Arup’s continuous innovation legacy

75+ years of pushing boundaries

Arup’s continuous innovation legacy

Our people are independent by nature, with the confidence to take on some of the world’s most challenging projects. For over 75 years we have nurtured pioneers and original thinkers, becoming a welcome home for the creative and ambitious. From concert halls that set new standards of acoustic detail to designing the physical connections between nations, ours is a story of relentless innovation.

This publication includes some of the most innovative projects that we’ve completed over the years. It is a testament to our ambition to push boundaries and hopefully serves as a source of inspiration to both aspiring and seasoned practitioners in the built environment.

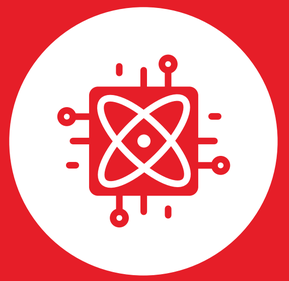
Guide

The projects included in this publication are innovative for various reasons. To enable easier understanding of the essence of their innovation, we have adopted the following five categories:

Innovation through out-of-the-box planning, design or engineering

Innovation through the invention of something new

Innovation through cross-collaboration



Innovation through cutting edge digital tools

Innovation through novel construction methodologies

Guide

Besides an introduction, for each project we highlight the following:

What the innovation is

The process of how the innovation came about

The value resulting from the innovation

Penguin Pool

1934, London, The United Kingdom

The Penguin Pool at London Zoo is a penguin enclosure. The structure has an elliptical pool at its centre, with cantilevered interlocking spiral ramps, seemingly without support. The design aimed to mimic the penguins' natural habitat, create a stimulating environment and serve as a theatrical stage for their displays to visitors.

Our construction expertise in concrete was both critical and groundbreaking, later earning acclaim as *'a new direction for British architecture, and also one of the first examples to demonstrate the expressive and structural potential of reinforced concrete'.*

What	**Pioneering the expressive and structural potential of reinforced concrete**
Process	**Integrating structural and material engineering for innovative design and construction**
Value	**A protected landmark of architectural design and engineering**

Kingsgate Footbridge

1963, Durham, The United Kingdom

The last structure that Ove Arup designed himself was the award-winning reinforced concrete Kingsgate footbridge, a striking example of his vision for ‘total design’ – the seamless integration of engineering and architecture.

From its extremely slender design to its unconventional construction method, the need for scaffolding on the river was eliminated by casting the bridge in two halves, one for each bank. The halves were then swiveled out from the banks to meet.

The two halves pivoted on revolving cones, with their meeting point marked by an understated bronze expansion joint. Bearings were designed at the base of each part to allow rotation, robust but cheap enough to be used only once.

What	**Elimination of scaffolding on the riverbank by an innovative swivelling construction approach**
Process	**An innovative solution was needed due to the impossibility of erecting scaffolding on the riverbank**
Value	**A striking example of Ove Arup’s vision for ‘total design’ combining architecture and engineering**

Sydney Opera House

1973, Sydney, Australia

Architect Utzon’s vision for a sculptural, curved building on the harbour broke radically with the cube and rectangular shapes of modernist architecture, marking a milestone in the 20th century architecture.

While the project commenced in the 1950s, the lack of a defining geometry would make it impossible for the builders to reuse formwork and would add to the building’s costs.

The complex design for the iconic pre-cast concrete shells was finally achieved through pioneering use of computers and a simple realisation: the form of the shells could be derived from the surface of a sphere. This elegant simplicity enabled the prefabrication of the building’s form using a repetitive geometry.

What	**Breaking away from the rectangular modernist architecture with a sculptural, curved building**
Process	**Numerous iterations in parabolic, ellipsoid and spherical geometry to derive the form of the shells**
Value	**Globally recognised as a masterpiece and one of the most famous buildings**

