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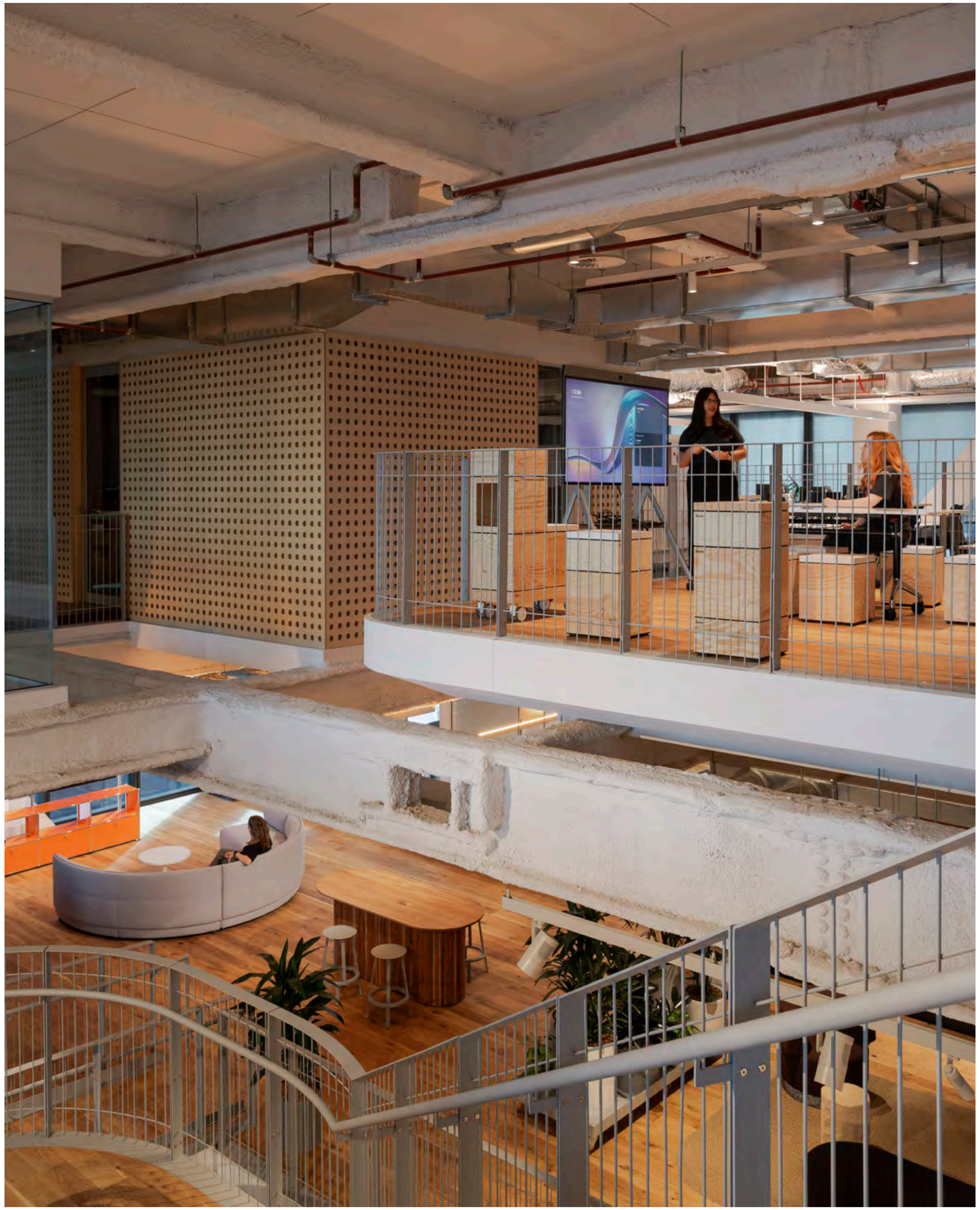

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WS2, Perth, Australia
Dion Robeson Photography

New hub turning north London's waste into energy

Replacing the Edmonton EcoPark with a modern recycling, waste and energy hub fit to serve seven north London boroughs

Authors Douglas Chisholm, Nick Finney, Carlo Tugulu, Nicola White

The North London Heat and Power Project (NLHPP) is the most significant public sector investment in the UK capital's waste treatment and disposal facilities this century. When it becomes fully operational, the 15.4ha complex will perform a critical, if largely unseen, role in the lives of more than two million north Londoners, managing their residual waste to generate electricity and heat for local homes and businesses, and supporting effective recycling services.

The NLHPP is taking shape on the Edmonton EcoPark, which has been turning north London's waste into energy for more than 50 years but is now reaching the end of its service life. The replacement facility is being delivered by North London Waste Authority (NLWA), the combined waste authority for the boroughs of Barnet, Camden, Enfield, Hackney, Haringey, Islington and Waltham Forest.

There are three core elements to the project. At the north end of the site, the Energy Recovery Facility (ERF) will replace the existing energy-from-waste (EfW) plant, with capacity to divert up to 700,000 tonnes of non-recyclable waste from landfill each year. This will be used to generate 78MW of electricity – enough to power up to 127,000 homes, almost double the current capacity.

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1: EcoPark House is a new 2-storey education and visitor centre

To the south, a Resource Recovery Facility, which includes a public reuse and recycling centre, will manage around 135,000 tonnes of recyclable materials a year. And next to this, there are upgraded facilities for the Edmonton Sea Cadets, as well as a visitor and education centre that will provide opportunities for the public to find out more about the circular economy.

Separate to the main project, a heat network energy centre has also recently been delivered at the southern end of the site. Connecting to two pipelines, this will be one of the largest district heating networks in the country, using waste heat from the ERF to supply heating and hot water to around 60,000 north London homes and businesses. The Authority's programme delivery team is a multidisciplinary team from leading industry partners that encompasses delivery, management, technical, legal, financial and commercial services. Arup's role has been instrumental at every stage of this immensely complex, multi-faceted project. The firm's planning experts helped the project achieve consent 16 months after the application was submitted. Throughout a robust, transparent planning process, the client was able to secure buy-in from both local communities and conservation groups, despite the project's potentially sensitive location next to Lee Valley Regional Park.

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The firm continues to advise NLWA in the delivery stage, providing multidisciplinary programme and project management services, alongside project partner organisations. Coordinating the project has involved complex construction sequencing, with major workstreams often overlapping, and required keeping costs on track through Covid lockdowns and sustained periods of high inflation. The 'one team' culture embedded by Arup has also helped keep this long-term, multi-stage infrastructure project focused and cohesive with a strong level of technical input from across the industry. To support the one team ethos in delivery, Arup worked with NLWA to develop a project vision that has proved to be an enduring and unifying force. The vision is to create a waste management facility in which local communities take pride, that demonstrates value and is a model for public sector project delivery.

The trust between the various partner organisations working on NLHPP has fostered collaboration and innovation, including new approaches to design for disassembly and groundbreaking use of cement-free concrete. As a result, it is a project that continues to give north London the benefits of its own waste management facility and offers a benchmark for urban waste management.

Assessing technologies and sites

In 2013, NLWA began to develop a plan to maximise the life of the existing EcoPark, while exploring options for a long-term replacement energy recovery facility. Working with its technical adviser Ramboll, NLWA analysed three options for energy recovery technologies: mechanical biological treatment, which combines mechanical sorting of waste with treatments such as composting and anaerobic digestion; gasification and pyrolysis, which involves the decomposition of waste at high temperatures; and EfW, the existing process for generating electricity through the combustion of residual waste.

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2: At the north end of the site, the Energy Recovery Facility will replace the existing energy-from-waste plant

3: Green roofs will help to achieve a BREEAM Excellent sustainability rating

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4: The chimney at the Energy Recovery Facility is the same height as the previous chimney, but is less visible against the sky

5: The Resource Recovery Facility's public recycling centre will manage around 135,000 tonnes of material a year

6: The Resource Recovery Facility demonstrates an accessible, public-facing approach to waste

EfW offered some clear advantages. The process had become considerably more efficient since the EcoPark was first developed in the 1970s and had been tried and tested at plants across Europe. Crucially, it was also proven to be able to operate at the required scale. Even in the most ambitious recycling scenario, north London is forecast to generate more than 500,000 tonnes of residual waste in 2050.

The team assessed various potential locations across north London, with the EcoPark identified as the most appropriate. It had good transport links, was available to the authority and was of sufficient size to accommodate not just the EfW plant, but also extensive recycling facilities.

It did, however, pose the logistical challenge of delivering major – and highly technical – construction works on a site where the existing facilities needed to remain operational throughout. A number of different site layouts were considered. Due to its size, the only possible location for the new EfW plant was in the northern-most section of the EcoPark, which also offered a sufficiently deep layer of London clay to support the facility and its foundations. With the existing plant occupying the middle of the site until its decommissioning, the other facilities would be located to the south.

Considering the community

Working in collaboration with architects Grimshaw, Arup provided a range of consultancy services on the NLHPP. The ERF was conceived with a compact form, its height kept to a minimum to reduce the visual impact on the neighbouring communities and regional park. As the most prominent feature on the site, the chimney stack was kept at the same height as the pre-existing stack but with a colour less visible on the skyline.

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7: EcoPark House will provide education, offices and a base for Edmonton Sea Cadets

8: Communications around the EcoPark included a series of public exhibitions

Air quality in surrounding neighbourhoods was a key area of focus throughout the design process. Arup carried out a detailed dispersion modelling study to assess concentrations of emissions at ground levels. This showed that the new facility would operate at 60% below limits for nitrogen oxide (NOx) emissions set by the Industrial Emissions Directive. Even at the peak level of NOx from the ERF, this is only 2.94% of local air quality concentrations, compared with road transport, which is responsible for 30.05% of NOx concentrations.

The Resource Recovery Facility, meanwhile, was designed to demonstrate an accessible, public-facing approach to waste. Louvred facades admit light and air while offering protection from rain and direct sunlight. A sawtooth roof provides space for 2,235 photovoltaic panels – the largest array in north London. The all-encompassing approach to reuse extended to a 300,000-litre rainwater storage system located underneath the facility.

The final part of the masterplan was EcoPark House, the 2-storey education and visitor centre. This included educational and visitor spaces on the upper floors, as well as a permanent base for the Edmonton Sea Cadets, who used the wharf at the edge of the site to access the River Lee. A minimum of BREEAM Very Good rating has been achieved for EcoPark House, and the project is now targeting BREEAM Excellent through a 20% increase in solar panels, as well as the implementation of a green roof, an off-grid system, battery storage and ground source heating pumps.

8.

A project of national significance

Ahead of planning, NLWA took ownership of the facility, paying for the development through the levy it charged to the seven north London boroughs. Arup, which had established a close working relationship with the waste authority by this point, now worked with the NLWA to navigate the route through planning. The project challenges included the proposed site being in a sensitive location, neighbouring a regional park and surrounded by a busy industrial estate, with nearby residential properties.

Due to the capacity needed to treat waste and therefore electricity output, the project was required to seek designation as a Nationally Significant Infrastructure Project (NSIP). The NSIP process was introduced under the Planning Act 2008 as a means of streamlining planning for critical infrastructure by enabling developers to apply directly to the UK government. By reorganising long-term, large-scale projects into a single application, a robust examination of all factors at once is possible, enabling the decision-making process to be achieved in about 18 months. Arup's planning experts had extensive experience of NSIPs, including for Hinckley Point, the Thames Tideway Tunnel and the A14.

The challenge of the NSIP process is that everything hinges on a single application, known as a Development Consent Order (DCO), which comprises detailed reports and statements covering all aspects of the project. A DCO involves statements of common ground with each major stakeholder, technical reports, compulsory purchase orders, environmental statements, plans and drawings, utility strategies, risk assessments and codes of practice. Any failure to follow the correct protocols can lead to a lengthy judicial review.

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9: Feedback was sought from the local community

10: Planning was sought and successfully attained through the Nationally Significant Infrastructure Project process

Gaining consent

The crucial element of the pre-application stage was gaining the support of the community and key stakeholders, including Enfield Council, the Greater London Authority and Transport for London, as well as Natural England, the Canal and River Trust and the Lee Valley Regional Park Authority. Consultation was undertaken in two phases – between November 2014 and January 2015, and in May and June 2015 – to allow interested parties a chance to understand and respond to the proposals.

The first phase sought views on the need for the development, the visual appearance of the new facilities, environmental considerations and community benefits. Effective communication was paramount. The project's location meant that 28,000 households across different local authorities had to be notified to provide a genuine opportunity to influence outcomes. Working with Copper, a communications agency that also had a wealth of experience of navigating the NSIP process, and the client's in-house communication department, the project team adopted a multimedia strategy including a website, leaflets to all affected homes, community briefings for schools and community representatives, and a series of public exhibitions. Cartoon explainer films were produced to convey evidence-based analysis, such as how the chimney stack would disperse emissions. Advertising included newsletters, social media campaigns, adverts in train stations and local newspapers, as well as a mobile display vehicle. The approach proved highly successful, with more than 11,000 visitors viewing the website in 90 days.

Arup also established an iterative process for embedding comments into the design process quickly and efficiently, acting on the consultation feedback in real time. For example, the community stressed the importance of incorporating ecological measures and integrating the design into the surrounding environment. In response, the design team proposed enhancement to habitats along the site's eastern edge, as well as green and brown roofs on the plant itself. The massing of the ERF was also refined to ensure it stepped down towards the park, further reducing its visual impact.

The second phase of consultation presented the final proposals and Preliminary Environmental Impact Report. To ensure the process was open and transparent, Arup convened a roundtable discussion for all the statutory consultees, also attended by the Planning Inspectorate, which would ultimately examine the application on behalf of the Secretary of State for Energy and Climate Change. Due to the responsive nature of the first phase, few objections were raised. The team were particularly pleased that, despite the environmentally sensitive location, Natural England felt that their concerns had been addressed and there would be no impact on protected species. In total, more than 180 comments arose from the consultation process, with fewer than 10 objections. The conclusion of the consultation allowed the application to be finalised. Over the next four

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months, thousands of pages of reports were assembled. The application was submitted to the Planning Inspectorate in October 2015 and accepted the following month.

The examination, which took place between February and August 2016, was a streamlined process – again, reflecting the robust nature of the public consultation. The examiner conducted visits to the site, met with NLWA and other interested parties, held three days of hearings and submitted written requests for further information, which were addressed within 48 hours as per the statutory requirement. Consent was granted by the Secretary of State in February 2017, just 16 months after the application was submitted.

Into delivery

In 2018, NLWA appointed Arup as delivery partner to provide multidisciplinary programme and project management services. One of the first tasks was to help establish a detailed cost estimate. A benchmarking exercise examined the major elements of the project's construction costs against comparable infrastructure projects to reach an estimate of £1.2bn at 2019 prices (with the estimate including a contingency allowance

11: The facility is being delivered by NLWA

12: Arup consulted a broad range of organisations

13: The ERF will generate 70MW of electricity – enough to power up to 127,000 homes, almost double current capacity

12.

based on a thorough risk assessment and wider experience of major infrastructure development). The project cost performance has tracked against this baseline. Fluctuations in construction inflation levels over the past few years have proved challenging to outturn cost forecasting. Transparent and robust communication with stakeholders has been key in providing assurance to the local authorities ultimately funding the development.

Building on the communication strategy from the DCO process, a strong identity for the development was established – North London Heat and Power Project – with its own brand, logo and website. Extensive public engagement has been paramount to ensuring the local community are fully informed of the development and construction activities which might impact them. Social value for the community was at the heart of the vision, with the scheme supporting local employment and training opportunities, while funding more than 30 local organisations and providing voluntary support. The project also enables the establishing of a new base for the Sea Cadets, offering fantastic opportunities for young people in the Edmonton area. In addition, Arup supported the client's strong safety-first ethos on site through regular workshops and close monitoring of working practices, as well as teaming up with the 'Mates in Mind' initiative to improve mental health in the workplace.

Fostering a trusting environment also had a pragmatic effect: collaborative teams work more efficiently, and with the need for new waste facilities in north London becoming ever more pressing, a streamlined delivery process across organisations was essential. Arup developed a detailed scheduling strategy, overlapping different parts of the project in parallel workstreams, all while the existing facility remained operational.

For example, early in the project a major sewer diversion was needed to prepare

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the ground for the Resource Recovery Facility. This involved one contractor completing a temporary transport yard for waste deliveries to site, while nearby another team was boring a 1.2m-diameter tunnel 10m underground – contracts that would usually be carried out in sequence but were run in parallel. Likewise, the project team was able to accommodate an entirely separate project on site – the development of the district heating energy centre by council-owned company Energetik – while work was ongoing.

Innovation and sustainable materials

The scheduling was aided by a whole lifecycle BIM strategy, which included 4D construction sequencing. The use of BIM has reduced risk during delivery and enabled the efficient operation of delivered assets – crucially, helping to provide cost certainty to a public sector client. The common data environment included geographic information systems – vital for utilities and hazard mapping – and advanced 3D modelling. This, in turn, has paved the way for further innovation, instilling confidence in the integration of new systems and enabling virtual design reviews at every stage.

These early decisions on project management and coordination created valuable breathing space on the programme, which proved crucial when Covid struck. Construction was paused completely for three months while NLWA and Arup assessed how work could be resumed safely. Measures included a wearable technology that monitored people's proximity to each other, enabling the project team to monitor hotspots on site and advise contractors on how to stagger their workflows more effectively.

