFID) sticker affixed to the vehicle windscreen, meets the requirements of the international standard for RFID technology management (ISO/IEC 18000-6). The first Toll Tag for each licenced vehicle is issued free of charge to the owner and there is no administration charge for using the HKeToll service. The DAS collects the tolled vehicle information by reading the Toll Tag, supplemented by an automatic number plate recognition (ANPR) system. Arup was also appointed by the HKSAR Government's Electrical and Mechanical Services Department (EMSD) for the design and construction of the DAS for a further three FFTS domains in Hong Kong; Tsing Sha Control Area, Shing Mun Tunnels and Lion Rock Tunnel.

The DAS equipment placed on gantries above the road includes an RFID antenna, an ANPR camera, an automatic vehicle classification (AVC) laser scanner, and a CCTV surveillance camera. When a vehicle approaches the tolling zone, a wake-up signal from the antenna on the gantry pings the Toll Tag, which sends data to the RFID antenna. The ANPR camera captures the front and rear vehicle number plate to ensure successful tolling even if the vehicle is not installed with a Toll Tag. As certain tunnels charge tolls according to vehicle types, the AVC captures and identifies the vehicle type. The CCTV also captures the video images of the passage of the vehicle, as backup information in the event of transaction dispute cases that require further investigation.

7: The HKeToll was first implemented at the three tunnels linking Shatin and urban areas

8, 9: Tolling equipment on gantries includes an RFID antenna, an ANPR camera, an AVC laser scanner and a CCTV camera

7.

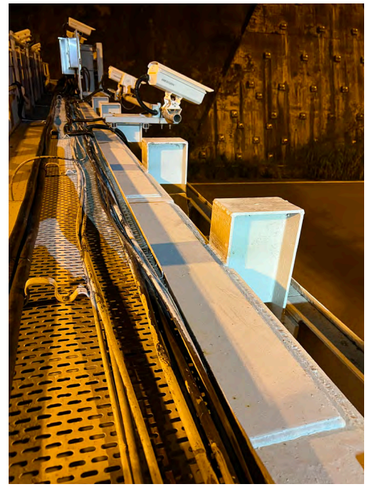
The data is then transmitted to the local DAS central system, which is typically located in one of the tunnel control rooms. There, the DAS central system automatically generates two sets of data packages for each tolling transaction, namely the transaction package (which consists of all the unique data associated with a single transaction, including location, time, vehicle number plate, etc.), and the evidence package (which consist of the photos and video clip of the associated transaction). Those two data packages are then transmitted to the BES via a dedicated communications network.

The transaction data is then validated for accuracy and matched with the vehicle and driver account as registered in the TD's vehicle licencing database. The BES then generates the notification of transaction to the vehicle owner via multiple channels, and also proceeds with the payment process.

Bespoke design features for local conditions

Multi-lane FFTSs implemented in several cities worldwide provided good references on the key design principles and technological parameters in the development of the requirements for Hong Kong. Nevertheless, such systems are only truly successful if their detailed functionalities are tailor-made to suit the exact local transport conditions and industry practice. In Hong Kong, Arup capitalised on its strong local expertise and insights into local transport operating practices, while also bringing in international technical expertise, to deliver one of the most sophisticated systems of its kind in the world, using a range of bespoke design features.

Vehicle owners are offered multiple channels to manage their tolling accounts and payments. Dedicated HKeToll mobile apps and a website allow users to view and manage their accounts. Notifications about transactions and payments can be received via mobile app, SMS or email. Payments can be settled by auto-payment with pre-registered credit cards, by direct debit, or even by post-payment using all the electronic payment means available in Hong Kong.