Used with permission of the Sydney Opera House Trust

Mannheim Multihalle

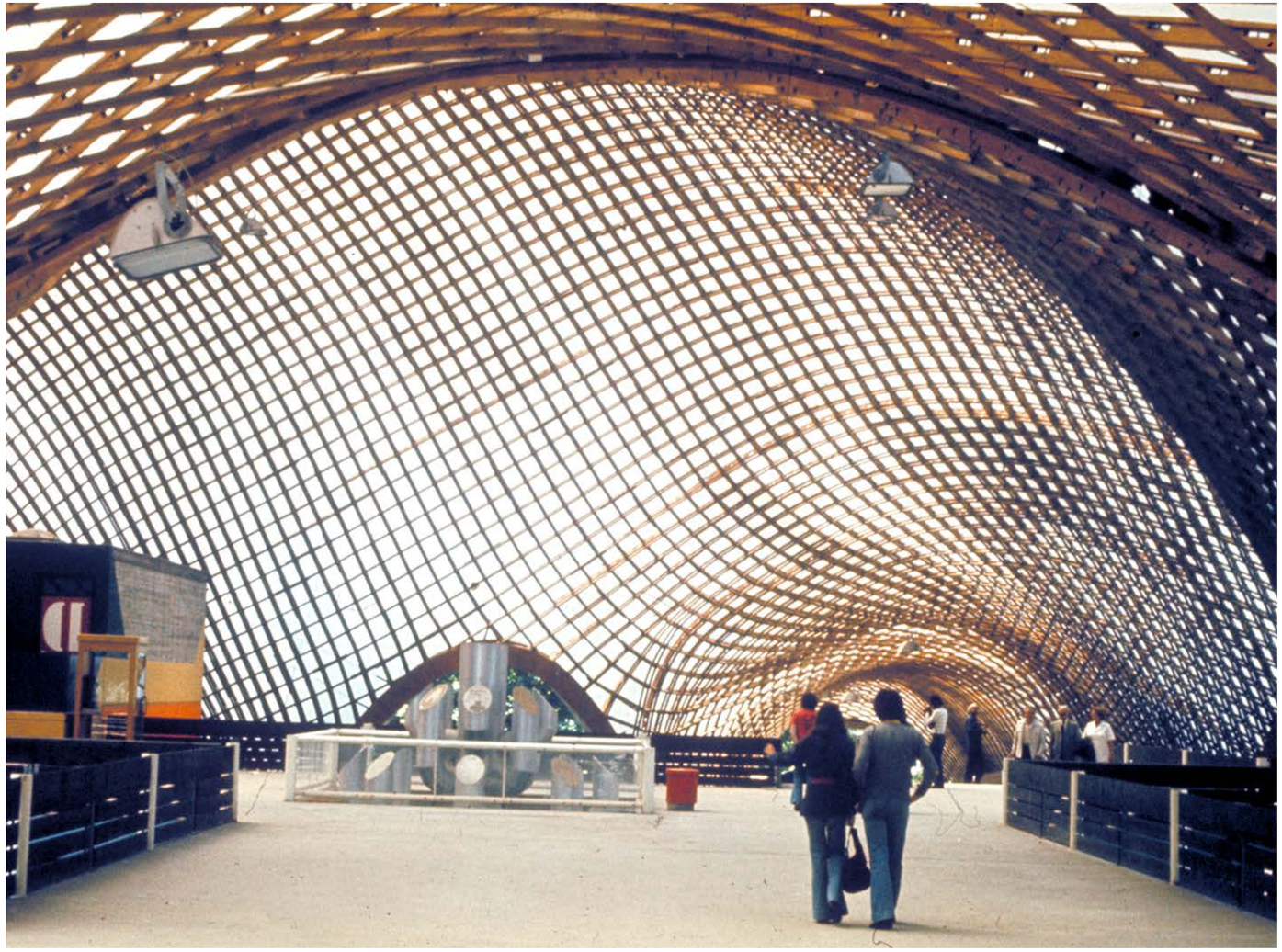
1974, Mannheim, Germany

The Multihalle is an icon of architecture and expression of a time defined by the search for new and freer forms of constructing buildings.

Designed by Carlfried Mutschler and Frei Otto, this filigree curved building is still the world's largest self-supporting timber grid shell construction. The design concept was to integrate the building visually with the topography of the man-made mounds and artificial watercourses.

Unique at the time, the roof comprises a filigree lattice structure that spans various spaces: a self-contained function room (the actual hall), walkways, open spaces and various operating facilities.

What	**First-of-its-kind and the world's largest self-supporting timber grid shell construction, integrating architecture and engineering**
Process	**A finely woven fly screen pinned on a wooden base plate and hanging models were used to assess the shape**
Value	**Provision of a flexible and versatile space that became an expression of its time and continues to inspire**