The collaborative culture instilled by NLWA and Arup has allowed innovation to flourish. A temporary facility built on site was designed to be disassembled so that the materials could be used on other projects – emphasising the importance of reuse in the waste hierarchy. Again, this gave the team the opportunity to engage locally, using contacts throughout Enfield to redeploy resources such as concrete blocks.

Arup also conducted an initial feasibility study exploring the possibility of introducing carbon capture and storage (CCS) at the EcoPark. It is hoped that CCS technologies will be installed in the early-to-mid 2030s in the central part of the site once the current EfW facility has been decommissioned and dismantled. While the new ERF will be the least carbon-polluting option for waste disposal in north London, adding CCS to the site will offer the potential to become a carbon negative solution.

Meanwhile, the Resource Recovery Facility, built by Taylor Woodrow, includes a 500mm-deep ground slab made entirely from cement-free concrete: VINCI's Exegy® Ecocem Ultra Low Carbon Concrete. The $450m^3$ pour was the first time that ultra-low carbon concrete had been placed via a pump anywhere in the world. The cement replacement comprised 96% ground granulated blast furnace slag

– another example of reuse of an existing waste stream. It is estimated that it has saved 90% of the carbon dioxide emissions associated with a traditional concrete structure.

Towards completion

The Resource Recovery Facility was the first phase of the NLHPP to be finished, in June 2024, and EcoPark House was completed in September 2024. The early phases of the project running smoothly meant work on the ERF could start on schedule in 2021, and construction is currently progressing on the site. Once complete, it will pave the way for the decommissioning of the 1970s facility.

The impact on the local community is already marked. The Resource Recovery Facility has been receiving about 10,000 tonnes of recyclable material a month.

Throughout construction of NLHPP, the project aims to generate more than 2,500 jobs, more than 100 apprenticeships and millions of pounds of social value, as well as enhancements to the biodiversity of the regional park. But its most significant contribution will come when the ERF starts to take the seven boroughs' vast streams of residual waste and spin it into electricity and low-carbon heat for north Londoners.

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Project credits

Client North London Waste Authority

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8, 9, 12: Daniel Imade/Arup

1.

Getting on track for climate change

Climate-proofing assessments of four cross-border railway projects connecting Germany with the Netherlands, Poland, Switzerland and Denmark, informing investments in resilient infrastructure

Authors Claudia Di Noi, Max Hemmerle, Caitlin Jay, Jörg Obergfell

1: Deutsche Bahn's aim is to be climate neutral by 2040

Transport networks are feeling the impact of climate change as excessive temperatures, sea level rise, heavy rainfall, flooding and forest fires become more common. Railways are vital to the operation of the global economy, generating massive financial and societal value by enabling connectivity to people, employment, education and goods. To continue delivering these benefits, railways need to be protected against the disruption and increasing threats from extreme weather, which are being compounded by ageing rail infrastructure assets.

Increasing maximum annual temperatures are creating network disruption as rails can buckle if they are heated rapidly by direct sunlight, risking derailments. In the summer of 2022, extreme heat in Europe caused widespread railway speed restrictions and service cancellations. In Germany in July 2021, flooding caused by the Bernd weather system damaged more than 50 bridges, 40 signal boxes and 1,000 electricity and signal masts, and energy and lighting systems. The multi-year repair costs are estimated to exceed €2bn.

In assessing both the impact of infrastructure on the environment and the impact of climate change on the infrastructure, a climate-proofing process can be used to integrate both climate neutrality (mitigation of climate change) and climate resilience (climate change adaptation) measures into the development of projects, including rail schemes. The climate mitigation process consists of a carbon footprint assessment

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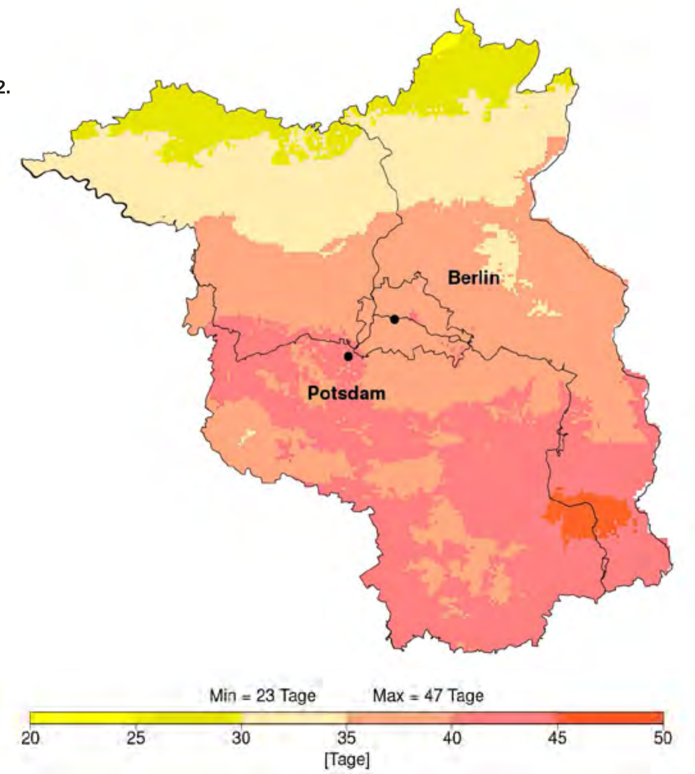

2: Rising temperatures caused by climate change are creating disruption as rails can buckle if they are heated rapidly by direct sunlight, risking derailments

3: Railways are facing increasing threats from extreme weather

of a project, while the climate resilience process comprises a climate risk analysis and identification of adaptation measures aligned with local, national, and international regulations and strategies.

European targets

To achieve its greenhouse gas (GHG) emissions reduction targets, the European Union (EU) aims to grow public transport and support low-carbon mobility, while at the same time reducing transport-related GHG emissions by 90% by 2050. A major challenge to meet those targets is to break the transport system's dependence on fossil fuels and improve its efficiency without compromising mobility.

In 2011, the European Commission set a target of revitalising rail freight transport throughout the EU to reach a 30% modal share by 2030 and to increase this to more than 50% by 2050. Germany has set environmental targets that not only align with that EU decarbonisation strategy but are even more ambitious, aiming to achieve climate neutrality by 2045 – five years sooner than the compulsory target.

Deutsche Bahn, the national rail company of Germany, has ambitious climate protection goals as it sets a course towards net zero. Its aim is to be completely climate-neutral by 2040 and to futureproof existing and planned infrastructure to withstand the expected effects of climate change.

Cross-border projects

Arup was commissioned by Deutsche Bahn to conduct climate-proofing assessments of four cross-border railway projects connecting Germany with Switzerland, Poland, the Netherlands and Denmark. This commission was put in place ahead of the June 2024 mandatory requirement under Regulation (EU) 2024/167, which stipulates an environmental impact assessment must be carried out for every project. The analyses assessed the carbon footprint of each project and set out the risk and likely impact of climate risks such as extreme heat, cold, flooding or storms, while also reviewing the mitigation measures already in place to identify what further measures might be required.

The first project assessed comprised parts of the new Karlsruhe-Basel freight rail line that plans to run between Karlsruhe and the Swiss city of Basel. It will consist of a double-track line designed to accommodate a maximum speed of 160kph, with operation planned for 2031.

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The second project was the evaluation of parts of the upgrade of the railway line between Angermünde and Szczecin in the west of Poland, expected to be in operation by 2026. This route, approximately 30km in length, aims to enhance the connectivity between Scandinavia, western and central Europe into Germany, and on to Poland.

Project Wunderline was the third assessment Arup carried out. This project analysed a section of the Dutch-German infrastructure upgrade project between the cities of Bremen and Groningen in the Netherlands, aimed at improving rail connectivity within the region. The analysis focused on the route section between Ihrhove in Germany and the Dutch border, which is due to be upgraded and in operation by 2027.

The final assessment was of a 11.4km-long segment of the Fehmarnbelt Fixed Link route between Germany and Denmark (including the existing Fehmarnsund Bridge), which is planned for operation by 2029. This project includes the double-track expansion and electrification of the existing line.

Climate proofing

For each of the projects, a climate-proofing process was used, integrating climate change mitigation and adaptation measures into the development of the infrastructure. The climate-proofing assessments were prepared in accordance with the European Commission's 'Technical guidance on the climate proofing of infrastructure in the period 2021-2027' (C373/2021). Arup calculated and monetised the operational and user-related GHG emissions of the four projects, using the European Investment Bank's Carbon Footprint Methodologies. The firm carried out a climate resilience analysis aligned to the EU taxonomy, which included a climate risk assessment (including hazard likelihood and vulnerability analyses) and an analysis of adaptation measures and monitoring mechanisms.

All analyses were assessed on compatibility with local, national and European climate targets for 2030 and 2050. The results emphasise that the partial shift of passenger and freight transport from road to rail is an important step towards a net-zero footprint in the transport sector.

Arup's work also evaluated whether the four projects aligned with national and European climate targets. The findings were used in the context of the Connecting Europe Facility (CEF) application process. CEF is a key EU funding instrument to promote growth, jobs and competitiveness through infrastructure investment at the European level – both through the construction of new transport infrastructure and the rehabilitation and upgrade of existing infrastructure.

This work drew on various areas of Arup's expertise, including transport and rail planning, economics, asset management, infrastructure, environment and law. The assessments aimed to provide valuable insights for making sustainable investment decisions and obtaining EU funding approval.

Adaptation to climate change (resilience)

Climate adaptation was evaluated through a risk-based framework whereby risk is the product of three components (hazard, exposure and vulnerability). A detailed assessment of a series of climate-related hazards was carried out – these included extreme heat, cold wave, wildfires, heavy precipitation, drought and flooding, among others. These hazards were investigated to define their likelihood of occurrence for current and future scenarios.

A vulnerability assessment was then carried out for each of the transport system components, against the hazards. Six system components were identified – carriageway and tracks, rolling stock, operational systems, buildings, energy and electrical system, and users. The final risk assessment combined the results of the hazard and vulnerability analyses, with the results showing that there were high or very high risks for a number of system components and hazards.

For example, for the carriageway and track component, extreme heat, cold wave/frost, wildfire, heavy precipitation (snow), drought, flooding (pluvial), windstorm and subsidence all returned high or very high risks, while the rolling stock components returned high risk for extreme heat, cold wave/frost and wildfires.

For all the high and very high climate risks identified, a gap analysis was then undertaken to identify which risks are currently covered by existing adaptation measures and which will need to be addressed through new measures during the project's planning, design, construction and operation stages.

4.

4: The climate adaptation assessment highlighted areas where Deutsche Bahn already has measures in place for adaptation

Mitigation of climate change (neutrality)

The mitigation assessment was carried out in three steps: calculation of the baseline emissions from a 'do minimum' scenario (without the project); absolute emissions, which is the scenario with the project in full operation; and a comparison of emissions between those two scenarios to give the relative GHG emissions.

The mitigation analyses determined that the projects provided significant reductions in GHG emissions (and air pollutant emissions) compared with a scenario where the projects were not implemented. The reductions are associated with a significant decrease in road freight vehicle-kilometres, resulting in a modal shift of freight from road to rail, as well as a decrease in travelled passenger car vehicle-kilometres and diesel train vehicle-kilometres. They show that the projects align with the directives of EU and national climate objectives to reduce climate impacts.

5.

5: The mitigation analyses determined that the planned projects provided significant reductions in GHG emissions

Whole life carbon assessment

As part of Arup's own research, the firm undertook additional research on capital carbon emissions by carrying out a whole-life carbon assessment for projects of a similar scope and size. The construction, operation and maintenance of infrastructure projects all result in GHG emissions. The assessment looked at capital carbon – emissions associated with the creation of an asset – and operational carbon – emissions associated with the operation and maintenance of an asset.

Arup's experience in designing transport infrastructure has shown that the capital carbon from the construction of a railway is considerable, and a significant proportion of the asset's total whole-life carbon emissions. The firm's assessment determined that for projects comparable in scope and size, 33% of total capital carbon emissions came from construction, with the remaining 67% associated with maintenance over the course of 60 years – the common service life for railway infrastructure.

Looking specifically at the construction phase, track construction and the overhead line equipment (OLE) accounted for 44% and 28% of capital carbon emissions respectively. This is due to the impact of the carbon-intensive materials – concrete and steel – used in ballasted track installation and electric equipment, and the steel used for OLE ancillaries. Points and crossings, meanwhile, contributed to 12% of the total construction emissions due to the high amount of steel in the components. Structural components like platforms, overpasses and culverts showed a lower impact (6% of total capital carbon for the construction phase) in comparison with other categories.

Assessing the maintenance phase over a 60-year service life, tracks and OLE emerged as the main contributors to capital carbon (58% and 31% respectively). This is due to the replacement frequency of sleepers and ballast (every 20 years). Furthermore, ballast cannot be reused or downcycled due to it being contaminated with other materials.

The study on capital carbon shows the importance of considering the maintenance stage, as well as the construction phase. It also highlights that construction and maintenance of tracks and OLE are the main hotspots in capital carbon assessment.

Insight

The overall insights gained from all four climate-proofing assessments helped support a funding application to CEF and has also provided a valuable tool for Deutsche Bahn. The climate neutrality assessments show the positive benefit in terms of GHG emission reductions with implementation of these infrastructure projects – an important step as it progresses towards its target of becoming climate neutral by 2040.

The climate adaptation assessment highlighted areas where Deutsche Bahn already has measures in place for adaptation, as well as areas where additional measures are required to provide the resilience necessary to cope with the effects of climate change on rail infrastructure.

Such climate resilience analyses are an important tool in assessing the potential climate threats that could impact rail infrastructure in the future, and how to effectively mitigate the risks to maintain a climate-resilient rail system. The insights learned can help us understand how extreme weather events may affect rail infrastructure. They also can guide decisions towards the development of more sustainable infrastructure for passenger and freight transport, and building a rail network that is resilient to the increasing effects of climate change.

Disclaimer: The projects underlying this article are subject to a non-disclosure agreement and, as a result, certain project details are not fully disclosed nor portrayed in their entirety.

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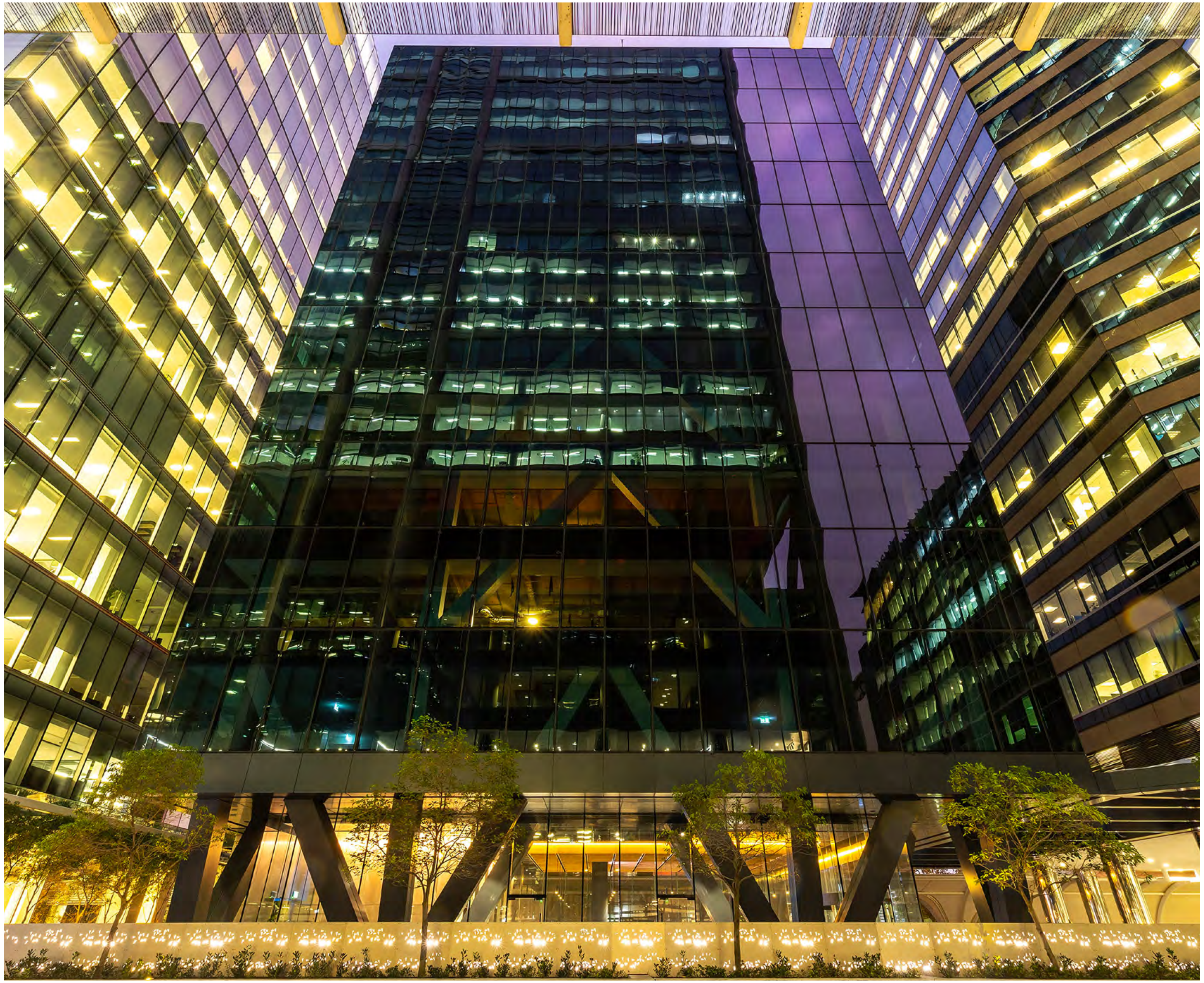


1.