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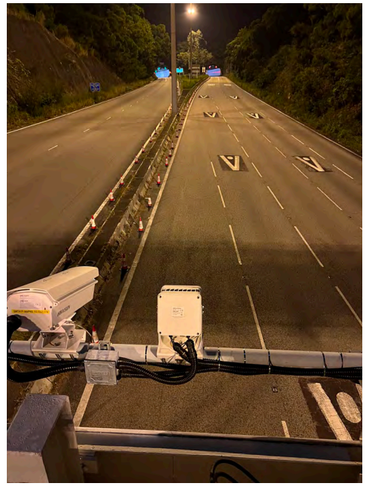

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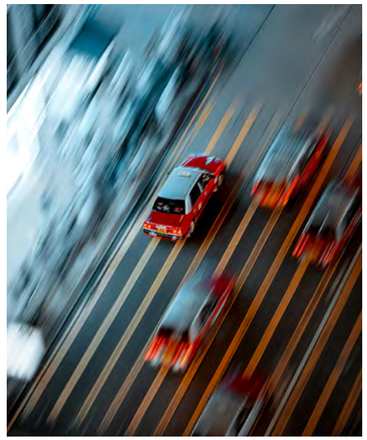
The commercial transport trade in Hong Kong is diverse. For example, some taxis are owned by individuals, while many are operated as a fleet by taxi companies that lease out their vehicles to drivers who work in shifts. The HKeToll is designed so that taxi drivers can check in via a dedicated mobile app before starting their shift, with any toll fees during the shift charged to the driver. Taxi companies can also manage the toll transactions and payments of their fleet through a dedicated HKeToll website for commercial vehicles.

While drivers are encouraged to install Toll Tags that are linked to individual HKeToll accounts, the system is also designed to allow freedom for drivers to choose not to install Toll Tags in their vehicles, or to make use of pre-paid vehicle Toll Tags, according to the vehicle type; these can be purchased from convenience stores.

While all elements of the HKeToll system were designed and tested for high accuracy and reliability, some inaccurate data may still be collected for certain transactions due to particular environmental conditions, or even misuse of Toll Tags. The HKeToll was designed with a manual image review mechanism, so that in cases where there



10.

11.

are doubts about the vehicle data that has been collected, the system is able to present detailed transaction information with photo records for the operator to confirm the accuracy of the transaction.

In addition to collecting tolls, the HKeToll system is able to collect detailed information on traffic flows along the tolled roads, and also to collate and generate detailed reports on traffic statistics.

The BES is hosted in a government-owned cloud environment, allowing more effective use of current government IT infrastructure. The BES system processing capacity is also designed to be scalable to allow for future expansion to cover new tolled roads in future, thereby enhancing the system's resilience in handling long-term transport network growth. The design of the DAS for all the existing tolled roads and tunnels specifically made use of existing sign gantries to install field equipment at toll points, without building any new major highway infrastructure, enhancing the cost-effectiveness and sustainability of the project.

Phased HKeToll implementation

The project was achieved in a remarkable time frame, from system development commencement to the substantial completion of the BES development within 20 months, with tolling implemented at Tsing Sha Highway in May 2023. The subsequent mission was to implement the system at the remaining seven tunnel sites within eight months, to meet the TD's pledge to roll out HKeToll at all government tunnels by 2024. The Arup project team faced the challenge of conducting extensive system tests on the new toll domains, and system switch-over, without causing any risk to the live operations of the tunnel sites that had already implemented HKeToll. This phased arrangement had rarely been faced when implementing previous FFTS systems in other cities, so the HKeToll presented an unprecedented challenge.

To allow for comprehensive system testing for phased commissioning arrangements, a non-production site was developed which was essentially a full-scale replica of the live production site of the HKeToll system. Prior to plugging in a new toll domain, a month-long shadow running exercise was conducted for the new toll domain at the non-production site with live traffic data. This allowed for the comprehensive testing of the performance and processing capacity of the HKeToll system with realistic traffic data loading, without facing the risk of erroneously charging the public for tolls.

10: Taxi drivers can check-in to HKeToll via a mobile app before starting their shift

11: The Western Harbour Crossing had one of the largest toll plazas in Hong Kong

12: Implementing the TVT redistributed traffic away from the more congested Cross-Harbour Tunnel