Centre Pompidou

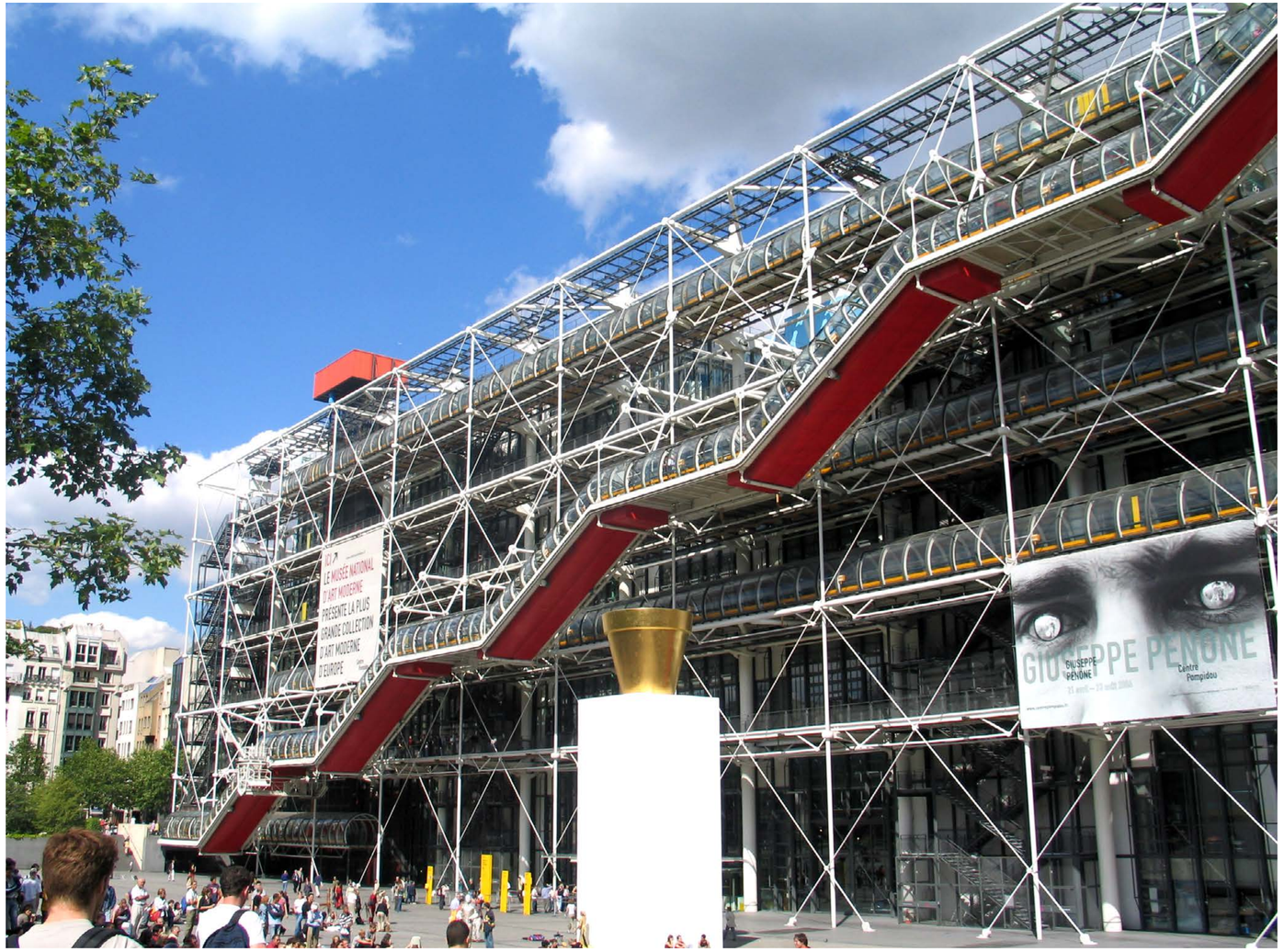
1977, Paris, France

To create the large, adaptable, uninterrupted floor areas that would allow for the circulation of large numbers of people, the design team consisting of Renzo Piano and Richard Rogers created an ‘inside-out’ building.

The design’s placing of structural elements and building services that are exposed on the outside of the building called for innovative approaches to the engineering. The colour-coded and visible pipes and ductwork were reimagined as part of the overall aesthetic, rather than being hidden.

The building’s exposed superstructure is comprised of more than 16,000 tonnes of prefabricated steel parts. Some of which are of a scale rarely seen in the construction industry, such as a 10-tonne gerberette.

What	**Structural elements and building services were placed on the exterior of the building, shaping its aesthetic appeal**
Process	**Driven by the request for large, adaptable, uninterrupted floor areas that allow for the circulation of large numbers of people**
Value	**Initially met with mixed reviews, the Pompidou has now become a global icon, revolutionising the museum industry**



Telford Gardens

1980, Hong Kong, China

This innovative project was initiated by MTR, Hong Kong's railway operator, with the aim of maximising the potential of building development around stations and depots.

Our groundbreaking analytical work for the development above the Kowloon Bay MTR depot was crucial in economically supporting the Telford Gardens residential development, which includes 41 apartment buildings and a large shopping centre.

To overcome the structural system mismatch, we invented an innovative transfer plate system, allowing the residential buildings to be supported by the pre-existing grid of depot columns designed by others.

What	**Invention of a transfer plate to facilitate the integration of two distinct structural systems**
Process	**Structural engineers faced with the client's challenge to optimise development around MTR stations and depots**
Value	**Setting a blueprint for numerous topside developments in Hong Kong and beyond**

HSBC Main Building

1985, Hong Kong, China

The HSBC Main Building remains a triumph of high-tech, user-centred design, exemplified by its innovative steel structure.

The office headquarters incorporates many advanced concepts and technologies, such as the provision of prefabricated plant-room modules, vertical transportation facilitated by escalators spanning the entire height of the building, cutting-edge security systems and an underfloor air-conditioning system.

The structure is composed of eight steel masts and five double-storey trusses, geometrically arranged to form an expressed, open suspended steel framework, creating a captivating ‘see-through’ effect.

What	**One of the world’s most technically sophisticated buildings with many advanced concepts and technologies**
Process	**Driven by the ambitious client brief to create ‘the best bank headquarters in the world’**
Value	**Upon its completion in 1985, the building set a new benchmark for high-tech corporate headquarters**

The Menil Collection

1987, Houston, The United States

To allow uniform daylighting in the gallery spaces and achieve a desirable architectural form for this modern art museum, we developed a system to supply air to the galleries from below, now known as ‘displacement’ ventilation.

To control the daylight entering the galleries as requested by the client, the design developed separate ‘beam light trusses’ which were later dubbed as ‘light leaves’.

Computer programs and mock-ups were used to model the daylighting performance, exploring the shape of the light leaves from a structural and architectural viewpoint. The final design proved to be visually unifying while providing the desired daylight control.

What	**Combining natural and artificial light in a pioneering way, leading to the creation of ‘light leaves’**
Process	**Meeting client requirements for high standards of daylight and internal environment within the galleries**
Value	**A visually unifying design that provides the required daylight control in a unique way**

Kwun Tong Bypass

1991, Hong Kong, China

This 4.8km bypass connects two tunnels, linking up Hong Kong Island, Kowloon and Shatin.