The hybrid: pushing the possible

Western Australia's first timber-hybrid office tower offers more space than a concrete solution

Authors Matt Lowe, Lewis Macdonald, David Williams

The ground-breaking Westralia Square 2 (WS2) is the first timber-hybrid office tower in Western Australia (WA). When completed in 2023, it was also the tallest building of its kind in Australia.

Located in the heart of Perth's central business district, the project, which has adaptive reuse and circular principles, sets benchmarks in engineering excellence, environmental standards and carbon savings for both construction and operation.

The building represents a step change for the local property industry in sustainable building design. The original 1980s structure was repurposed and vertically expanded rather than demolished, creating a cost-effective and sustainable design, and enabling a viable commercial development on a highly constrained site.

WS2 is now home to Arup's new workplace in Western Australia. The office showcases repurposed materials and provides a reconnection with Country. This workplace has people's wellbeing at its core, exemplifying inclusion and diversity.

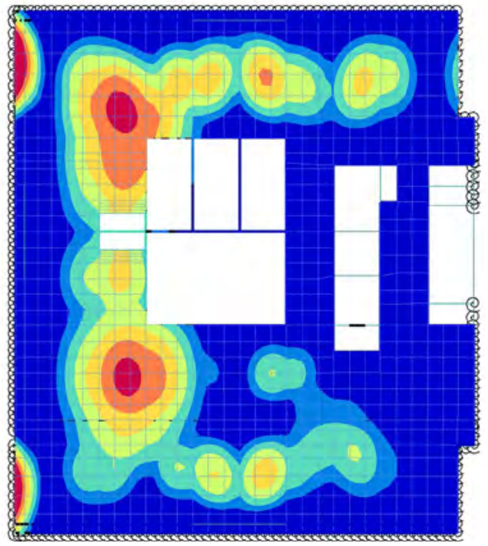
This 12-storey commercial development was constructed above an existing 5-storey parking structure, in between two commercial towers. In overcoming these site constraints, the Arup team developed solutions that demonstrated technical excellence.

Arup was able to achieve approximately three times more floor area than would

2.

1: Without this hybrid design, the commercial redevelopment of the WS2 site would not have been cost effective

2: WS2 is home to Arup's new workplace in Western Australia – an office showcasing repurposed materials and providing a reconnection with Country



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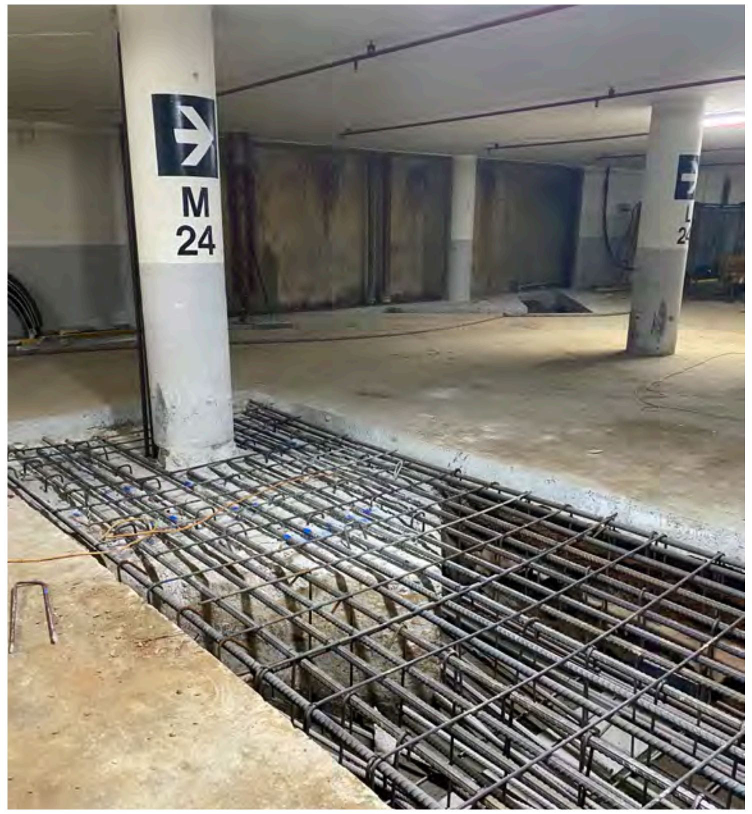


5.

3: A vibration response factor heat map, used to design the in-floor TMDs, which reduce vertical vibration of the CLT floors

4: The CLT floor has a 170mm deep build-up spanning between secondary beams at 3m centres

5: Some tie beams were constructed between pad foundations to spread the additional vertical load where required

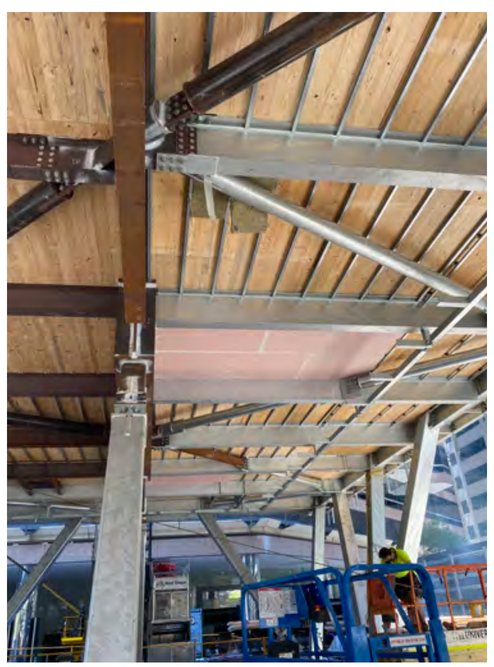
have been possible with a traditional concrete solution built above the existing structure. The solution included a detailed analysis of the ground, minimising strengthening works to the existing structure, and using an innovative timber and steel hybrid structural frame. This enabled the floor design to increase from four to 12 storeys, increasing the floor area from 3,000m^2 to 9,500m^2 above the base design.

The car park below remained active throughout the duration of construction. The novel approach also included designing the new building without a plant room, as it uses the plant room of the adjacent Westralia Square 1 (WS1) building, which has upgraded services.

Hybrid structure

Arup was the original structural engineering consultant for the precinct in the 1980s – designing the reinforced-concrete framed WS1 building, the precinct's basement concrete frame and the podium slab above. In 2017, when the client, GDI Property Group, acquired the site, they sought Arup's advice based on the firm's extensive history with the area. Initial assessments and testing of the podium showed the existing structure could support an additional 3 to 4-storey building using typical concrete structures.

Given that the commercial return was not sufficient to warrant the limited additional area gained through that traditional engineering approach, the challenge was then set to redevelop the site. The design response was unique, addressing the opportunity differently



4.

by using materials and innovative solutions that were outside the norm for WA.

Arup developed a cross-laminated timber (CLT) and steel hybrid solution, significant strengthening works not being required for the basement and support columns. This approach resulted in approximately a 70% embodied carbon saving compared with a reinforced concrete equivalent. Not only was this an exceptional solution for this project, but the adaptive approach is already helping reshape building design and inform future developments with the client using this approach and learning from WS2 for three other projects.

The strengthening works were limited to concrete encasement of a small number of existing basement columns using 65MPA high-strength concrete and the construction of some tie beams between pad foundations to spread the vertical load where required.
In addition, just one of the shear walls in the existing stair and lift core required strengthening. The size was increased from 200m to 400m thick. These upgrades were carried out ensuring minimal impact to the existing basement car park spaces.

Vibration control

While CLT has the advantage of being light enough for the existing structure to support the additional floors, the material's low density makes it more prone to footfall vibration when the building's occupants move around.
As a person walks across a floor, they produce impulse forces with each step. These forces are mainly in the vertical direction and can cause the floor to vibrate, making it feel like the floor is bouncing or shaking excessively.

Adding more floor supports or making the floors thicker would reduce vibration but also add too much extra weight onto the carpark below, exceeding the load capacity of the existing columns and foundations. Stiffening the floor structure was prohibitive from a cost perspective, requiring 700 tonnes of additional steelwork, so the local team worked with Arup's dynamic specialists from around the globe to design a damping system to overcome this issue.

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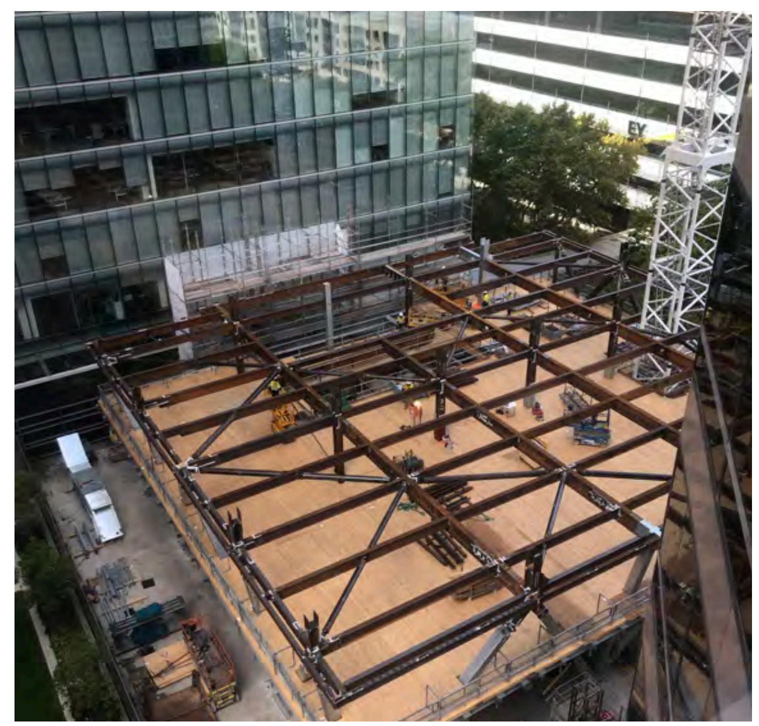
8.

The base-build was designed with in-floor tuned mass dampers (TMDs) to reduce vertical vibration of the floors without increasing steel tonnage. There were 59 TMDs installed, with five TMDs per floor on levels 2–11. Level 1 required nine TMDs, as it had a different structural layout to the other floors. These dampers act like shock absorbers in a car, reducing the motion of the floor and making it feel sturdy to walk on. Tests conducted during installation showed that the TMDs were effective in increasing the damping from 2–5% (ratio of critical damping, without activated TMDs) to 4–6% (with activated TMDs).



6.

6: A 12m x 6m grid was used on the upper floors – extended to 14m x 7.5m at the perimeter to increase lettable area

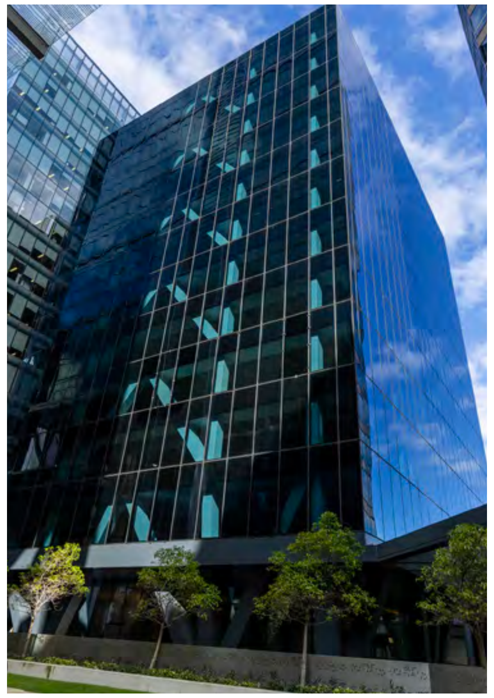
7: To create the void in the Arup office, sections of CLT floor were taken out

8: Five TMDs were installed on each floor, on levels 2 through to 11

Excellence in adaptive reuse

The existing car parking grid of the retained podium structure was at 45 degrees to a viable and usable commercial planning grid on the upper floors. The car park grid was typically 8.4m x 8.4m, which resulted in a 6m square grid. Therefore, the commercial grid was designated to be 12m x 6m within a commercially acceptable internal planning grid. This was then extended to 14m x 7.5m at the perimeter to increase lettable area.

To reorientate the grid of the commercial building to the car parking grid and achieve increased area at the perimeter, raking columns were used to transfer loads from the first floor of the proposed building development to the podium level below, which avoided costly and heavy transfer structures. The perimeter raking columns were also used as the stability system to the new superstructure. This distributed the horizontal forces to the perimeter at the podium level and allowed the vertical circulation core to be a non-structural element with no lateral stiffness. This removed the need for the new core to extend to the basement level, minimising the impact on basement parking, and avoided impactful and wasteful excavation in the base slab for lift pits.



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Steel beams form the 14m x 6m structural grid, with secondary steel beams at 3m centres. The CLT floor has a 170mm deep build-up spanning between those secondary beams. This make-up also meets the requirement for a 3.75m floor-to-floor height, matching the adjacent WS1.

WS2 without plant room

Early in the design phase of WS2, Arup identified the opportunity to use spare capacity in the central plant in the adjacent, existing WS1 tower. By connecting into existing infrastructure, the cost, space requirements, construction time and weight of the building services installations were greatly reduced. The Arup team studied WS1's spare capacity to understand how the base build system could be augmented and the existing infrastructure upgraded (such as switching systems) to cater for both buildings. The process needed to ensure that any changes didn't compromise the services in the existing building or limit their resilience.

This required close collaboration between engineering disciplines and trade-offs between systems design and system selection to ensure the existing capacity was not compromised. Using the neighbouring plant room also significantly reduced the carbon associated with construction. The design has enabled WS2 to perform at a high standard and still meet the ambitious environmental ratings for energy efficiency, occupant comfort and wellness.

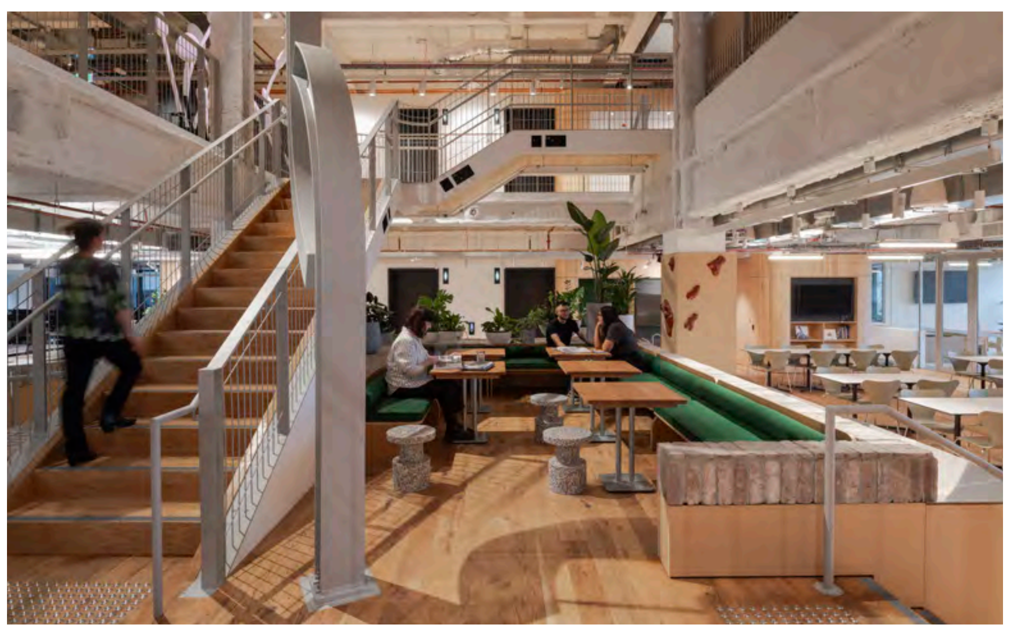
WS1 provides power (including emergency standby generator power), water and cooling (chilled water and condenser water) to the new tower via services routed through the shared basement. The design avoided the need for cooling towers, allowing for a cleaner, uncluttered roof area, an important consideration given how the building is overlooked by its taller neighbours. Plant rooms were still required, predominantly to house air handling units, both at roof level and in the building's basement, and are concealed from view.

A fit out committed to reuse

Not only did Arup design the building, but the firm also co-designed the fit out of three floors – as the new home for Arup in Perth – taking a regenerative and sustainable design approach for the office. A large void in the centre was created during the fit out and the finished space provides a more connected office experience, enabling several different views of the flexible workspaces.

With ceilings exposed in the office areas, the structure – including the dampers – and building services are all visible. A small 'storytelling window' enables the building occupants to view the stacked CLT floor build-up, along with the steel support beams. These features, along with the void in the centre of office, provide a tangible view of Arup's work and shows the commitment to material reuse.

To create the void, sections of CLT floor were taken out, with the void matching the building's structural grid to avoid any timber wastage. The panels were unscrewed and removed in their entirety. Each CLT section was then reused creatively to form raised platforms around the floorplate to create changes in level within the workplace, while retaining within the fit out all material that was removed when creating the void. Some steel beams were reused to support operable walls and others were stored with the stacked CLT panels. If required in the future, the infilling of the stair void can be achieved using all the original material that has been creatively integrated within the fit out.