13: The TVT has also significantly reduced traffic congestion during peak hours

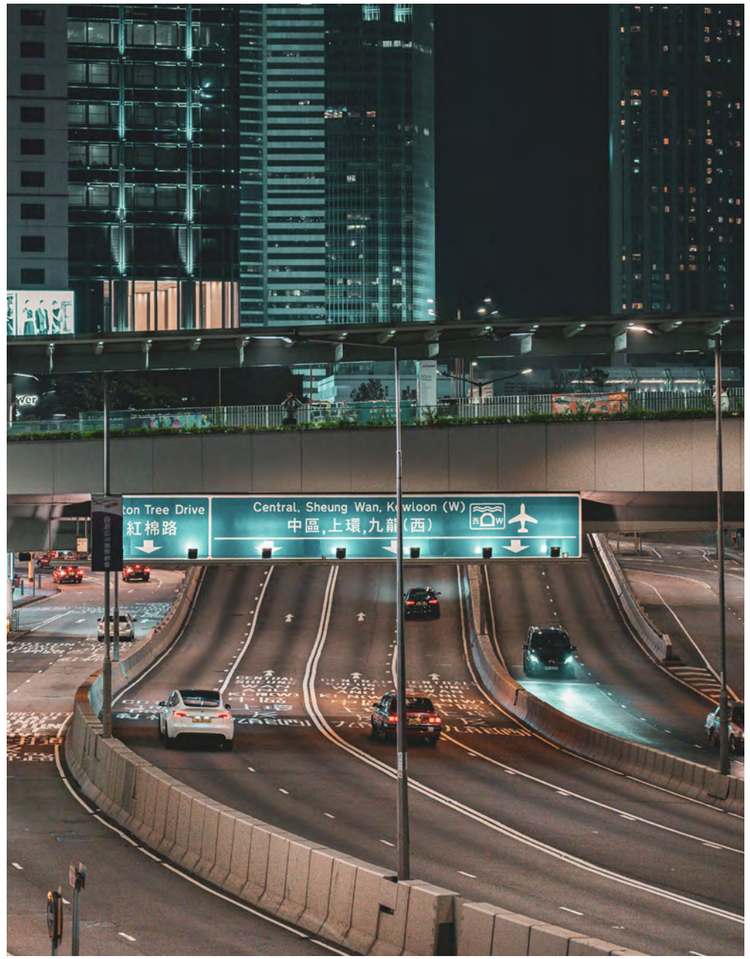
12.

Functional scalability of HKeToll for future demands

Arup worked with the client team to establish scalability and resilience concepts in the design of the HKeToll system to suit other potential types of pricing mechanisms and other forms of mobility charging. After the system was implemented at the three road harbour tunnels between Kowloon and Hong Kong Island in mid-2023, a new time-varying toll (TVT) system was introduced as a form of congestion charging scheme at those three road harbour tunnels in December 2023. There are specific rates for peak periods from Monday to Saturday in the morning (07:30 to 10:15) and evening (16:30 to 19:00), with cheaper rates outside of these times.

The implementation of TVT effectively redistributed traffic away from the more congested Cross-Harbour Tunnel, and also notably reduced traffic congestion during peak hours. The government is also planning on expanding the functionality of the HKeToll to cover car park payment at government-owned parking facilities. The BES can be adapted to this new functionality without fundamental changes.

Looking further ahead, as Hong Kong's urban development and road network continues to expand, HKeToll could also be used to serve future mobility pricing functions such as congestion charging, or even low-emission zone enforcement.



13.

Authors

Carmen Chu was the Project Manager and the Government Representative Designate supervising the Works Contract. She is Arup's East Asia Region Intelligent Mobility Skills Leader and a Director in the Hong Kong office.

Brad Fong led the design team for the back-end system and also worked on the design and construction of the front-end tolling equipment. He is an Associate in the Hong Kong office.

Hamlyn Kuong led the construction, testing and commissioning of the overall HKeToll system. He is an Associate Director in the Hong Kong office.

Wilfred Lau was the Project Director. He is an Arup Fellow based in the Hong Kong office.

Project credits

Client Hong Kong Special Administrative Region Government's Civil Engineering and Development Department, Electrical and Mechanical Services Department
Traffic engineering, digital, transport planning, transportation Arup:
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Image credits

1-5, 7-9, 11, 12: Arup
6: Google Earth DigitalGlobe
10: Paul Tsang/Unsplash
13: ARS/Unsplash

1.

Green building at scale

PepsiCo's new manufacturing facility shows how the food industry can adopt circular economy principles

Authors Bernadetta Badura, Tomasz Frej

One of the world's leading food and beverage companies, PepsiCo, was looking to expand its operations in Poland, a strategic move to meet growing demand in the region. The company, which has had a presence in Poland for over 30 years, envisioned a new, state-of-the-art facility that would increase production capacity and embody its commitment to sustainability and environmental stewardship. Arup helped to translate this vision into reality while overcoming numerous technical challenges, meeting regulatory requirements and dealing with several exceptional circumstances, including a global pandemic and war in a neighbouring country.