After careful consideration, we successfully introduced the novel use of precast segmental construction with epoxy-glued joints, which was the first time in Hong Kong and Southeast Asia. This approach not only resulted in significant savings in steelwork but also enabled the team to meet the extremely tight construction schedule. As a result, the project was completed one month ahead of schedule.

Another innovative feature was the introduction of a 120m long overhead ‘launching girder’. The specialist equipment was brought to Hong Kong following its successful use overseas.

What	**Novel use of precast segmental construction on a large scale**
Process	**Close collaboration with the contractor to develop a competitive proposal during the tender stage**
Value	**Significant savings in steelwork and completion within an extremely tight construction programme**

The Pavilion of the Future

1992, Seville, Spain

The Pavilion of the Future, erected for Expo 1992 in Seville, was one of the largest and most iconic buildings. This prominence was partly due to the fact that our engineers were given a free hand by the architects to demonstrate the future of stone usage.

The façade’s free-standing structure is outstanding for its innovative assembly of stone elements into loadbearing, open units – a feat made possible by modern stonecutting technologies and the availability of strong, reliable adhesives.

The unique nature of the stonework required a specially devised analysis method, based on non-linear computer software, to enable structural validation.

What	**Innovative use of natural stone made possible by modern stonecutting technologies and strong, reliable adhesives**
Process	**Our engineers were given a free hand by the architects to demonstrate how the use of stone could be brought into the future**
Value	**The pavilion stood out as one of the most prominent features of the Expo and is one of the few buildings that remain**

Kansai International Airport

1994, Osaka, Japan

At Kansai International Airport, another collaboration with Renzo Piano, we made pioneering use of computational fluid dynamics (CFD) to design the roof of the steel-clad passenger terminal. The result is an expressive, unobstructed space with a draught-free climate for the main passenger area.

The form of the roof came from extensive studies of structural and ventilation requirements. It was decided that the air could simply be projected across the space, from the rear of the building towards the front where the runways are located. The roof design we see today mimics this predicted trajectory of air movement.

What	**Pioneering use of CFD to design the roof of the passenger terminal**
Process	**Three proprietary CFD programs were used to carry out the analysis over many months, starting with the competition stage**
Value	**An expressive, unobstructed and draught-free space, allowing easy navigation by its users**

Yannawa Wastewater Treatment Plant

1998, Bangkok, Thailand

Yannawa district in Bangkok lacked a system for collecting sewage. We assisted in laying 55km of major sewers beneath the canals, dramatically minimising disruption to the roads.

Yannawa was the first major environmental project to become operational in the Thai capital, setting a new standard for successful multinational co-operation. This partnership involved Thai, Korean, British, American, Australian and German plant suppliers, contractors, designers and supervisors.

At the time, the collector system constituted one of the largest trenchless pipelaying contracts undertaken. Moreover, the advanced technology, small footprint, and treatment works made it the largest multi-storey nutrient removal plant constructed in the world.

What	**Setting a new standard for multinational co-operation with the first major environmental project to become operational in Bangkok**
Process	**Limited local knowledge and expertise required an innovative model for collaboration and exchange**
Value	**Delivering a highly effective facility that helps keep Bangkok clean and meets international standards**

South Hillcrest

2004, Hong Kong, China

Driven by the development of new building technologies by another contractor and the accolade won by another project, we supported Hip Hing Construction Co Ltd on this project.

This 35-storey residential high-rise tower in Hong Kong pioneered an innovative concrete construction method, which involved extensive structural and volumetric precasting, significantly reducing costs and increasing quality through repetition.

About 50% of the total concrete volume was precast, far exceeding the 15% seen in conventional construction. The precast elements included fully precast shear walls, modular structural kitchen and bathroom units, structural columns with bay windows, balconies, planks, façades, and stairs.

What	**Pioneering use of precast concrete construction**
Process	**Driven by the development of new building technologies by another contractor and the accolade won by another project**
Value	**Similar costs as conventional building, yet with 6% GFA concession granted for adopting precast construction**

Water Cube

2008, Beijing, China

The design of the former Olympic swimming venue, now a water park, is inspired by the formation of soap bubbles.

Our designers and structural engineers realised that a structure based on this unique geometry would be highly repetitive and buildable, while appearing organic and random.

It has a self-cleaning façade made from translucent ETFE plastic that is 100 times lighter than glass and much better at collecting heat, saving on both lighting and heating.

The Water Cube's breathtaking architecture is matched by engineering innovations in fabrication, materials and environmental management.

What	**Innovative use of ETFE as façade material for enhanced environmental performance**
Process	**The façade design is inspired by the natural formation of soap bubbles**
Value	**One of the most dramatic sporting venues for the 2008 Beijing Olympic Games, while being highly sustainable**

Shanghai World Finance Centre

2008, Shanghai, China

The 492m tower, among the tallest in the world, comprises offices, hotel accommodation, conference rooms, observation decks and retail space on the ground floors.

The challenges posed to our engineers were how to speed up the evacuation process during an emergency, to control smoke spread in the viewing deck section during a fire and to convince the Shanghai authorities to accept the concept of using elevators as supplementary means of evacuation for this super-high-rise building.