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9: WS2 is a new 12-storey commercial development constructed above an existing 5-storey parking structure

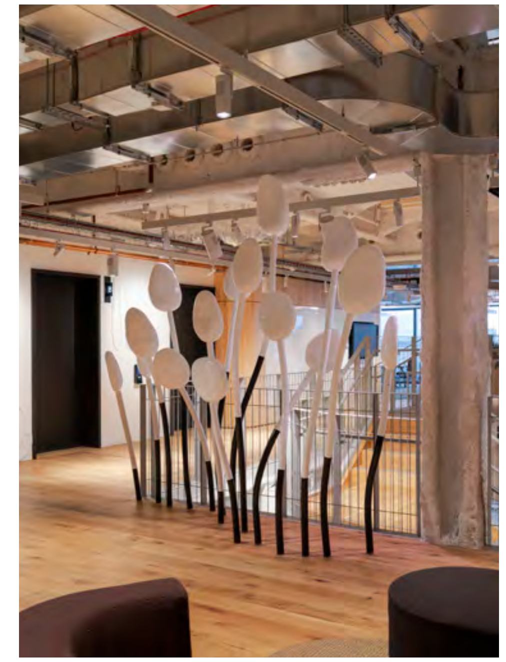
10: The kitchen and winter garden feature salvaged brick slips

As part of the process, every aspect of the build was designed to fit in the goods lift, eliminating the need to use a crane or openings in the facade. In keeping with the design philosophy for the new workspace, Arup designed an elegant floating staircase. It twists inside the void, connecting each level, and is supported by a steel column that was prefabricated in sections so that it would fit inside the lift. Inspired by tensegrity structures, which comprise alternating tension and compression members, each column piece is curved and connected by a thin rod, creating a striking office centrepiece. This approach significantly reduced the steelwork required to support the concept of a floating staircase without the columns and enabled a simple CLT prefabricated stair system to span between the steel frames. All the elements have bolted rather than welded connections to aid assembly and any future disassembly.

Connecting work, nature and Country

In addition to the engineering excellence and sustainability principles driving the fit out, Arup demonstrated equity, diversity and inclusion in engineering by embedding a First Nations voice into the design. The building's location is on Noongar Country – Noongar means 'a person of the south-west of Western Australia', or the name for the 'original inhabitants of the south-west of Western Australia'. Adjacent to the Swan River, the Country upon which Westralia Square sits was originally a wetland peninsula rich in resources where the Traditional Owners would go to gather food.

Arup worked in collaboration with Peter Farmer Designs (Peter is a Noongar artist and his wife Miranda Farmer is a cultural advisor), Ingrid Cumming (Custodian and Traditional Owner of Whadjuk Noongar Country) on Noongar language, Dr Roma Winmar (Elder in Residence at Edith Cowan University) and interior design agency Hames Sharley on the fit out.



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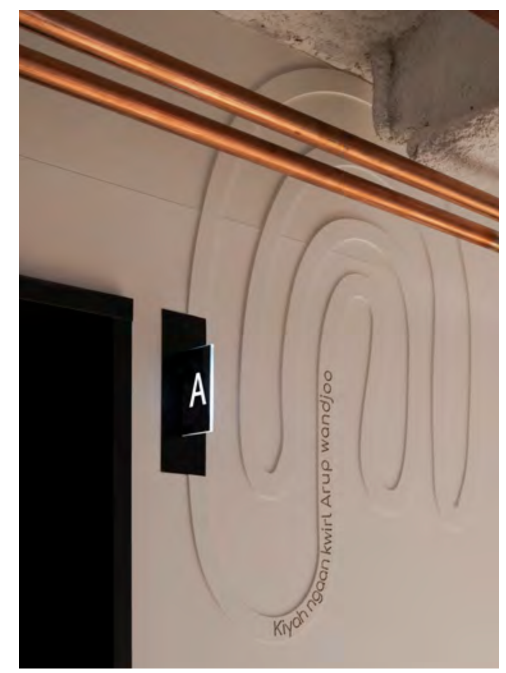
> "We wanted to remind people who travel through the space of the older world – our connection to the natural environment."
>
> Miranda Farmer, Cultural Advisor, Peter Farmer Designs



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11: The large welcome sculpture at the Arup office entrance represents regrowth, telling a story around the regeneration of the land

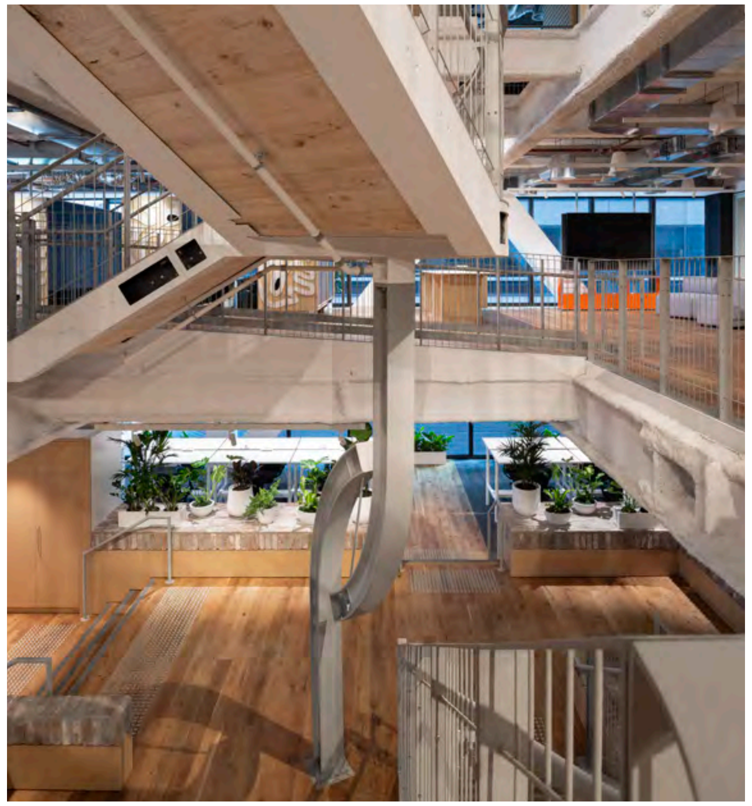
12: Arup's past, present and future journey is represented in artworks incorporated into the building's material design, including in the building entry area

Starting with a conversation, it moved into a co-design process with diverse authentic voices creating a shared understanding of the site and its connection to Country. Whadjuk Noongar art and language were part of the fit-out design, meaningfully connecting to First Nations culture in Western Australia. Together, Arup and the Traditional Owners created a design philosophy that could communicate a connection between the old world and modern worlds by telling stories that encompass Arup's past, present and future journeys or 'Biddi' in Noongar language.

The stories are represented in artworks incorporated into the building's material design, including the lockers, building entry area, wall engravings and kitchen – each with a different meaning and significance. The lockers have a river motif, showing stories of how the river was created and its journey. On entering the office, there is a collection of installations that tell a story about how the elements were sourced. The large welcome sculpture at the entrance represents regrowth, telling a story around the regeneration of the land. The lighting of this art installation changes across the year to match the six Noongar seasons.

A living building

With the fit out of the office, Arup's goal was to meet the requirements for Living Building Challenge certification to create a regenerative and sustainable workplace that prioritises people and the natural environment. This is an international sustainable building certification programme created by the



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13: A large void in the centre was created during the fit out, providing a more connected office experience

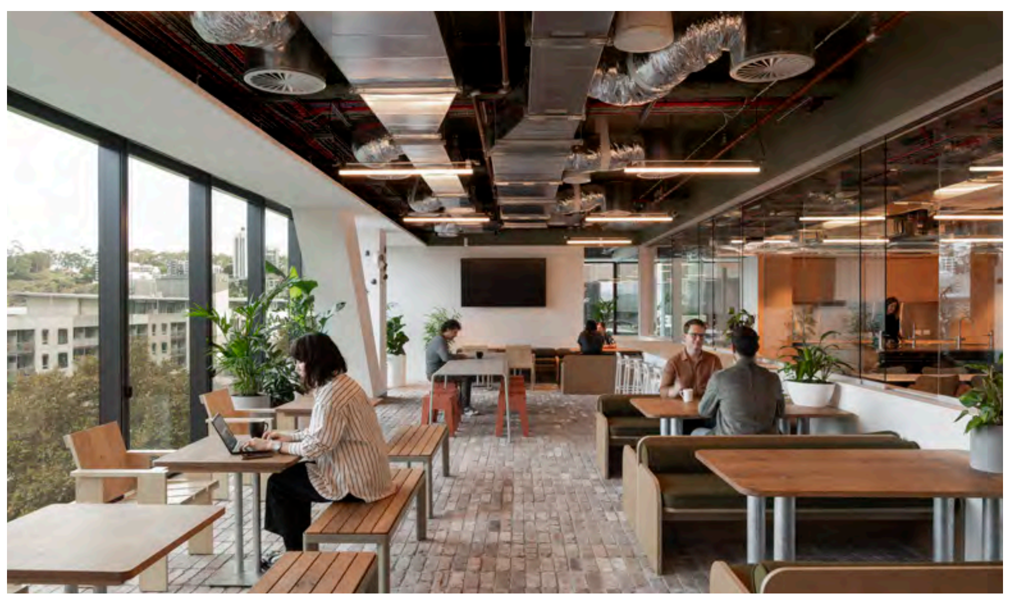
14: The winter garden features seating made from surplus wood stock

15: The design solution for WS2 enabled a viable commercial development on a highly constrained site

Living Future Institute that is also an advocacy tool, providing a philosophy to create regenerative buildings. It is awarded to buildings that have a positive impact on the environment and the people who interact with them. Applying for Living Building Challenge certification enabled Arup to embed sustainability and circular economy principles into the office fit out.

Conscious design and construction choices were made by the design team, along with construction partner Built, to positively impact the natural environment and optimise occupant wellbeing. The space incorporates biophilic design principles, reused and non-toxic materials. In-depth engagement was required with the supply chain, with a focus on reuse and sourcing of local and low impact materials and equipment.

Energy use is metered and closely monitored to meet a 35% reduction annually compared with typical offices in Australia. Sensors and timing controls ensure energy for lights, screens and HVAC is minimised when the office is unoccupied. The workplace is powered by 100% renewable energy as part of Arup's global commitment to have all of the firm's building portfolio powered in that manner. In addition, the embodied carbon emissions associated with the construction of the office were accounted for with the purchase of high-quality carbon offsets.



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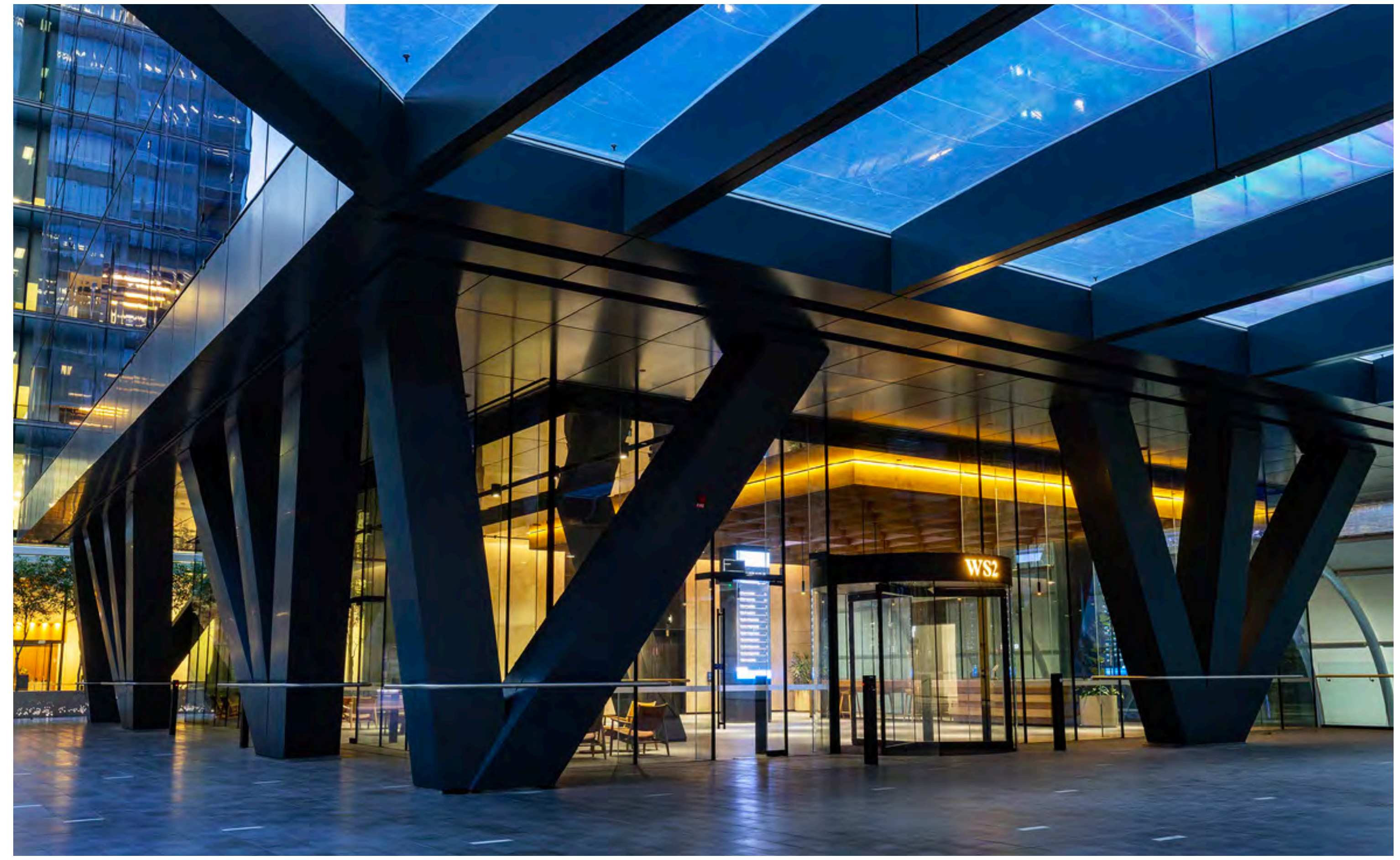
Water usage was limited by the installation of water efficient 5-star WELS-rated taps, and 6-star rated dishwashers. The building is designed to a 5-star NABERS rating for both energy and water. Air quality is maintained by directly exhausting air from high pollutant areas and limiting exterior pollution infiltration. Sensors continuously monitor air quality for pollutants and toxins. Good air quality has been ensured by selecting interior materials – paints, adhesives, carpet and furniture – that have been tested to show low-volatile organic compound (VOC) emissions and using low-VOC cleaning products. By carefully investigating the material composition of all products, it minimised use of those containing Red List chemicals. These are chemicals that are harmful to humans or the environment during production, use or disposal.

Locating workstations and meeting rooms next to the facade maximised access to daylight and views. With Arup choosing to take space across the second, third and fourth floors, the office is located just above the tree canopy. The occupants can look out over the street trees below and to the adjacent Kings Park and Botanic Garden in the west. The varied plants throughout the office also provide frequent opportunities for them to connect with nature, boosting



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creativity and productivity, and helping lower stress.

To support sustainable practices, the wood products in the office were made from salvaged, FSC-certified or Australian-sourced timber. The office features table-tops made from storm-felled Marri timber from the south-west region of WA, and salvaged WA Blackbutt timber slabs. The kitchen and winter garden feature salvaged brick slips, cupboard carcasses made from salvaged board, reused cable trays and booth-seating made from surplus wood stock, and concierge tables made from limestone blocks reclaimed from old quarries. This helped to reduce new materials used in the fit out.

More than 20% of the construction budget was spent on products with a last point of assembly within WA, while more than 50% was spent on Australian products, supporting local businesses and minimising transport impacts.

Authors

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David Williams was the Project Director for WS2 and lead structural engineer. He is a Principal in the Perth office.

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Cultural advisor Peter Farmer Designs
Interior designer Hames Sharley
Fit out project manager Acuity
Fire engineer Holmes Fire
Contractor Built
Acoustic, audio-visual, electrical, facade, fire services, hydraulic, lighting, mechanical, structural engineering, vertical transport Arup: Steve Adam, Samantha Baron, Fernando Bernal Roures, Florencia Bignell, Szymon Borowy, Keanu Breen, Efren Cerrero, Kenji Li Hee Cheong, Steve Cook, Laura Cowie, Tim Elgood, James Flattery, Zac French, Fred Gao, Ross Griffiths, Tony Hadi Poernomo, Rebecca Ho, Terri Hopkins, Ada Hortle, Matt Hughes, Renz Hugo, Sigurjon Ingolfsson, Kameel Ismail, Brynn Jarrett, Daniel Jimenez Pinilla, Jonathan Khoo, Ben Kirkwood, Sasha Kravetz, Win Kyaw, Matt Lowe, Lewis Macdonald, Fatima Nawal, Brandon Nguyen, Nathan Parkins, Joyce Rabbah, Beata Rakowska, Mhairi Riddet, Jack Robinson Lake, Nic Scanlan, Victor See, Jonathon Skotny, Youngbo Shim, Rachel Smith, Alan Tu, Adrian Tung, Nick Wedd, David Williams, Gwen Willox, Clare Xu, Vida Yan.