In terms of architectural and engineering feats, the construction of PepsiCo's new plant in Środa Śląska stands as a testament to innovation, sustainability and efficiency. The plant, located on a 30ha site in south-west Poland, is one of the company's largest in Europe, producing Lay's potato chips and Doritos nachos.

Arup acted as PepsiCo's holistic partner from the beginning of the project to the factory opening in May 2023. The firm provided full engineering, procurement and construction management services, as well as architecture, structural design, mechanical engineering, electrical design, and plumbing and sanitation. Arup also helped with the site selection, with permits including environmental ones, with cost management and procurement strategy, and then with tendering for the general contractor. Finally, the team provided site supervision and project management during construction. More than 100 Arup team members were involved in total.

Unexpected challenges

The project began shortly after lockdowns were imposed around the world as a result of the COVID-19 pandemic. The team quickly had to adapt to the new reality and implemented online collaboration tools; this was the first construction project to be delivered remotely and wholly in a digital Building Information Modelling (BIM) environment for PepsiCo.

During the delivery of the project, the global economic situation also evolved in unexpected ways. The first wave of inflation occurred after the pandemic had peaked, and was followed by a second caused by the effect on the Polish property market of Russia's invasion of neighbouring Ukraine. Arup was responsible for cost consulting, and successfully renegotiated the contract with the general contractor.

The war also impacted resources. Poland imports much of its steel from Ukraine, and the war affected steel availability and prices. Many materials needed for the plant would typically also have come from Russia, but due to sanctions, the team procured material from elsewhere. Then, when the design was already in progress, the client's needs changed significantly. Due to market demand, the initial planned factory size of 30,000m^2 was increased to 55,000m^2. The plant not only had to be larger, but as it was decided that more types of products would be made there, additional production lines had to be added. With a specific date to bring product to market, the existing project timeline could not be extended.

The entire project was developed using BIM to enable modern construction methods. Arup's cost consultants also used BIM for quantity surveying, which helped to accurately evaluate the costs of different options. The team created a digital twin of the plant to facilitate future maintenance and implemented a range of digital tools and methods, including virtual design reviews, the Arup Carbon Tool and One Click LCA (to calculate carbon emissions), IMAGINiT Clarity (an internet-based tool for automated BIM processing), and Enscape (a commercial real-time rendering and virtual reality plugin).

Despite the hurdles encountered, the project was completed within the original

1: The Środa Śląska plant is one of PepsiCo's largest manufacturing facilities in Europe

2: The project was delivered entirely in a BIM environment

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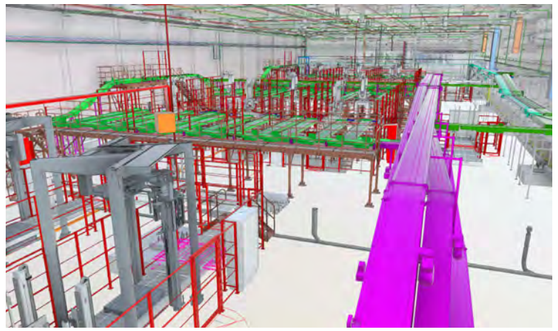

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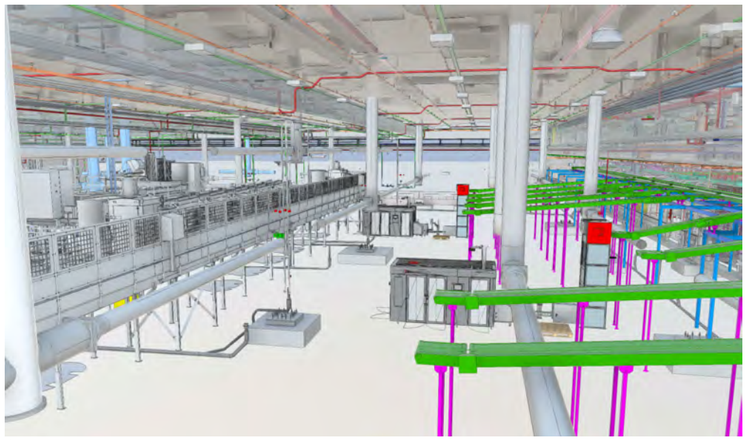

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3: Using BIM for quantity surveying helped Arup's cost consultants to accurately evaluate the costs of different options

4: The team created a digital twin of the plant to facilitate future maintenance

timeline, and sets a precedent for other major food manufacturing plants across Europe and further afield.