Ultimately, evacuation time was brought down by over 40% and the findings were captured in a manual for potential future developments.

What	**Innovative use of lifts as supplementary means of evacuation during an emergency**
Process	**Challenged to speed up the evacuation process, performance-based fire engineering solutions were developed and approved**
Value	**Evacuation time was reduced by over 40% and findings were captured in a manual for potential future developments**

California Academy of Sciences

2008, San Francisco, The United States

The vision for the new Academy was to create a structure that embodied nature in both form and function. A series of innovative and sustainable strategies were incorporated to conserve water and energy, reduce pollution and maximise natural ventilation and light.

One of the most innovative elements is the living roof that covers 10,000m^2 and has 1.7 million native plants. The roof helps to reduce energy, prevent stormwater runoff and provide habitat for wildlife.

An expert noted that the roof over the Academy's central space was engineered with great dexterity, hovering with a grace that dazzled visiting architecture critics.

What	**A living roof that covers 10,000m^2 and has 1.7 million native plants**
Process	**Challenged to embody nature in form and function, as well as minimise energy consumption and provide superior indoor quality**
Value	**Extensive green roof that helps to reduce energy, prevent stormwater runoff and provide habitat for wildlife**

Stonecutters Bridge

2009, Hong Kong, China

The Stonecutters Bridge is a testament to the innovation and collaboration of the bridge industry, and a landmark for Hong Kong and the world.

Building a bridge with a span of 1,018m exposed to strong typhoon winds posed many challenges to the design team and required a thorough analysis of wind patterns at the site and considering mitigating against potential ship impact.

An innovative twin-deck system was used to reduce wind load and weight, whereas stainless steel-concrete composite towers were deployed to optimise strength and durability.

What	**Application of a twin-deck system and stainless steel-concrete composite towers to optimise strength and durability**
Process	**Building a bridge with a span of 1,018m exposed to strong typhoon winds required a novel approach**
Value	**As one of the longest spanning cable-stayed bridges, it provides a landmark gateway to Hong Kong**