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1.

Australia's offshore wind potential

Arup's analysis reveals investment and collaboration opportunities to expand Australia's offshore wind market

Authors Oliver Davey, Damon Sunderland

The global emphasis on renewable energy has led to an increased focus on offshore wind (OSW) as a crucial component in achieving sustainability goals. As nations strive to reduce carbon emissions and transition to cleaner energy sources, the potential of offshore wind farms has become more evident. In this context, the Australian offshore wind market presents a significant opportunity.

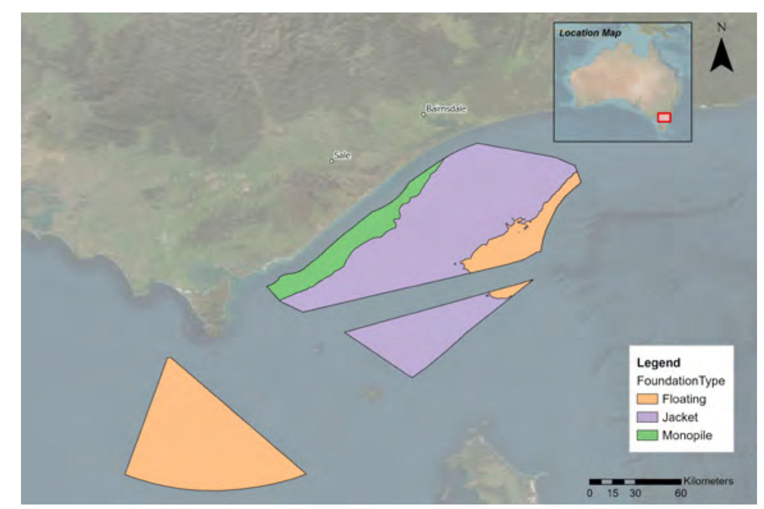
Recognising the need for a comprehensive understanding of the supply chain that is required to support the burgeoning offshore wind industry, the UK's Foreign, Commonwealth and Development Office (FCDO) commissioned Arup to conduct an assessment and gap analysis. The Australian Offshore Wind Market Study aims to evaluate the current capabilities, identify gaps within Australia's supply chain and highlight opportunities for collaboration between Australian business and UK international organisations, ultimately providing recommendations to enhance market readiness and ensure successful deployment.

The UK has substantial offshore wind experience and established supply chains, and there are opportunities for businesses to either set up new Australian divisions or fabrication yards from existing businesses in the UK based on the North Sea experience. With offshore wind in Australia in its formative stages, there are substantial gaps in its supply chain. These range from capabilities in manufacturing of wind turbine generator components, to critical parts such as secondary steel, cables and experts with relevant experience.

Key findings from the study showed that the market could vastly benefit from working with UK suppliers. The UK

1: The Australian government is aiming for a 43 percentage point increase in renewable electricity generation by 2030

2: The Gippsland region in Victoria, where 12 offshore licences have been awarded, has rich wind resources



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3: Vital parts such as inter-array cables can be exported tariff-free between the UK and Australia

4: Establishing a clear and supportive regulatory framework will provide certainty for investors and encourage long-term commitments to the offshore wind sector

boasts the second-largest offshore wind market globally, with 14.7GW of installed capacity as of 2024 and 23 years of experience. It was the first major economy to commit to net zero by 2050 as law, and it cut its emissions by 50% between 1990 and 2022, while at the same time growing its economy by 79%. The British Energy Security Strategy, published in April 2022, set the ambition to achieve up to 50GW of offshore wind by 2030 and the need to install an additional 35.3GW in the remaining six years.

Arup was an ideal choice of partner for the FCDO, offering unparalleled local knowledge based on its work on various Gippsland offshore wind projects in Victoria, which is likely to be Australia's largest area for offshore wind potential. Since the rapid increase in offshore wind projects in Australia over the past two years, Arup has had 50 offshore wind commissions. Work ranges from feasibility studies and licence support, planning work for state governments and assessing feasibility licence applications for the Federal government, to the oversight of offshore geophysical surveys. The firm also handles work for port authorities, including a significant body of work in the Port of Hastings comprising a business case and an environmental impact assessment for the port to be set up for offshore wind.

The current state of OSW in Australia

The Australian offshore wind market is in its nascent stage, with several projects in the early phase of development. The nation boasts vast coastal areas with substantial wind resources. Key projects, such as the Star of the South off the coast of Victoria, highlight the potential for large-scale offshore wind farms. There were 37 applications for Gippsland alone, with 12 licences awarded. Despite these promising developments, Australia's offshore wind industry lags behind more mature markets in Europe and Asia.

However, the regulatory landscape for offshore wind is evolving. Recent government initiatives and policy frameworks aim to facilitate the growth of this sector. However, several legal hurdles remain, including complex approval processes and the need for clear guidelines on environmental impact assessments and the auctioning process.

The report recognises trials the market will face, including the distance between the two countries, local content requirements and public perception of offshore wind projects. But the Australia-UK free-trade agreement enables tariff-free exports of crucial parts, such as dynamic cable products, wind turbine blades and inter-array cables.

Australia is seen as a safe place to develop projects, thanks to its credit rating, political stability and renewable energy potential. The country has set ambitious targets to decarbonise and reach net zero emissions by 2050. The government has pledged to increase renewable electricity generation from 39% in 2024 to 82% by 2030. To hit this target, Australia will have to double

5.

its installed renewable energy capacity from 54GW to 96GW by 2035.

According to the International Energy Association (IEA), Australia has more than 4,000GW of offshore wind potential, more than half of which falls within deep water. The Australian offshore wind market is growing, with six priority areas for OSW across Victoria, New South Wales, Western Australia and Tasmania. Gippsland (Victoria) and the Hunter (New South Wales) areas have been the first declared zones. In Gippsland, 12 licences have been awarded, with a total potential of 25GW from these projects. The Hunter region could supply 2GW through a 'preliminary' feasibility licence recently awarded.

Supply chain assessment and methodology

At the time of reporting, Arup's analysis used a series of assumptions to convert the projected offshore wind development in gigawatts into a timeframe and a high-level breakdown of the required key components and services. The projected market size was estimated to reach 20-40GW by 2040. This estimate assumed the development of 9-12GW in Victoria (based on the state government's 9GW target by 2040), 8-12GW in New South Wales (now potentially downgraded), 3-4.5GW in Western Australia (for which the Bunbury area has recently been declared) and 3-4.5GW in Tasmania (for which the Bass Strait region is awaiting declaration), with the potential for an

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additional 10GW in later stages across various states in the high-level scenario. The report then assessed the UK and Australia's supply chain capabilities as of the first quarter of 2023, to identify strengths, weaknesses and opportunities for fostering industry growth in Australia.

The analysis was framed across 27 supply chain categories, with the capability ranked on a scale of one to six, from the highest-ranked organisations, able to provide full capabilities, to the lowest-ranked organisations, which may need significant investment to provide the necessary supporting capabilities.

Arup's assessment employed quantitative data analysis with qualitative insights from industry stakeholders. Key metrics included manufacturing capacity, infrastructure readiness and workforce availability. Data sources ranged from industry reports to direct consultations with key players in the offshore wind sector.

The offshore wind supply chain encompasses several core components, including turbine manufacturing, engineering design, logistics, installation, operation and maintenance. Each segment plays a vital role in ensuring the smooth deployment and operation of offshore wind farms. Australia's existing supply chain capabilities are limited but show growth potential. The country possesses some manufacturing facilities capable of producing components for offshore wind turbines, yet these would not meet the demands of large-scale projects. Additionally, the workforce skilled in offshore wind technology is relatively small.

Gap analysis

Arup's analysis identified several gaps in the Australian supply chain. One is the lack of domestic manufacturing capacity for critical components such as blades and nacelles housing the turbine components, as well as electrical infrastructure such as cables and substations. This dependency on imports could lead to supply chain bottlenecks and increased costs. Infrastructure gaps, particularly in port facilities and specialised vessels for installation and maintenance, were also highlighted.

The report acknowledges that UK suppliers face challenges with competition closer to Australia, given the greater than 18,500km distance and potentially higher labour costs in the UK compared with Asian supply chains. To stay competitive, the UK will need to leverage low-carbon, high-quality and automated supply chains to add value to the Australian market. Because of the distance, it might be more effective for firms to establish a base in Australia.

These gaps could significantly impede the development of the Australian offshore wind market. Delays in obtaining necessary components, logistical challenges and a shortage

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5: Australia has some manufacturing facilities for offshore wind components, but nothing suitable for large-scale projects

6: Arup's analysis found Australia lacked manufacturing capacity for offshore wind electrical infrastructure, such as cables

7: Targeted training programmes are needed to attract new talent to the offshore wind sector

8.

8: The UK has substantial installed offshore wind capacity. With targeted actions, Australia can also see offshore wind contribute significantly to its renewable energy goals

of labour could result in project delays and increased costs. Additionally, reliance on international suppliers introduces risks related to geopolitical factors and supply chain disruptions.

One of the biggest challenges in this project was anticipating the future, as the sector is evolving so rapidly. Another ongoing challenge was identifying businesses and opportunities, as companies, particularly from China and Japan, are frequently exploring entry into Australia. Historically, Australia's offshore wind sector has been closely tied to the oil and gas industry, but it lags 10-15 years behind the UK, where offshore wind has gained momentum as oil and gas decline.

Recommendations and strategies

To bridge the gaps, several short-term solutions are recommended. Establishing partnerships with international suppliers can help mitigate immediate component shortages. Enhancing port facilities and investing in specialised vessels is also crucial. Implementing targeted training programmes to upskill the existing workforce and attracting new talent to the offshore wind sector is essential for building a competent labour force.

Investing in domestic manufacturing capabilities for key components will reduce reliance on imports and create local jobs. Encouraging innovation and technological advancements through research and development programmes can drive efficiency and cost reductions. Developing comprehensive infrastructure plans, including upgraded port facilities and transportation networks, will support the entire offshore wind supply chain.

Collaborative efforts between industry, government and educational institutions can foster innovation and workforce development. Establishing a clear and supportive regulatory framework will provide certainty for investors and encourage long-term commitments to the sector.

Future outlook

The assessment conducted by Arup for the UK government highlights the significant potential of the Australian offshore wind market, while identifying key gaps in the supply chain. Addressing these gaps and increasing the clarity and strength of the OSW pipeline (in terms of gigawatt targets in all states/ nationally) are essential for the successful deployment and operation of offshore wind farms in Australia. With strategic investments and targeted actions, Australia can develop a robust offshore wind supply chain. The future outlook for the nation's offshore wind market is mixed across each state, but with the potential to contribute substantially to Australia's renewable energy goals.

A strong supply chain is crucial for the growth and sustainability of the offshore wind industry. Arup's assessment and gap analysis provides a roadmap for overcoming current challenges and building a resilient supply chain. By implementing the recommended strategies, Australia can unlock the full potential of its offshore wind resources and achieve significant progress in its transition to renewable energy.

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Project credits

Client UK's Foreign, Commonwealth and Development Office

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1.

Transforming rail travel in the north of England

Rail capacity is being improved for millions of passengers across the Pennines and making the network more resilient

Authors Andrew Belcham, Andrew Carr, Jane Collins, Chris Jackson, Jonathan Ridley, Graham Thomas

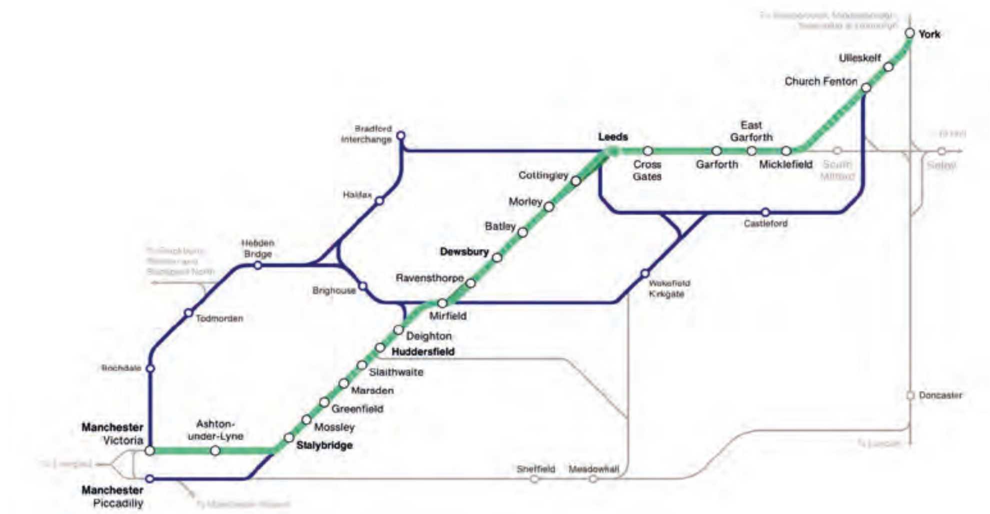
1: The TRU will improve journey times, with four express trains an hour travelling between Manchester and York

The Transpennine Route Upgrade (TRU) is a multi-billion-pound railway improvement programme that will bring better journeys to passengers travelling in the north of England across the Pennine Hills and surrounding areas between Manchester, Huddersfield, Leeds and York. Launched in early 2017, the TRU aims to create faster and more reliable journeys, increase train frequency and enhance existing stations, while providing sustainable travel to users by fully electrifying the route. Estimates show savings of up to 87,000tCO_2e of operational carbon emissions annually, helping to support the UK government's net zero objectives.

The upgrade programme will also facilitate the transportation of more freight by rail, with up to 15 extra trains each day, which is expected to remove more than 1,000 trucks from the route daily. More frequent passenger trains will encourage additional commuters to use a more sustainable form of travel, and enhance local employment and career choices for people and suppliers who live and work alongside this route.

The upgrade of this busy operational railway involves complex interfaces, including electrification, signalling, stations, civil structures, electrical and track improvements over the 70 miles

(122km) of existing route between Manchester and York, along with elements of significant diversionary route upgrades, and enhancements of 65 bridges, six tunnels and 12 stations. The TRU West projects, taking place on 68km of the section of railway between Manchester and Leeds, are an essential part of the TRU programme that will increase the line's capacity and alleviate congestion during peak periods, while enhancing safety and comfort for passengers.



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The TRU West Alliance, a collaboration between Network Rail, BAM, Arup and Amey with Siemens, is working on making this vision a reality. The Alliance's work includes electrifying the line (the first section from Manchester Victoria Station to Stalybridge is complete, with the first electrified passenger trains running in August 2024) and doubling the number of lines from two to four at Huddersfield Station through to Ravensthorpe.

The topography and constrained corridor is challenging on the West route, which rises from Manchester through the Pennines and down to Huddersfield, travelling through historic mining areas. The upgrade is being delivered progressively as part of a multi-year programme of interventions that are being commissioned incrementally to enable phased release of benefits to customers who use the railway.

From the outset, the Alliance established best practices and used a collaborative design approach with early contractor involvement to overcome the complex engineering issues.

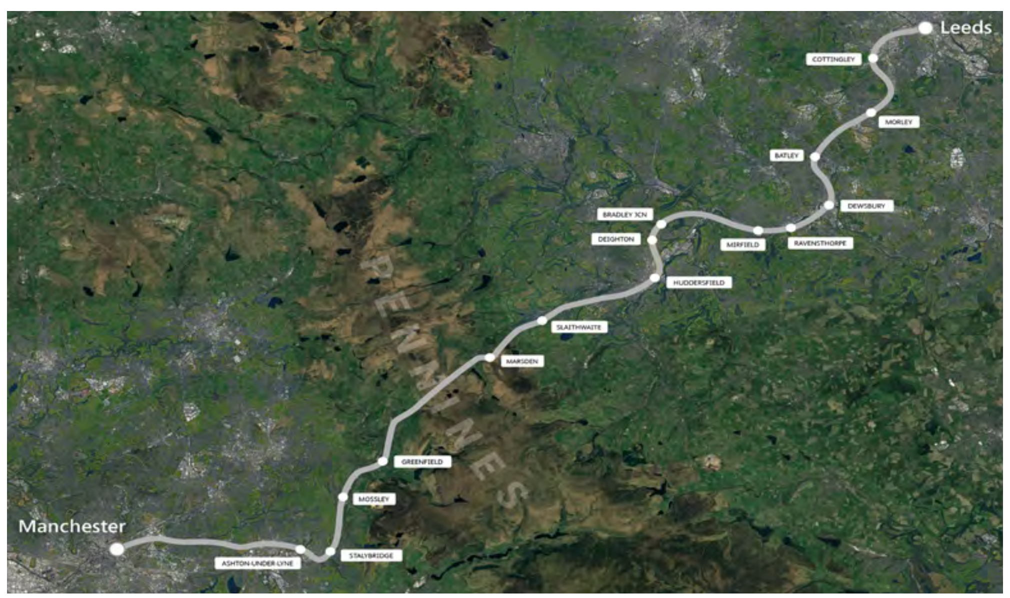
The TRU West Alliance has four major components: Manchester to Stalybridge, Stalybridge to Huddersfield, Huddersfield to Dewsbury and Dewsbury to Leeds. It integrates at programme level with the separate TRU East Alliance, which is working on the section from Leeds to York, and the team developing Leeds Station alongside important diversionary route upgrades.