Sustainable design solutions

Arup's expertise in sustainable design played a pivotal role in shaping the architectural blueprint of the PepsiCo plant. One of the highlights of the project was the integration of cutting-edge technologies to optimise energy efficiency and reduce environmental impact. Through advanced computational modelling and simulation, Arup engineers devised innovative solutions for heating, ventilation and air conditioning (HVAC) systems, lighting, and water management, ensuring optimal performance while minimising resource consumption. The HVAC design was rewarded by the Polish Ventilation Association with the PASCAL 2024 award. Arup's innovative solutions will help the investment in the facility in Środa Śląska to achieve climate neutrality by 2035.

The plant's design also prioritised natural ventilation and lighting (supplying as much natural light as possible within the process constraints), harnessing fresh air and daylight to create a healthier and more productive working environment for employees. Arup's approach to sustainability extended beyond mere compliance with regulations, setting a new standard for green industrial architecture in the region.

To help design a user-friendly factory, Arup interviewed PepsiCo's employees at existing plants in Turkey and Poland to thoroughly understand their needs and experiences. By doing so, the team was able to ensure it designed the best production process, as well as suitable people flows. Because the plant was designed at the start of the COVID-19 pandemic, the team also took into account potential for future pandemics. This included designing corridors that could be divided if need be, while lockers for the workers were laid out in such a way as to avoid the mixing of workers on different shifts. The Arup team also helped plan and account for future enlargements or refurbishments in a way that would entail minimum disruption to the factory.

The Środa Śląska plant in numbers

- 55,000m² plant which will produce crisps and other snacks
- 450 jobs generated locally
- Exports to over 20 European countries
- More than 100 Arup engineers and consultants involved
- Carbon neutral by 2035

The power of the potato

In the new plant, PepsiCo used the power of the potato to the maximum. For example, the facility has been prepared for a biomass generator that uses potato peel to provide power. In the next step, this peel is converted into fertiliser in a composting plant for farmers who work with PepsiCo, to help them grow their crops. There is also a water management system designed for the use and reuse of potable water and rainwater. This is used in the potato cleaning processes and transport, as well as for cooling and irrigation, and finally for toilet flushing. Using the onsite wastewater treatment plant, the treated, processed water is also reused for production. Arup ensured that the entire water system can be regularly analysed and monitored for improvements.

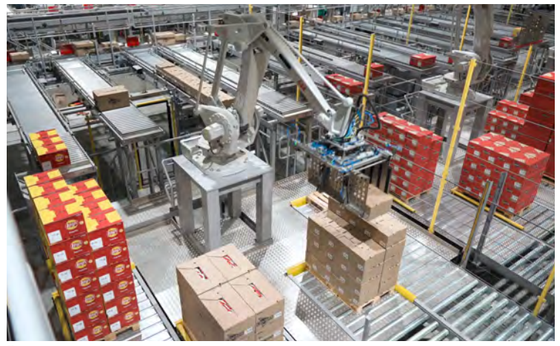
As part of PepsiCo's zero waste policy, a starch recovery process was implemented. This system extracts starch from post-processed water and then helps produce starch flour from any crisps that cannot be sold. Arup designed a comprehensive whole-life carbon assessment, including for the production lines, and provided the guidelines for the design. Materials were sourced consciously; for example, by using locally found materials for construction, to reduce the carbon footprint.

5.

6.

Engineering challenges

Arup's multidisciplinary team tackled the challenges of constructing a large-scale manufacturing facility by leveraging their expertise in civil, mechanical and electrical engineering to deliver a robust and resilient infrastructure. The firm collaborated with PepsiCo to calculate the plant's carbon footprint lifecycle, including a potential future demolition phase. The firm analysed the building's environmental impact, as well as the ratio of embodied carbon to operational carbon during the building's lifespan, and identified the areas with the most potential to reduce emissions. The data gathered allowed Arup to identify key carbon hot spots in the factory and, together with the client, apply carbon emission reductions within the design.