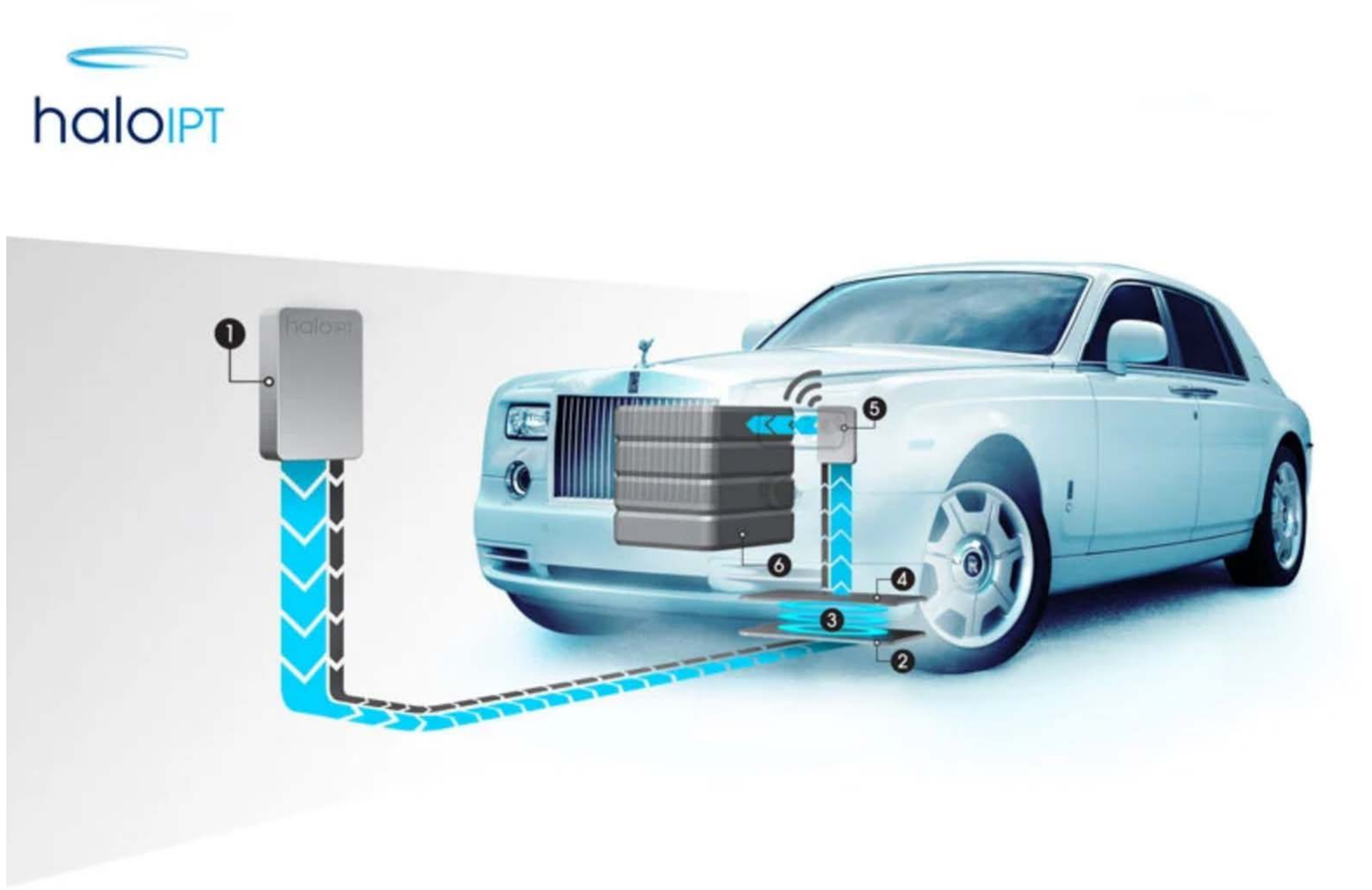
HaloIPT

2010, Global

We collaborated with HaloIPT, a technology development company, to pioneer the development and production of wireless charging technology for the transport sector.

Drawing on 20 years of wireless power research at the University of Auckland, combined with our global expertise and market knowledge, the HaloIPT team has rapidly emerged as a leading developer in wireless electric vehicle charging solutions, receiving widespread industry recognition and numerous awards.

We provided specialist technology and analytics and research and transport consulting services.



What	**Development and production of wireless charging technology for the transport sector**
Process	**Working in close collaboration with the University of Auckland to provide an easy-to-use charging method**
Value	**Qualcomm acquired Halo IPT technology in 2011, underlining confidence in the future of induction charging technology**

Parkview Green FangCaoDi

2010, Beijing, China

This hotel, shopping and commercial hub was designed with energy efficiency as its goal, setting the standard for a completely new approach to architecture in the region.

The structure is the first in Beijing to make use of a ‘microclimate’ as a means of minimising energy consumption. The building encases four towers in a transparent ‘envelope’, a shield from the environment. The resulting ‘buffer zone’ is a contained environment within which the climate is relatively uniform.

The microclimate is supplemented in summer with a mechanism to let trapped heat escape through ventilation louvers, installed at the top of the envelope. These act as chimneys, allowing the warmest air to escape and creating an upward flow of air.

What	**Utilising a glass envelop to control the micro-climate as a means to minimise energy consumption**
Process	**Challenged to create an energy efficient environment that suits Beijing’s climate of hot humid summers and cold dry winters**
Value	**While lauded for its innovative approach, the key value is its contribution to sustainable building design in China**

Marina Bay Sands

2010, Singapore

The SkyPark of Marina Bay Sands is the world's longest public cantilever. This rooftop superstructure is 200m high straddling three 55-storey luxury hotel towers.

The construction of the 38m x 340m structure presented various challenges, including addressing the natural and individual movement of the three towers, constructing the basements in deep marine clay, building the massive cantilever, managing densely packed side works and realising the geometrically-challenging structure of the lotus-inspired museum.

Using innovative 3D modelling technologies at the time, we pushed the boundaries of existing software and systems, achieving significant reduction in modelling time and optimised designs.

What	**Adopting innovative 3D modelling technologies to deliver a unique design while saving time**
Process	**Multiple structural, technical and schedule challenges required a novel and integrated approach**
Value	**Successful delivery of one of the most recognisable skyscrapers in the world**

Canton Tower

2010, Guangzhou, China

Canton Tower is one of the world's tallest structures with 600m in height. It has a unique architectural form designed by Information-Based Architecture. Its shape is created by a rotation between lower and upper-level floor plates, characterised by a twist and narrowing elliptical waist of only about 22m.

Its innovation lies in the use of parametric associative software, which can generate geometrical and structural models based on a set of variable parameters and link the geometrical data to the analytical and drafting software.

Furthermore, the team also adopted the most advanced technologies in wind engineering and wind tunnel studies based on sectional models with computer simulation.

What	**Using parametric associative software to optimise the geometrical and structural model**
Process	**Unique architectural form dictating an innovative approach to create coherence between structure and architecture**
Value	**A landmark tower that is smooth, curved and graceful, rather than angular, heavy and clumsy**