Geotechnical approach

Working collaboratively with Network Rail at the commencement of the programme, the TRU West geotechnical design team comprised an integrated team of more than 60 geotechnical engineers and engineering geologists from design consultants Arup and Amey, sub-consultants TGP and COWI, contractors BAM, and specialist geotechnical sub-contractors BAM Ritchies and Structural Soils Ltd.

The ground investigation (GI) design for the route had significant constraints, including the requirement to minimise any rail line closures to maintain an operational railway at full capacity. Close collaboration between the TRU West Alliance contractors and designers enabled them to complete more than 1,500 boreholes to tight schedules.

The team produced a strategy to reuse 230,000m^3 of excavated material within the project, reducing both waste and the demand for primary aggregates, while taking into consideration the challenges of a complex construction programme with short duration railway closures that dictated the sequencing of the works.



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2: The TRU will enhance journeys for passengers travelling between Manchester, Huddersfield, Leeds and York

3: The 68km section of the route west of Leeds crosses the Pennine Hills to Manchester


4.


5.

Mitigating mining risk

The legacy from a long history of mining, quarrying and subsequent landfilling can present significant geotechnical challenges to infrastructure schemes such as TRU. To address these challenges, as part of the Alliance, Arup led the development of a mining mitigation strategy across the entire footprint of the railway west of Leeds. A detailed geological model was used for the route, built from a desk study and GI data from borehole information. It identified likely mine locations in a number of critical areas along the route.

The coal mining risk was managed through dialogue with Network Rail, agreeing where and how appropriate mitigation should be put in place while working in a live rail environment, around buried infrastructure, through landfill areas and adjacent to water courses.

The route electrification process required the introduction of piled foundations along the rail corridor. Arup instigated pioneering research to investigate the extent to which ground-borne piling vibrations dissipate with depth. At field trials in Manchester, the firm engaged in-house global acoustics experts to manufacture and install instruments up to 10m below ground to monitor vibrations resulting from piling. The data proved that displacements that occur due to piling were sufficiently small to be deemed acceptable to any mine workings in close proximity. This industry-leading work allowed piling to proceed and avoided the use of more costly and slower augured piles.

Safety by design

Within the Alliance, Arup worked with Amey and BAM in an early contractor involvement phase to incorporate buildability and efficiencies into the preconstruction phase. The Alliance leadership formed monthly briefings and reviews across the project and


6.

4: Across the full 122km route, 65 bridges are being enhanced

5: Electrification of the existing route in Manchester city centre

6: The topography and constrained corridor was a challenge on the West route, which is also punctuated by historic mining areas

7.

7: Changes to the track alignment on the route out of Manchester have boosted line speed by 42kph

8: One of the challenges of the complex construction programme was to minimise the quantity and duration of railway closures

invested in digital technology to widen understanding of safety hazards.

Safetibase software was used to identify clear ownership and enable transfer of individual hazards. This is particularly useful within the Alliance to reduce the risk of hazards being overlooked, while also increasing the likelihood of mitigation being built into the design. TRU has also led the way with safety conversations and the culture of raising close calls to share positive learnings and insights across the teams. Arup deployed staff to manage the transfer of known hazards from the design phase to the construction phase and formalised this ‘handshake’ process. This provided the contractor team with a much deeper understanding of the issues considered and mitigated by the design team.

Manchester to Stalybridge

The constrained geometry of the track alignment at Miles Platting on the route out of Manchester previously limited the attainable line speed to 30mph (48kph). As part of the TRU, Arup, with subconsultant TGP, developed a design solution to remove this constraint. The firm performed extensive optioneering exercises to determine how the line speed at Miles Platting could be increased by flattening the radius of the existing curve. Numerous options with different radii were developed, each one in outline and appraised to determine the optimal balance between capital cost, consents, land-take and environmental impact.

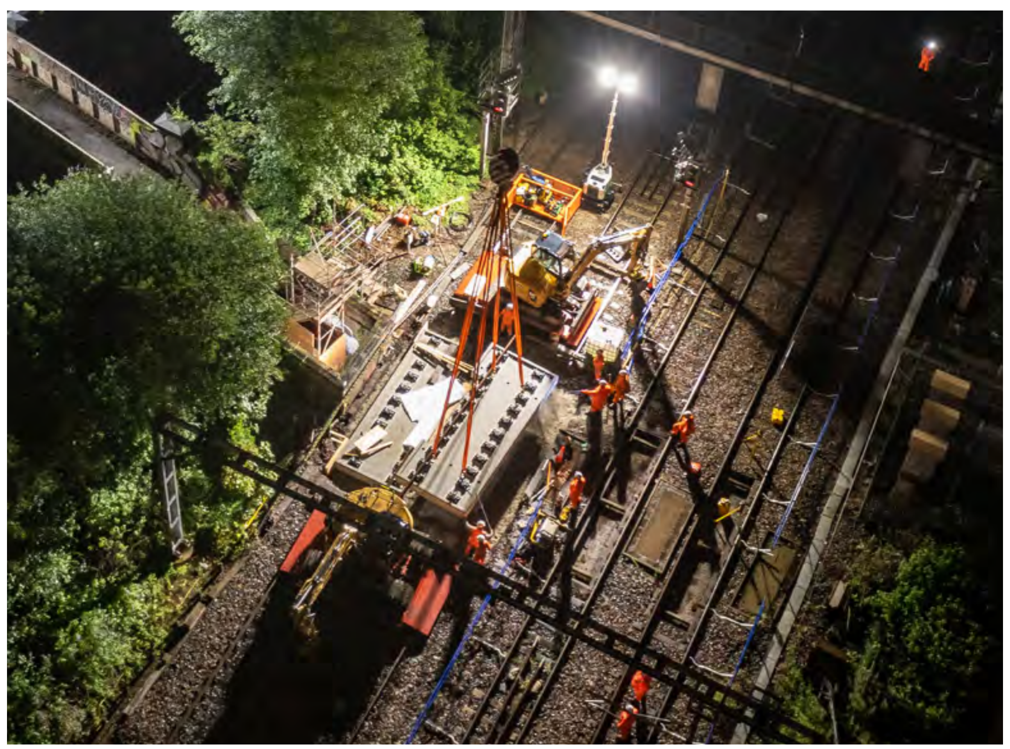
A key objective was an option that would meet the required track design criteria but could rapidly realise early journey time passenger benefits. The selected option delivered a 55mph (90kph) line speed, deemed the minimum viable intervention as it avoided the need for third-party consents, removed any requirement to reconstruct a major underbridge and did not impact upon an area leased to an adjacent freight operator. This option avoided additional capital cost over £10m and a prolonged delivery timescale, and is now complete, with commuters benefiting from the upgraded route section.

One of the first major sections of the route was delivered in the summer of 2024, with the running of the first electric trains on the eight-mile-long (13km) section of railway between Manchester and Stalybridge.

Many of these key upgrades were completed during a 26-day closure of the railway in March and April of 2023. The first electric train completed its test run in March 2024, and since August 2024 passengers have been able to travel by electric train on this route.

Huddersfield to Dewsbury

The section of the route between Huddersfield and Dewsbury is particularly challenging as it is the most congested and restricted part of the line. The planned upgrade includes increasing from two tracks to four, electrifying and resignalling the route, upgrading/rebuilding



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stations and introducing a major grade separated junction. This 14km section includes 16 new earthworks elements, such as embankments, rock cuttings and soil nailed slopes, and 13 new retaining walls.

For this section, the Arup-led design team applied a systematic approach for what was, at the time, the largest ever Transport and Works Act Order (TWAO) application by Network Rail, with the scheme value at around £1.5bn. The design and consents team developed and adopted new digital tools and methods to manage the volume of documents required for an application of this magnitude. Understanding what was required, they developed a clear audit trail and implemented a Design Approval Panel (DAP) approach, which ensured the team recorded the when, why and how of each decision made. The DAP approach enabled planning approval and listed building consent for major construction and engineering works at the Grade l-listed Huddersfield Station, a busy regional interchange station.

The team also attended the public inquiry, provided expert witnesses and responded to comments from stakeholders. As an example, the team were able to use the information documented during the robust option selection process to counter arguments related to land purchase for a road diversion in Ravensthorpe. Arup produced high quality visualisations that enabled the public and other stakeholders to engage with the project and gain a deep understanding of how they would be impacted by the proposed works.

Key train operating companies, TransPennine Express and Northern, as well as freight operating companies, were engaged in decision-making and long-term access planning from the outset. Their engagement in early blockade planning enabled the design team to ensure that disruption to customers was minimised and communicated early. The TRU West Alliance also consulted operators’ representatives during scheme development and facilitated their active participation in option selection. Arup successfully coordinated a multidisciplinary team drawn from several organisations to successfully deliver the TWAO over a 15-month programme, which was granted six months ahead of schedule.

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9: The Grade I-listed Huddersfield Station will benefit from an additional track as well as a refurbished roof

10: The upgrade is being delivered progressively as part of a multi-year programme of interventions, enabling phased release of benefits to customers

10.

Huddersfield Station and Viaduct

Within the Alliance, Arup led on the feasibility, concept and detailed design development of improvements at several stations, including major remodelling at Deighton, Mirfield and Ravensthorpe Stations, to facilitate the new four-track layout and modern standards with access for all. At all stations, this work involved a multidisciplinary approach with skills drawn from civil/structural engineering, highways, building engineering, architecture, mechanical and electrical, heritage, telecoms and station systems, acoustics and pedestrian modelling. The firm led an extensive optioneering exercise to ensure that the works could be appropriately staged and constructed with minimal impact on surrounding properties and the operational railway.

At Huddersfield Station, Arup, with subconsultant AHR Architects, was responsible for designing a revised

11.

11: Huddersfield is a busy regional interchange station so disruption to the operational railway had to be minimised

12: The first electric trains between Manchester and Stalybridge began running in the summer of 2024

layout for the station to provide the capacity, reliability and operational flexibility critical to the success of the TRU West scheme. This includes major works to reconfigure track and platforms, increasing the number of tracks from three to four, refurbishment of the principal station roof, and the installation of lifts and a new footbridge. Ahead of the major station upgrade works, mine mitigation measures were completed in June 2024, which saw the backfilling of voids with cementitious grout within old coal seams approximately 15-20m below the station.

The line east from Huddersfield Station carries the railway over the Grade II-listed Huddersfield Viaduct, which is a Victorian era, predominantly masonry arch structure. Various elements of the structure, located in the centre of the town, need to be strengthened and modified to fulfil the requirements of the TRU. The 47-span viaduct will accommodate additional tracks, as well as portions of the amended platforms and overhead electrification infrastructure. Under the viaduct are busy main roads through some of the spans that need to be maintained, and many of the spans are occupied by businesses requiring legal and commercial negotiations for access.

A variety of interventions are being made to the viaduct, enabling most of the structure to be reused and upgraded to serve the modernised railway without the requirement for substantial demolition. These include replacement of several of the large steel spans over existing highways, pinning and strengthening of masonry arches and spandrel walls. These works are extremely complex, staged around an operational railway working on top of a high-level viaduct surrounded by dense urban infrastructure.

During the feasibility design stage, the design team queried the requirement for the 3m separation

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between the fast lines and slow lines for approximately three miles of the route between Huddersfield and Bradley Junction. By establishing an effective working relationship with Network Rail, Arup was able to show that the separation required by the track design standards was deemed to be overly conservative. Reducing this dimension allowed for the volume of earthworks modifications and structure renewals required to be reduced. Working with the BAM estimating team, Arup assessed that the revision achieves a cost saving in excess of £10m.

13: A major grade-separation junction is being constructed at Ravensthorpe for the two fast and two slow lines

14: The 19th century Huddersfield Viaduct is being strengthened and modified

14.

Four-tracking and grade separation

A key component of delivering improved capacity, reliability and journey time on the TRU was the introduction of four-tracking from Huddersfield Station to a new junction to the east of Ravensthorpe, from where the existing two-track railway is retained on to Leeds.

Operational modelling showed it was necessary to grade-separate the two fast and two slow lines at Ravensthorpe near Dewsbury, requiring the construction of a new alignment adjacent to the existing railway. Working with the Alliance members, Arup led a series of constructability workshops with experts from rail systems and civil contractors to review options, address health and safety risks, and select the most cost-effective and stageable solution with least impact on the ability to run trains during construction. The grade separation requires major new structures and earthworks, including widening the existing Ravensthorpe cutting, where the new fast lines diverge to climb towards the grade separation structure.

The new fast line alignment with 110mph (180kph) line speed will be achieved by flattening the radius of the alignment of the existing 70mph (113kph) curve. By placing these lines to the south of the existing alignment and bypassing the existing junction, the infrastructure required can be constructed with limited impact on the operational railway. This delinks approximately seven months of earthworks excavation from railway operation and simplifies a kilometre of track delivery into a single package.

The topography of the area and the need to provide an improved horizontal alignment for the fast lines necessitated a new earthwork cutting at Heaton Lodge. To mitigate the impact of work in a deep sandstone cutting, the designers worked with the construction team to revise the initial scheme proposal to reduce the depth of cutting, while ensuring the revised vertical alignment would not compromise train performance. By careful interpretation of the geotechnical investigation, slopes were steepened through rock excavations to reduce the volumes of materials excavated, which resulted in significant cost savings in earthworks volumes and land purchase. Excavated materials are being reused as engineered fill for embankments and structures to minimise off-site disposal.

Baker Viaduct

The new alignment at Ravensthorpe requires the construction of the new Baker Viaduct – a 350m-long four-track section. The viaduct will cross the historic Hebble & Calder Navigation Canal, the River Calder and a disused railway embankment repurposed as a walking and cycle route. It also passes over a series of former mine workings. Currently under construction, it is the largest new structure on the TRU.

The design requirements for the viaduct were for an efficient and durable structure that optimises materials to save both costs and embodied carbon. The viaduct was designed using extensive Arup

15: Train operators TransPennine Express and Northern, as well as freight companies, were involved in long-term access planning

16: More frequent passenger trains will encourage additional commuters to use a more sustainable form of travel

in-house automation tools, in particular track structure interaction analysis. This allowed the interaction phenomenon to be analysed earlier in the design than is usually possible, resulting in an optimised approach that eliminated rail expansion joints. The strategy has maximised design for offsite manufacture to reduce waste and wet trade requirements over the watercourses in the area.

Close collaboration with the contractor, fabricator and precast manufacturer has allowed integrated solutions in the deck and diaphragms. The viaduct is a nine-span steel composite structure on piled foundations, with an offsite manufactured precast deck. The structure is generally formed with four primary steel girders, increasing to six for the trifurcation region of the tracks on the approach to the adjacent grade separated junction. The west abutment is formed on driven piles to minimise contaminated arisings from the former landfill, which is 15m deep and filled with inert waste and asbestos.

15.

The selected construction strategy has reduced the delivery programme by 12 months, avoided significant road and utility diversions, minimised the impact of the work on the local community, realised more than £40m of construction cost savings and reduced maintenance and operation costs.

The team working on the TRU, including more than 1,000 members of Arup, has brought experience, innovation and planning to bear on the challenge of upgrading one of Britain's oldest railways. As part of this long-running project, the Alliance has deployed graduates and apprentices from local offices into the TRU, providing significant development opportunities. Arup has engaged up to five apprentices every year on the TRU since 2017. Because of the project duration, this has enabled a cohort of apprentices to complete their training and move into higher education.

The TRU will improve journey times, with four express trains an hour travelling between Manchester and York. Alongside passenger benefits, the significant reduction in road freight and electrification of the route will surely stand out as key legacies of this complex modernisation project.

16.

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Project credits

TRU West Alliance partners Network Rail, BAM, Amey Rail, Amey Consulting, and Siemens.
Arup sub-consultants AHR, Balfour Beatty, COWI, TGP, Wentworth House Partnership.
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1.

Hillside solar: establishing best practice

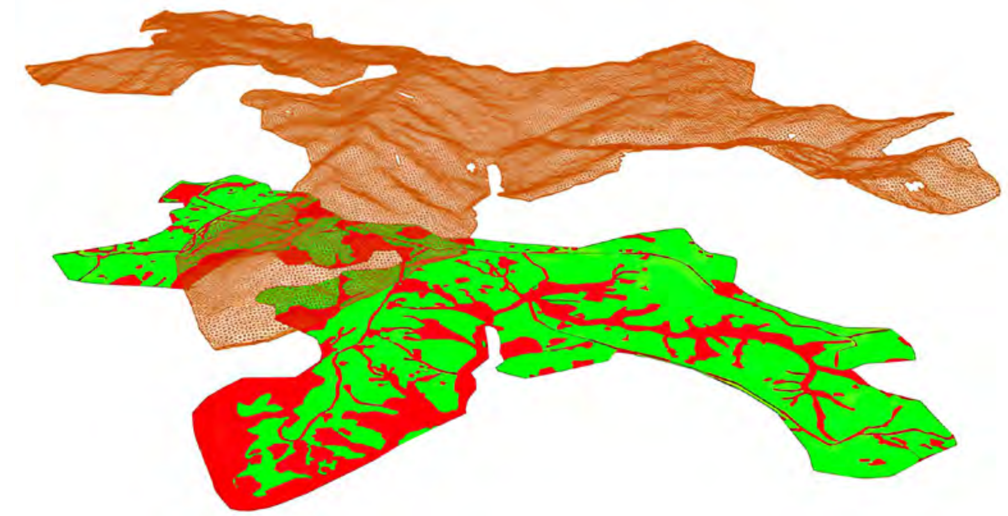
Designing the first hillside solar power plant for the Philippines

Authors Lynn Dimayuga, Gilang Judhinaputra, Mark Wallace

1: The Philippines is aiming for 50% of its energy mix to come from renewable sources by 2040

Solar photovoltaic (PV) plants are typically built on flat terrain, but hillside locations bring social and ecological benefits. They also avoid competition over valuable agricultural land. The Cayanga solar power plant, a first of its kind for the Philippines, was installed on rolling mountainous terrain and sets out a blueprint for how to approach such projects.