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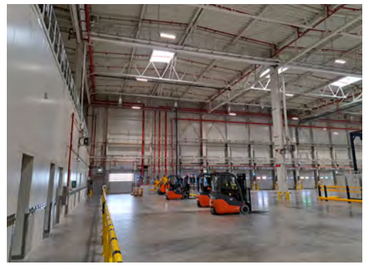
5: The HVAC systems are designed to ensure optimal performance while minimising resource consumption

6: The design supplies as much natural lighting as possible

7: The production lines were included in a comprehensive whole-life carbon assessment

8: Allowance has been made for potential future enlargements



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To help achieve its aim to be a zero-carbon factory, the plant will generate solar power and wind energy. The addition of a private wind turbine involved a change to the local urban development plan, which Arup was able to assist with. In years to come, the factory will also produce biogas and fertiliser from the fermentation of potato peel.

By combining wind and solar energy generation technologies, Arup's design ensures that the new plant operates with minimal environmental impact and achieves a high level of energy self-sufficiency. This approach not only reduces the plant's operating costs over time, but also demonstrates the feasibility and benefits of renewable energy

Planning a sustainable plant

1. Whole-life carbon analysis
2. Calculation of embodied carbon included:
   a. 1,182 entries
   b. 9,825 equipment units
   c. 7,160 tonnes of various materials
   d. 199km of piping and other items
   e. 73.2ha of various materials covered
   f. Over 15,000m³ of concrete and other materials
3. Waste heat utilisation for heating: 92%
4. Average fresh water needed for the process for the first five years of operation is 280,000m³. After condensate recovery and stormwater utilisation, the average freshwater needs have been estimated at 146,000m³. This reduces CO_2 emissions by 40,000 tonnes.

9.

9: The thermal insulation in the walls was optimised using IES software

10: An array of 100kW photovoltaic panels is installed on the roof, and there are plans to expand this in future

10.

adoption in large-scale industrial settings. Arup's expertise in renewable energy integration has helped PepsiCo advance its sustainability goals while setting a benchmark for future projects in the manufacturing industry.

At the start of the project, Arup planned to visit similar PepsiCo sites in Turkey, but due to the pandemic and travel restrictions, this wasn't possible. As a result, everything, including site tours and interviews with PepsiCo engineers, was done remotely.

Arup worked closely with PepsiCo to establish the best, most environmentally friendly solutions. During the crisp production process, a lot of energy is consumed due to gas usage and the frying of potatoes. It was important to work out a way to not lose this energy, and to reuse any waste. Waste heat from the production is reused for heating water and producing cooling water used in the production process. The heat recovery system generates 3MW of power, which is 60% of the heat necessary to heat the entire building. This also enabled the material thickness in the walls to be reduced, resulting in lowered construction costs. The thermal insulation in the walls was optimised using IES software, with high-efficiency glazing also used in the façade.

Arup's meticulous planning and coordination were instrumental in optimising the plant layout for seamless workflow and operational efficiency.

Working with the client, the team fine-tuned the arrangement of production lines, storage facilities and utility systems, minimising bottlenecks and maximising throughput.

Sustainable manufacturing

From energy-efficient building materials to onsite renewable energy generation, every aspect of the facility was meticulously engineered to minimise its carbon footprint and environmental impact. Arup worked with PepsiCo's sustainability roadmap to help guide the selection of sustainable solutions. This ranged from using sustainable materials, such as a steel structure that was selected with future reuse of the material in mind, and locally sourced durable fabrics, to logistics. The factory is located near potato suppliers, who deliver the raw material according to a careful schedule to avoid the need to store the potatoes. Sustainability is at the core of this production plant's design process.

As part of the plan to use sustainable energy sources, an installation of 100kW photovoltaic panels was situated on the roof of the factory. However, this only produces a fraction of the energy needs of the plant, so the team devised a plan to prepare the site and buildings to be able to install more solar power sources in the future. PepsiCo is aiming to transition to net zero or net positive systems in the future using alternative fuel and water technologies.