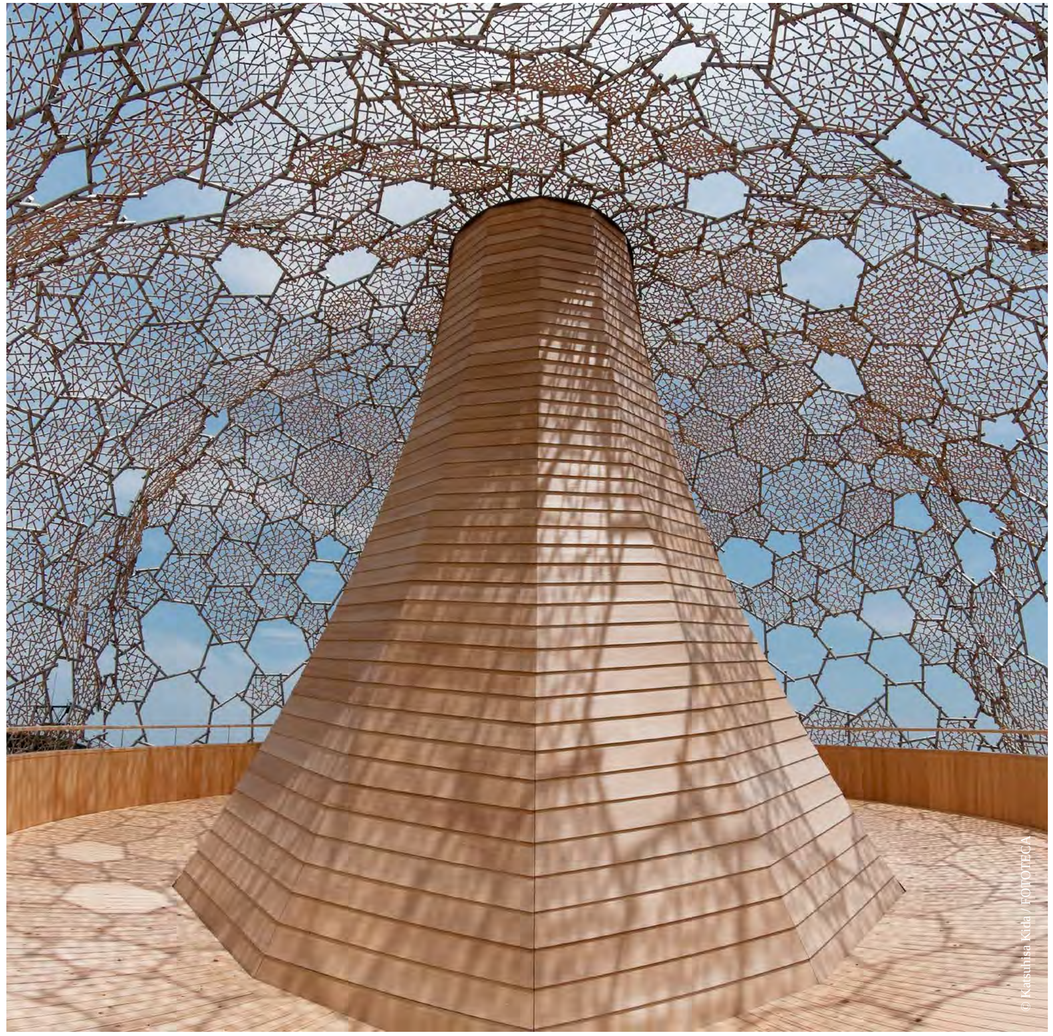
Rokko Shidare Observatory

2010, Kobe, Japan

The Rokko Shidare Observatory is a unique landmark that not only takes in spectacular views, but also provides a place to experience the natural energy and beauty of the Rokko Mountain, attracting 100,000 visitors per year. The key visual feature of the observatory is the 16m diameter meshed dome that provides partial shelter against the weather.

We broke down the complex geometry and developed a computer solver program – Shift Frame Geometry – to manipulate and accurately define the complex shift geometry. To construct the dome, we exported the geometrical data of individual members and connection locations directly to the fabricator, along with three-dimensional models indicating the precise locations of each individual member.

What	**Development of a computer solver program – Shift Frame Geometry – to break down the complex geometry**
Process	**Challenged to model the complex design of interlocking steel pipes that comprise a tessellation of triangles and hexagons**
Value	**Delivery of a spectacular observatory with a unique and highly complex architectural dome**



Helix Bridge

2010, Singapore

This landmark bridge at Singapore’s Marina Bay is inspired by the geometric arrangement of DNA, with a walkway encircled by opposing double helix structures of stainless steel.

At first glance, the bridge appears incapable of carrying substantial load. However, we designed the bridge’s two delicate helix structures to act together as a tubular truss – inspired by the inherent strength of the curved DNA molecule.

Using our own 3D software, we explored possible solutions and ultimately found a method to effectively link the two helices. The concept was then further developed in 3D in a virtual, digital environment.

What	**The world’s first curved double helix bridge**
Process	**Delivering this complex structure was only possible by using our in-house 3D software**
Value	**Standing as an iconic architectural marvel, it is seen as a testament to innovation and artistic brilliance**

International Commerce Centre

2011, Hong Kong, China

The International Commerce Center (ICC) is the tallest building in Hong Kong at 484m high. Due to its location in a major fault zone with difficult geological conditions, adopting a conventional end-bearing piling system was not a viable option. Following a series of detailed studies and comparison of various foundation types, shaft grouted friction barrettes were chosen as the foundation system.

ICC is the first private development in Hong Kong that has adopted this special system to enhance the friction capacity of the piles. To ensure the feasibility, five trial piles and four working barrettes were constructed for testing. The results turned out to be satisfactory in load carrying capacity as well as settlement performance.

What	**First private development in Hong Kong that adopted shaft grouted friction barrettes as the foundation system**
Process	**To ensure feasibility, five trial piles and four working barrettes were constructed for testing**
Value	**Enabling the construction of Hong Kong's tallest building above a major fault zone with difficult geological conditions**

CCTV Headquarters

2012, Beijing, China

The headquarters of China Central Television (CCTV) is a 234m tall building with a highly unusual shape, described as a ‘three-dimensional cranked loop’. The building is formed by two leaning towers, bent 90° at the top and bottom to form a continuous tube – redefining the traditional form of a skyscraper.

The building’s innovative primary support is achieved through the irregular grid on its surface, a visible expression of the forces travelling through the tube structure; the smaller the diagonal pattern, the stronger the load and the greater the support.