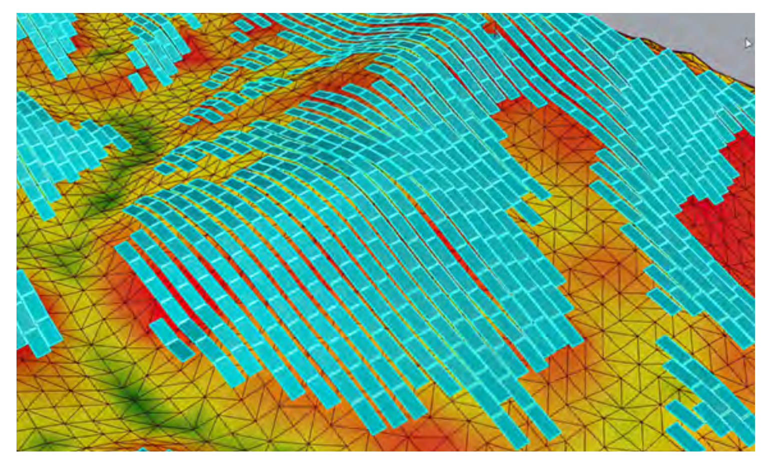
The Philippines is seeking to diversify its energy mix in the face of regular power outages linked to system functionality issues at the country's fossil fuel power stations. Reserves at the country's Malampaya gas field, by far its largest source of gas, are also expected to be depleted by 2027. The country has committed to renewable energy contributing 50% of its energy mix from 2040. Solar power is a natural fit for the Philippines, which is located just above the equator. The government is currently using clean energy auctions to involve the private sector in the energy market. The auctions are breaking down the barriers to entry, for example, by abolishing the requirement that energy assets need to be owned by Filipino companies, and therefore, opening the door to international firms.



2.

2: Terrain analysis and constraints mapping was carried out for the project

3: An automated design tool was developed to provide fast optimum placement of the solar panels over the undulating terrain



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Arup, which has been present in the Philippines since 1990, was engaged by major energy provider AboitizPower in 2021 to develop a utility-scale solar PV plant on hillside terrain. Aboitiz's undulating Cayanga site in the Province of Pangasinan, approximately 220km north of Manila, is spread over 196 hectares. The area is now home to a 90MW solar farm capable of providing power to 100,000 households.

Arup conceptualised the plant with minimal site development works to avoid major disturbance to the existing terrain. The team developed an automated panel placement design tool for the solar panel tables from the idea of smooth form facade engineering and geometry control knowledge that Arup had within the firm. The digital solution developed could rapidly test alternatives and adjust the table positioning to maximise the layouts on the usable areas of the terrain. The firm developed the concept design and reference design, and handled procurement of the contractor for the design and build of the solar facility and interconnection line. During construction, the firm provided engineering support to review the contractor's design and assist the client in the quality compliance checks.

The hillside opportunity

The design solutions used to place the PV panels on the undulating terrain made the project cutting-edge. A key challenge was reducing the risk of landslides into the valley below. Locations in remote hilly areas suffer in the event of landslides and erosion of mountainous hillsides, something that solar PV plants can be designed to mitigate, as was the case in Cayanga. Land and forest restoration was used, along with an effective drainage system to protect the site and prevent erosion. As well as providing clean renewable energy, the project aimed to increase usability of the surrounding land and improve

4.

4: The Cayanga site stretches over 196 hectares, largely made up of denuded forest

5: GIS-based analysis and constraints mapping of the terrain was used to aid the suitability of the site for panel placement

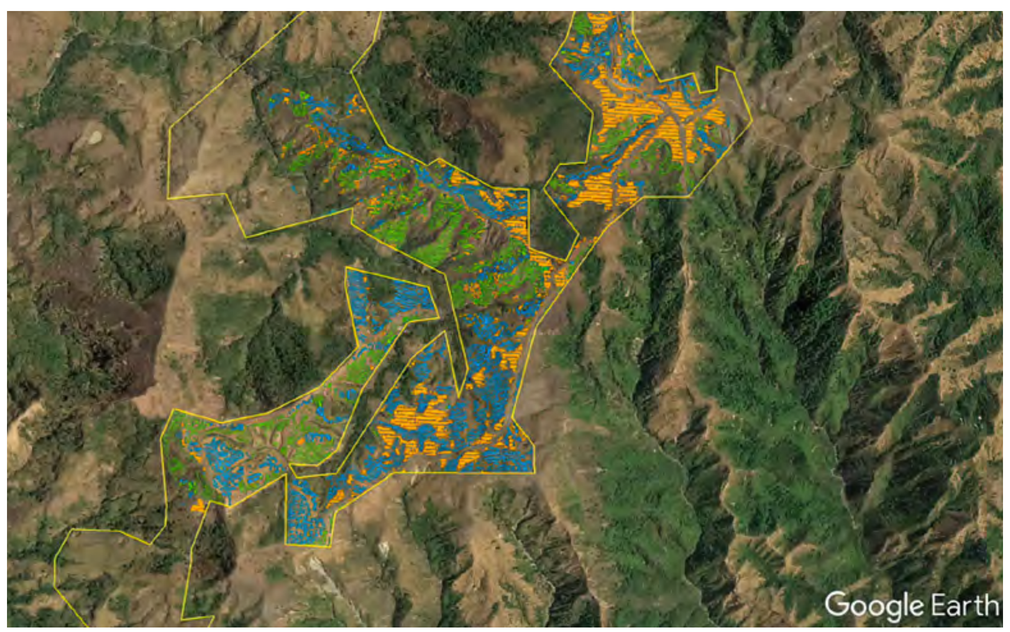
employment opportunities for local communities as hillside solar plants present significant local employment prospects.

A specific issue relating to the Province of Pangasinan was the legacy of *kaingin*, the practice of slash and burn farming, where forests are cut down and burned to create sites for agriculture. Tens of thousands of hectares of forest are burned each year to make way for agricultural land, with the fires often getting out of control and burning for days and weeks. When the fires spread to hillsides, the destruction of vegetation effectively leaves rural areas with vast swathes of undulating barren soil, increasing the likelihood of landslides. Due to *kaingin*, some local communities can be hostile to agriculture in their area. The construction of large-scale PV plants gives a more positive and secure purpose for these hilly sites.

Large PV projects have been built on hillside locations previously, with successful projects in China, but this was the first project of its kind in the Philippines. For the client, designers and the contractor, building a large solar PV plant on undulating terrain was new, as solar power plants tend to be situated on large areas of flat land. When planning Cayanga, the Arup team drew on insight from across the firm, working with engineers who had experience installing efficient solar panels on buildings with pitched roofs at varying degrees, and those with design expertise in creating access roads on hilly terrain.

The hillside challenge

As Arup navigated the challenges of developing solar plant on a hillside, it needed to find safe, stable ground and identify the optimal positions for panels to maximise the solar yield. Among the issues to be addressed were plant and animal life, waterways and access, both for the contractors and for maintenance, once the plant is active and feeding into the grid. As a multidisciplinary firm, Arup was able to draw on expertise in all these areas and more in designing the installation at Cayanga.



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The design team developed and prepared maps, data and observations of historical events to identify natural hazards, to help determine the most appropriate location for the PV panels. This was done by developing buffers, boundaries and a constraints map that defined the usable areas by avoiding unstable terrain, vegetated areas, steep terrain and unfavourable facing slopes. As Arup was able to lean on teams across multiple specialisms and geographies, terrain assessment was quick and efficient, while automation helped streamline the design process. The team also visited the site, enabling a better understanding of the terrain. Most of the area is denuded forest, meaning there is little vegetation and primarily soil. Where there is vegetation, it is brush or thick grass, with roots that are not thick enough to hold the soil steady against erosion.

Arup discussed with the client how to improve surrounding areas with the benefit of reducing landslide risks to the site and the surrounding communities by targeting reforestation and erosion control measures through a programme of tree and shrub planting.

6.

6: The design solutions used to place the PV panels on the undulating terrain made the project cutting-edge

7: Solar power plants tend to be situated on large areas of flat land (as shown)

7.

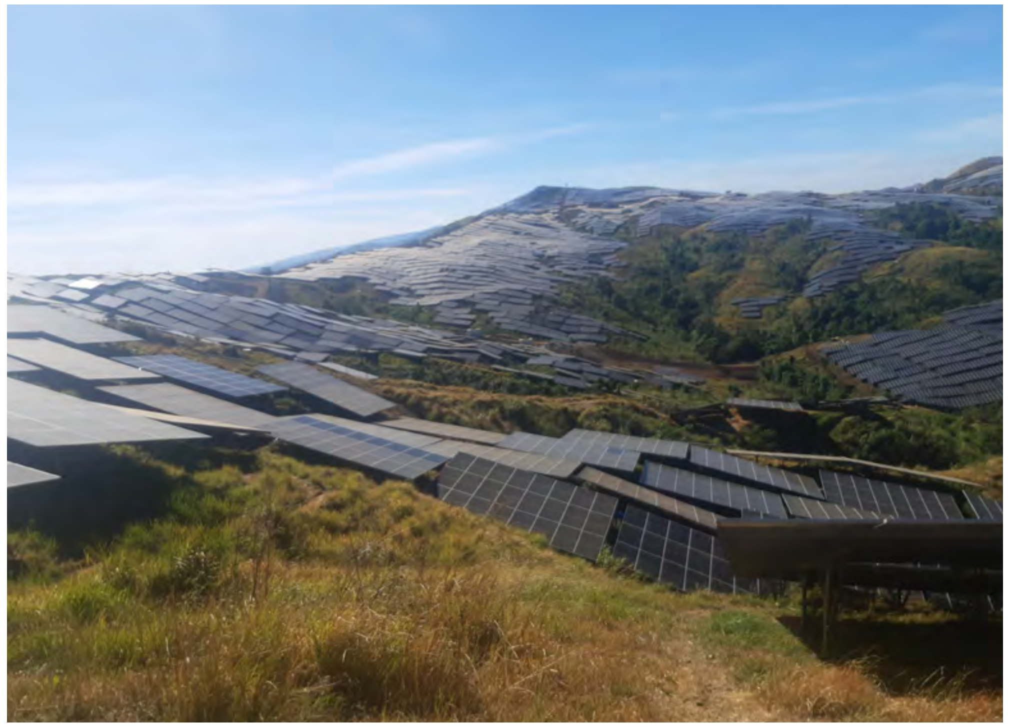
On the ground, the team identified that some areas had more vegetation and steeper terrain than anticipated and extended the constraints mapping to cover those locations. Tree cover was limited but was still a factor in some areas. Where a small number of trees were felled to make way for the plant, they were compensated with replanting elsewhere.

Innovating with automation

While on-the-ground research and human expertise were integral, it was automation that was critical to providing the optimum layout, given both the location and the tight timeline the team were working to. Using geographic information systems (GIS), Arup developed a hillside solar tool to generate the best layout of the plant, review the topography and create a constraint map.

It was this map that enabled PV and digital specialists to automate the design and generate the layout of the plant. The panels were orientated to maximise energy yields. Each time there was a new design iteration, an analysis could be run immediately and a decision made on whether the yield was high enough. If not, a solution was found by tweaking a parameter or an aspect of the design to obtain the desired yield.

Arup's technical capability was key to this process. The digital team in the firm's Hong Kong office helped the project teams across the different offices to automate their day-to-day



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tasks, using scripting and programming to aid the design process. The teams worked together to develop the tool to plan and execute a large-scale PV panel project in the most efficient way possible. The process enabled Arup to hit a challenging deadline and cut the timeframe by a third compared with the manual design process.

The tool enabled the team to plan for the unique conditions of this mountainside location, and its efficacy was tested early on when the area was struck by two typhoons during the construction process. The site withstanding these weather events not only demonstrated the value of the tool, it gave the client added confidence in the plant's ability to face more severe weather in the future. Arup also ran simulations for energy yield and calculations for high velocity wind to study how the wind would flow around the solar panels.

A network of knowledge

Elsewhere, Arup's ability to bring in expertise from across a range of disciplines was key to providing an integrated, optimised design. Engineers with experience constructing hillside road networks and buildings in erosion-prone landscapes were essential to the project. As well as planning the location where the panels should be situated to best capture the solar energy, the GIS tool was used to keep track of all individual panel data. The large data sets created can be used in future projects, both to maximise yield and streamline the construction process.

A critical challenge early on was establishing best practice for construction on the hillside terrain. The detailed geotechnical investigation performed on the site determined that beneath a thin layer of soil was rock, necessitating the use of screw piles in the construction process. The depth of the soil varied, meaning the contractor needed to use various lengths of piling. Once the contractor had installed the panels, they adjusted them to provide a more laminar airflow over the panels.

Higher tilt, less maintenance

The solar panels at Cayanga are tilted around 10 degrees to mirror the hillside below and, as such, the surfaces of the panels are cleaned by rainwater running down the panel surface. This reduces the need for cleaning away dust and dirt, a considerable logistical challenge and expense at traditional solar farms located on flat land. From an operational and maintenance standpoint that means there is less cleaning requirement for the site, aside from where grass and vegetation may grow over the panels and need cutting.

Building further solar capacity

Connecting Cayanga to the national grid was an engineering challenge, with the transmission line traversing ridges before connecting at the Kadampat-Bolo substation. The GIS methods developed for Cayanga enabled the best route to be readily planned.

8: Once the contractor had installed the panels, they adjusted them to provide a more laminar airflow over the panels (panels in foreground shown unadjusted)

9: The Arup team visited the site, enabling a better understanding of the terrain and identifying areas with more vegetation than anticipated

10: The 90MW solar farm can power up to 100,000 households

9.

10.

Following the completion of this project, AboitizPower appointed Arup as engineer for the Laoag 1 and Laoag 2 solar power projects on 180 hectares of land owned by the Department of Environmental and Natural Resources, using the concept design from Cayanga to provide engineering, procurement and construction services, as well as support on connection to the electric grid. These two sites face similar challenges to the Cayanga project. As well as the threat of typhoons and earthquakes, the hillsides are liable to landslides and fires. The automated hillside solar placement tool quickly mapped out suitable locations on the site for PV panels. The two plants will ultimately be linked with Cayanga via a 20km transmission line.

As well as providing a source of solar power, the projects will boost the economy in remote areas and make otherwise dangerous and unpredictable hillsides safer and more secure from landslides, fire and flooding. For the local communities in Cayanga, the barren and slowly eroding mountain range has been given a new purpose. The land erosion prevention measures that were initiated to protect the project from damage, such as tree planting, are also protecting the communities from the dangers of landslides.

Work is underway to develop the GIS hillside solar design programme so that engineers are able to use it for other projects without access to a developer, which will widely expand its use on complex and large-scale solar projects throughout the world. Outside the Philippines, the intelligent workflow and expertise at Cayanga can easily be deployed on projects with similar landscapes around the world, driving the global energy transition. The impact extends beyond clean energy generation too, enhancing the usability of the surrounding land by mitigating erosion and creating job opportunities for local communities.

Authors

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Mark Wallace was the Project Director. He is a Director in the Hong Kong office.

Project credits

Client AboitizPower

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Image credits

All images: Arup

Transforming LAX the Delta Sky Way way

The Delta Sky Way project at Los Angeles International Airport combines innovative design, environmental efficiency and a successful transformation of the passenger experience

Authors Ben Anstiss, Jenny Buckley, Jon Phillips, Simon Rees, Regine Weston

Arup, as lead designer and engineers of record, spearheaded the design for the new Delta Sky Way facility at Los Angeles International Airport (LAX), one of LA's largest recent infrastructure endeavours. The project involved the unification and modernisation of Terminals 2 and 3 into a seamless operation, offering integrated landside and airside services, and providing a consistent experience for passengers.

The project also required relocating Delta Air Lines from Terminals 5 and 6 on the south side of LAX to Terminals 2 and 3 on the north side. For years, Delta operated from Terminals 5 and 6 on the busy south side, located between American Airlines and United Airlines. As a result, the facility faced significant logistical challenges. Planes often remained on the tarmac for long periods after landing, caught in aircraft traffic gridlock. What should have been a seamless experience became a test of patience for passengers and crew alike,

1.

1: The project saw Delta Air Lines relocate from Terminals 5 and 6 to unified and modernised Terminals 2 and 3 underscoring the urgent need for a transformative change.

The relocation required 21 different airlines to shift their operations across the airport – the largest move at an operating airport to date. Initially, the move was expected to take six months, however, the expertise of Arup and the project team reduced the timeline to just three nights. The move significantly reduced taxiing times across the airport, having a significant impact on the airport's operational efficiency and on the customer experience at this important international hub.

Once the move was complete, the next task was to design and construct a new state-of-the-art facility for Delta, rebuilding and consolidating Terminals 2 and 3 while keeping Delta's operations running throughout. The project team embraced this logistical challenge, detailing the construction into three main phases to support Delta's operations and maintain the customer experience.

When the pandemic began, instead of pausing the early stages of construction, the team, comprising the airport, client, contractor and designers, took advantage of the sudden drop in global air travel to accelerate the schedule. It was a bold decision that ultimately enabled the project to finish 18 months ahead of the original end date.