11: Steel was selected for the structure of the plant, with future reuse of the material in mind

12: Electric vehicle charging points encourage green commuting

11.

Social cohesion and wellbeing

As well as environmental benefits and a focus on the circular economy, the project strengthens community ties in the region. The plant will create more than 450 jobs, and to encourage the breaking down of social barriers, blue- and white-collar workers share facilities. Another key aspect is a focus on green commuting, including bike paths and pavements, and easy access to public transport.

In this way, the project's commitment to sustainability extended beyond the confines of the plant itself. By advocating for eco-friendly transportation modes and implementing smart distribution strategies, it reduces the plant's overall carbon emissions and ecological footprint, contributing to a more sustainable future for the region.

Through a combination of pioneering solutions, technical expertise and a commitment to sustainability, Arup helped transform an ambitious vision into a tangible reality. By harnessing the collective ingenuity of architects, engineers and sustainability experts, the firm has not only delivered a world-class manufacturing facility, but also paved the way for a more sustainable and resilient future for the industry as a whole.

12.

Authors

Bernadetta Badura was the Project Director. She is a Director in the Krakow office.

Tomasz Frej was the lead electrical engineer and the Project Manager. He is an Associate in the Krakow office.

Project credits

Client Frito-Lay
Architect Ingarden & Ewý Architekci
Lead contractor Budimex
Architecture, building physics, civil and structural engineering, cost management, fire protection, geotechnics, HVAC design, planning and permitting, process installation, project management, site supervision and commissioning, sustainable building design, waste to energy solutions Arup: Jakub Arczyński, Bogumił Augustyniak, Bernadetta Badura, Maksym Beichuk, Paulina Biestek, Joanna Bogasz, Miroslaw Bogusz, Bartosz Borowicz, Adam Brania, Hassan Dia, Michal Dulo, Karolina Dziag, Michał Filipek, Tomasz Frej, Paulina Gagatko, Dominika Gawlik, Marcin Giers, Marcin Golabek, Marta Golonka, Karolina Grudzien, Joanna Iwaniuk, Bartosz Jachimczak, Anna Janda, Jaroslaw Jendrzejczak-Jendrzejewski, Nikodem Kajetanowicz, Michał Karwala, Rafal Kaszyca, Magdalena Klos, Tomasz Kmuk, Aleksandra Kocot, Maciej Kolodziejski, Weronika Kowal, Beata Krajewska, Krzysztof Krzyżański, Klaudia Kubica-Kozlik, Maciej Kupczyk, Maciej Kurus-Rosloniec, Marlena Kus, Bogumil Lipiecki, Marlena Maczka, Beata Mamel, Bartosz Marcol, Jacek Marzec, Wojciech Metych, Mateusz Muskus, Piotr Napiorkowski, Anna Norowska, Tomasz Nowacki, Anna Nowak, Stefan Oblakowski, Karol Oczos, Agnieszka Okulowska, Pawel Paluch, Marcin Pawlik, Dobromila Pierzchala, Wojciech Pietruk, Jowita Podraza, Wojciech Polak, Anna Popowczak, Andrzej Potoczny, Wojciech Pruszkowski, Tomasz Puchala, Adam Pyjor, Dorota Radzieta, Andrzej Rucinski, Błażej Skaza, Marek Skorupa, Agata Spilkowska, Patryk Stawiany, Emilian Szarow, Dorota Szczepanik-Gurgul, Aleksandra Szott-Mazur, Beata Tarczewska-Sidelko, Pasan Walisundara, Anna Waskowska, Maciej Wlecial, Jakub Wlodarz, Karolina Wontorska, Patrycja Zgierun, Aneta Ziarkowska.

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Front cover image: Porthcawl Sandy Bay Coastal Scheme, Bridgend, UK: Knights Brown

The Arup Journal
Vol.59 No.1 (1/2024)
Editor: Macdara Ferris
Designer: Wardour
Email: arup.journal@arup.com

Printed by Geoff Neal Group
Produced on FSC® paper
and printed with vegetable-
based inks.

Published by Arup
8 Fitzroy Street
London W1T 4BJ, UK.
Tel: +44 (0)20 7636 1531

www.arup.com

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