2.

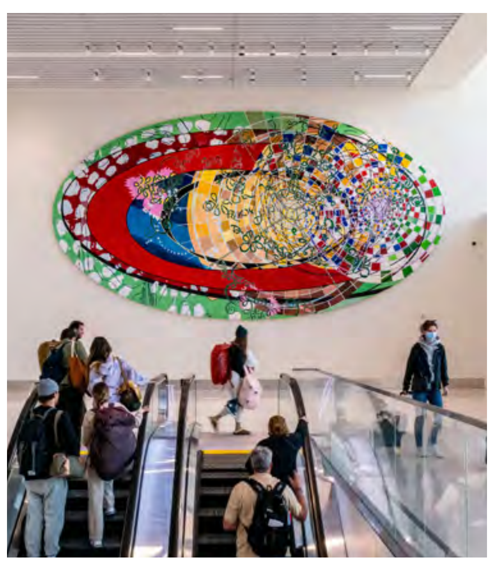
2: The multi-phase construction next to active airport operations required careful planning and coordination

Overhauling the West Coast's principal airport

LAX is the eighth busiest airport in the world, with 75 million passengers passing through it in 2023. Terminals 2 and 3, built in the 1960s and 1980s, played a critical role in the airport's growth and development over the decades. However, by the early 2000s, the ageing infrastructure of these terminals was no longer sufficient to meet the demands of modern air travel. The facilities were dated, lacked sufficient passenger amenities and could not handle the increasing numbers passing through LAX. Moreover, the terminals were not designed to meet the sustainability standards now essential in contemporary construction, or to modern seismic safety standards.

The Delta Sky Way facility was conceived as a response to these challenges, with the primary objective of transforming Terminals 2 and 3 into a state-of-the-art facility that could meet the needs of 21st-century travellers. The overarching goal was to significantly improve the passenger experience by creating a more efficient, comfortable and connected environment. This involved consolidating the two terminals into one, providing seamless transitions between services, and ensuring that passengers could move effortlessly through the terminal and the wider airport complex without having to exit and re-enter through security screening.

Increasing throughput capacity was a further crucial objective, both



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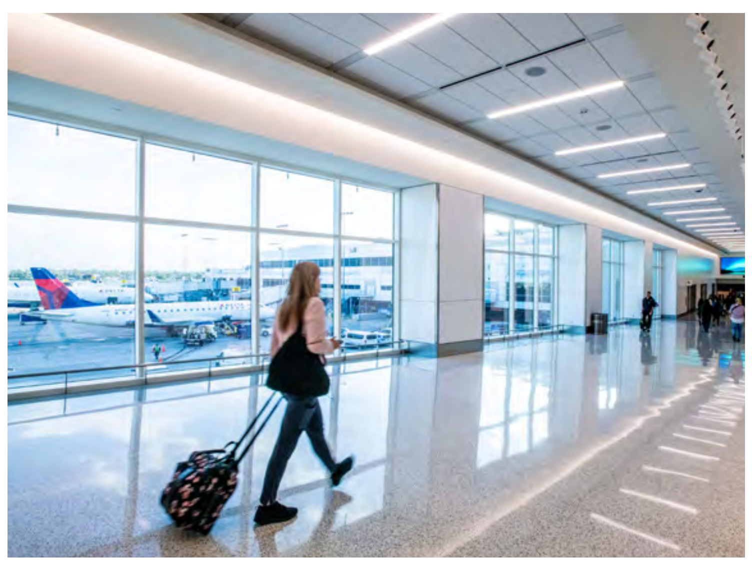
3, 4: Creating ample space in key circulation routes is essential for avoiding bottlenecks and reducing stress for passengers and employees



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5, 6: The combined Terminals 2 and 3 offer Delta passengers state-of-the-art facilities

7: Arup coordinated the move of 21 airlines in just three nights

to accommodate more passengers and reduce delays, leading to an improvement in operational efficiency and an enhancement to overall airport functionality.

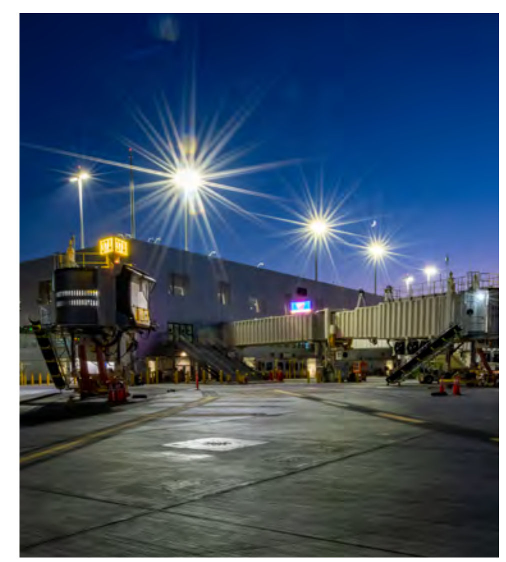
The impossible move

How did Arup facilitate moving 21 airlines in just three nights instead of the planned six months? The key issues were the lack of spare capacity at the airport (with the existing facilities at Terminals 2, 3, 5 and 6 fully occupied prior to the move) and the tight timeline (less than a year to plan, design, permit and build more than one million square feet of construction). In addition, the move was taking place in an operational environment within LAX, the USA's second-busiest airport. The relocation affected approximately 40% of the airport's capacity and required coordination and negotiation with more than 30 individual airport stakeholders.

The plan involved relocating all of Delta's operations and staff to a temporary trailer complex in the middle of the airport landside area, to create an 'empty chair' to allow the vacated areas to be prepared for other airlines to move into. The Arup team performed a comprehensive capacity review of all aspects of five terminals to identify capacity enhancements needed, as well as temporary requirements during the transition process. The team determined the ideal timing for the move as May 2017 during Mother's Day weekend in North America, as this is the quietest travel weekend in the US. Establishing relationships ahead of time was key to the relocation's success and helped to manage any issues as early as possible.

A significant challenge for the move was the apron striping – part of the airport markings that ensure aircraft are parked safely and connect properly to the terminal building. During Arup's initial assessment, it appeared straightforward since different aircraft fit within the same gate sizes at both terminals. However, six weeks before the move, Delta stated that it used its own bespoke striping standard, meaning other airlines couldn't use the Delta gates at Terminals 5 and 6, and conversely, Delta was unable to use the gates at Terminals 2 and 3 without changing almost every paint line on all four aprons. Although the move spanned three days, the team had just five nights to repaint the lines and test them with aircraft before they could be ready for live operations. With as little as four hours between the last departure and the next morning's first flight, the team had to work quickly to ensure everything was in order, with safety paramount in everyone's mind. Each aircraft is worth hundreds of millions of dollars, and they are planned to be as little as 4.5m (15 feet) apart from one another, so there was very little room for error.

Another major challenge was moving the information and communications technology (ICT) systems. At LAX there are two main ICT providers and different airlines use each one, so a swap was needed for the physical relocation of the airlines. To ensure operational readiness, Arup had to fully test the ICT systems



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8: The 1960s satellite building has been transformed into a modern facility

before the move, ensuring staff could communicate from central reservations systems to check-in, to the gate counter. Because the airlines swapped overnight, the team installed double systems at each counter, with Delta using one set during the day and the other hidden underneath. After Delta's operations ended, Arup conducted overnight testing before the first flight of the new airline the next day.

Despite the local media dubbing the move "Airmageddon," the entire move was executed on plan and was a complete success. Following the relocation, Delta achieved a 50% reduction in taxi times for inbound aircraft and a 25% improvement in passenger connection times. They were then poised to start on their unification and modernisation of Terminals 2 and 3: the Delta Sky Way redevelopment.

Design and engineering challenges

The Delta Sky Way project presented the design and engineering teams with a series of complex challenges. For example, Delta and Los Angeles World Airports (LAWA) required that construction activities be carefully orchestrated to minimise disruption to daily operations. This required a design approach that could seamlessly integrate new construction, while keeping the airport fully functional and coordinating the interests of multiple stakeholders.

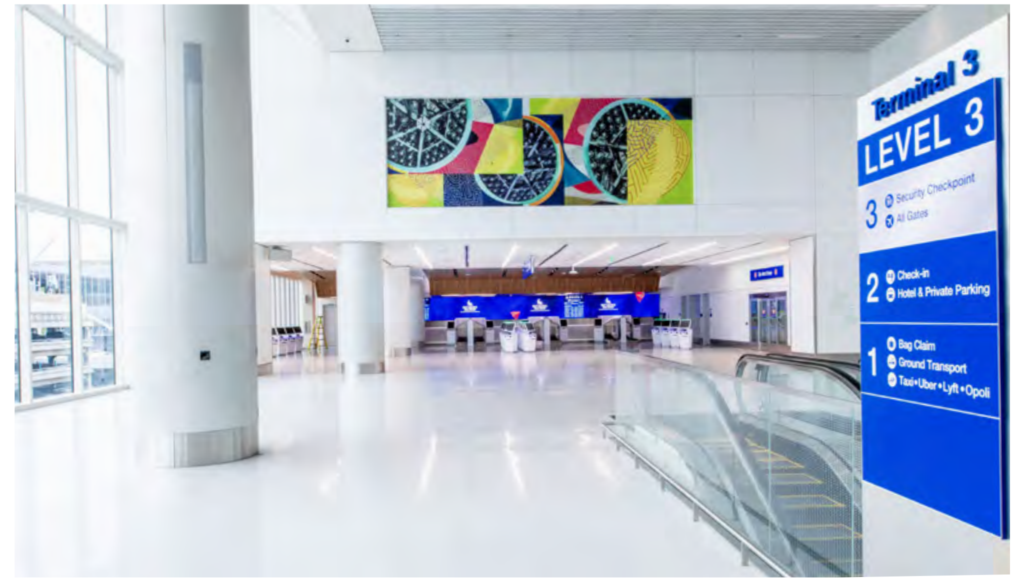
To overcome these challenges, the design team employed several solutions. To address the operational constraints, the project was divided into more than 30 phases, allowing construction to proceed in specific areas while others remained fully operational. The project's phasing strategy was then later adapted to take advantage of the significant drop in air traffic during the Covid-19 pandemic. With fewer flights and passengers using LAX, the project team accelerated the construction activities that would have been much more disruptive under normal circumstances. This included expanding work zones, increasing the number of construction shifts and reducing the need for temporary operational facilities. The pandemic also allowed the team to resequence certain aspects of the project. For instance, work that would have traditionally been done during nighttime hours to avoid disrupting airport operations could now be conducted during the day. This shift not only increased efficiency but also improved safety by allowing workers to operate in better lighting conditions.

Key statistics

- The cost of the Delta Sky Way project was **$2.4bn** .
- Arup, as lead consultant, was responsible for the coordination of **22 disciplines** across **17 enabling packages** and **13 main design phases**.
- The first phase of works was completed in **2022** (consolidated security screening capacity with automated security lanes, more gate-area seating, integrated in-line baggage system and new Delta Sky Club).
- The final phase was completed by **mid-2023**, including the secure connector along the northern side of the airport and the renovated Terminal 3 satellite; it represents a **50% increase** in overall area and throughput capacity for Delta.

Another design challenge was the need to adhere to California's seismic standards, which have become more stringent since the terminals were built. Both of the existing terminals, Terminal 3 which dated from the 1960s and Terminal 2 which was from the 1980s, needed to be upgraded to meet current expectations for seismic safety. Initially, the team planned to demolish the older Terminal 3. However, after detailed study, the team opted for a seismic retrofit of the Terminal 3 Satellite building rather than a complete demolition and rebuild. This provided meaningful time, cost and embodied emissions reductions. Performance-based non-linear response history analysis was used as a design tool to confirm that LAX's enhanced seismic performance and resilience objectives would be met. Approximately 85% of the original steel structure of the Terminal 3 satellite building was retained, while selective elements were added or replaced where structural analysis or geometrical changes required new steel framing.

In a first for LA, the project used bolted SidePlate moment frame connections



9.

within the seismic force resisting system of the newly constructed portions of the terminals, which sped up steel erection within the tight construction schedule. Performance based non-linear response history analysis was again used as a design tool to confirm that LAX's enhanced seismic performance and resilience objectives would be met. The designs ensured that the terminal structures provide enhanced resilience in the event of a major earthquake without a significant increase to upfront cost.

The lighting design focused on simplicity, reducing cognitive burden by minimising visual complexity, enhancing wayfinding through repetition and similarity, and increasing spatial intelligibility by reusing lighting design elements and details across typical space types. Logistical drivers included creating a seamless passenger experience through increased visual comfort and intelligibility, limiting the overall quantity and type of light fixtures, and installation details to improve cost effectiveness and constructability. They also included selecting fixture manufacturers with a proven commitment to product reliability and consideration of access and maintenance, and energy efficiency over time. The visual lighting design focused on indirectly illuminating both the vertical and horizontal surfaces and materials throughout the spaces, increasing perceived brightness, balancing contrast, and accentuating wayfinding and the linear experience of moving through an airport.

Sustainability considerations

Sustainability was a critical requirement of the project. The 93,000m^2 (1,000,000ft^2) redevelopment is aiming for at least LEED Silver certification, reflecting a commitment to reducing the environmental impact of the new terminal. This is in addition to meeting all state CalGreen requirements and ordinances of the City of Los Angeles. This was achieved through the combination of retrofitting existing structures to reduce embodied emissions and demolition waste, incorporating energy-efficient systems, and selecting materials with lower embodied carbon.

In line with Arup's decarbonisation commitments, whole life cycle assessments were conducted to track the buildings' whole-life global warming potential. The seismic retrofit and adaptive reuse of the 1958 satellite building proved advantageous, saving approximately 50% of embodied carbon compared with new construction in that portion of the project. Futureproofing has been effectively integrated into the design, such as a purple-pipe recycled water system that will replace the potable supply where appropriate, once the airport-wide distribution system is complete.

Further improvements included more automated security lanes, expanded gate seating and new concession areas to improve the customer experience. Additionally, the new connector to the Tom Bradley International Terminal removed the need for passenger buses between terminals. The connector is an elevated, 180m (590ft) long walkway that features expansive views of LAX's north airfield. For LAWA, it was key that the connector was sustainable, robust and resilient. The design team drew inspiration from the airport's existing materials and architectural language.

Smart tech for project oversight

A key tech contribution was the use of HoloBuilder, which enabled the project

10.

9: Arup worked closely with LAWA to develop an approach that seamlessly integrates art, advertising and wayfinding

10: The Sky Deck is a key feature of the Delta Sky Club, providing passengers with outdoor space

11.

team to have a complete 3D record of the project from the early construction stage. The tool enabled the capture, view, management and sharing of project progress, including 3D files and 360-degree photographs. It was particularly useful during the pandemic period for Arup, Gensler and Delta when there was limited access for their staff to be based on site.

A key takeaway from the project is the importance of innovative data management. Arup's custom web-based document system highlights the need for robust digital tools in large-scale projects. This system not only streamlined operations but also enabled the team to focus on core project goals rather than administrative tasks. The experience gained from integrating such advanced digital solutions can be applied to future infrastructure projects. By adopting similar data management systems, teams can enhance collaboration, reduce delays and maintain better control over complex projects. Additionally, incorporating the various futureproofing measures has equipped this new terminal complex for future changes.

A real-life test run

Arup played a pivotal role in managing the operational readiness activation and transition (ORAT) process ahead of the opening of Delta Sky Way. ORAT is essential in ensuring that new or significantly upgraded transport facilities are fully operational and functional before going live. One of the critical components was conducting a live operational trial to test the readiness of the new terminal facilities. Arup organised a trial involving 250 volunteers and 600 pieces of test luggage at the new Terminal 3.

This trial simulated real-world scenarios, such as check-in, security screening and baggage handling, including baggage claim carousels, allowing the team to identify potential issues and make necessary adjustments. The use of volunteers provided valuable feedback on passenger experience, while the test luggage helped assess the efficiency and accuracy of the baggage handling systems. This thorough testing ensured that all systems were functioning optimally before the terminals were opened to the public.

Arup's meticulous planning and execution ensured that the opening was smooth. By identifying and addressing issues during the trials, Arup was able to mitigate risks and ensure that all systems and processes were fully operational from day one.

Lessons learned

Multidisciplinary collaboration was crucial to the project's success. The effective management and integration of all the Arup disciplines, along with those of the multiple subconsultants, ensured a complex phased design that met both the client's requirements and the mandatory requirement of keeping Delta's operations functional at all times.

The final result is a new facility that not only enhances the passenger experience but also sets a new standard for airport redevelopment.

11: The lighting design purposefully minimises the visual complexity and creates a consistent visual language throughout the terminals

12: The integration of new technologies – such as self-service bag drops – gives passengers multiple options for their journey

12.

Authors

Ben Anstiss was the Project Manager and Design Manager. He is an Associate Principal in the Los Angeles office.

Jenny Buckley was the programme Design Leader. She is Arup's Global Aviation Leader and a Principal in the New York office.

Jon Phillips and Simon Rees have both fulfilled the Project Director role. Jon is a Principal in the Singapore office (and was formerly based in Los Angeles) and Simon is a Principal in the Los Angeles office.

Regine Weston was the Planning Lead for the project. She is an Arup Fellow and is based in the Toronto office.

Project credits

Client Delta Air Lines, Inc.
Architect Gensler
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