The project has become a testament to Beijing’s evolving skyline and China’s ambition to create iconic architectural landmarks.

What	**Redefining the traditional form of skyscrapers and expression of structural forces in the façade**
Process	**Driven by OMA, the architect, it was an explicit ambition of the building to hasten the end of the skyscraper as a typology**
Value	**The building has become a symbol of modernity and China’s technological advancement**

CIC Zero Carbon Park

2012, Hong Kong, China

The Zero Carbon Park (ZCP) is Hong Kong's first zero carbon building. It is a pioneering project to showcase state-of-the-art zero carbon building technologies and raise community awareness of sustainable living in Hong Kong.

The building goes beyond the traditional definition of zero carbon. An integrated approach was adopted, combining passive design measures with green active systems and on-site generation of renewable energy. Efforts were also made to minimise material use and embodied energy through efficient structural design and low carbon construction practices.

Overall, the ZCP has been fitted out with more than 90 innovative environmental features.

What	**Adopting an integrated approach with over 90 innovative environmental features to achieve zero carbon**
Process	**Commissioned by the Construction Industry Council, the key purpose was to show leadership in net zero building design**
Value	**Still standing as a pioneering project to showcase state-of-the-art zero carbon building technologies and raise community awareness**

Al Bahr Towers

2012, Abu Dhabi, The United Arab Emirates

With a striking aesthetic that defines its character, the project boasts innovative measures that improve its environmental performance and limit its energy use.

The project’s key challenge was to reduce its energy consumption while ensuring a comfortable internal environment. Our solution was to implement unique dynamic shading, which features a modular system that opens and closes like an umbrella to provide self-shading as the sun moves around the building.

Reducing solar energy entering the building by an estimated 20%, this sun shading system helps to lessen the development’s operational carbon by decreasing its reliance on energy intensive air conditioning and artificial lighting.

What	**Intelligent shading façade system that opens and closes as the sun moves around the building**
Process	**Driven by the aim to reduce the energy consumption while creating a comfortable internal environment**
Value	**The solar energy entering the building is reduced by about 20% and the aesthetics are striking**

SolarLeaf façade

2013, Hamburg, Germany

This pilot project includes the world´s first bio-reactive façade that generates renewable energy from algal biomass and solar thermal heat.

The biomass and heat generated by the façade are transported by a closed loop system to the building’s energy management centre, where the biomass is harvested through floatation while the heat is extracted by a heat exchanger. Thanks to the system’s seamless integration with the building services, the excess heat from the photobioreactors can be used to support hot water supply or provide heating for the building or be stored for future use.

The SolarLeaf façade is an outstanding example that generates energy without taking up additional space.

What	**The world´s first bio-reactive façade that generates renewable energy from algal biomass and solar thermal heat**
Process	**Outcome of a research project between Arup, the Strategic Science Consult of Germany and Colt International**
Value	**An outstanding example that generates energy without taking up additional space**

Ribbon Chapel

2013, Onomichi, Japan

Inspired by a flying ribbon, the unique design includes two spiral staircases that start at different locations before ascending and connecting at the 15.3m high rooftop platform to form a single ribbon, symbolising two paths ending in marriage.

With just four connections where the inner and outer spirals meet, the two spirals mutually support each other and create a self-standing structure.

In terms of structural innovation, the Ribbon Chapel employs 10cm-diameter steel columns that exclusively support vertical loads, thereby enhancing the overall sense of openness. To prevent the double helices from flaring, rotating, or sinking, connecting beams are strategically placed at the four points of intersection.

What	**Adopting a unique aesthetic approach of two intertwining spiral staircases supporting each other**
Process	**Structural models and computer simulation were used to calculate the potential deformation due to rotational sagging**
Value	**Seamlessly integrating architecture and engineering to create a building of unprecedented composition**

Singapore Sports Hub

2014, Singapore

This sports centre is a fully integrated sports, entertainments and lifestyle hub, made suitable for all-weather.

The elegant, energy-efficient dome structure is the largest of its kind in the world, developed using our bespoke parametric bowl generation software. The ultra-thin roof design reduces the amount of steel needed and is retractable to provide shelter from Singapore's humid tropical climate when needed. Once opened, it reveals the city's stunning skyline.

At ground level, a system is designed to deliver cool air to every seat in the stadium, using carbon neutral ventilation.

What	**A pioneering retractable ultra-thin roof design provides shelter that allows year-round use of the venue**
Process	**Required a total architecture approach of architecture, master planning, sports design, structural and environmental experts**
Value	**The acclaimed Hub enables a sustainable and competitive advantage for the nation's sports and tourism industry**

Bosco Verticale

2014, Milan, Italy

Bosco Verticale is a significant innovation, demonstrating how we can merge vegetation and urban architecture to create more sustainable and livable cities.

The design creates a biological habitat within a total area of 40,000m^2 , featuring 900 trees, 5,000 shrubs and 11,000 floral plants. The vast amount of greenery on the building encourages the production of energy, oxygen and humidity and absorbs CO_2 and dust particles.

We designed the structural stability of the trees through the botanical analysis of the species and their geometry. We also conducted a detailed wind climate assessment and two wind tunnel test campaigns to understand the impact of growing trees at such heights on the building's overall structure.

What	**Provision of an unprecedented vertical forest with a total area of 40,000m²**
Process	**The structural stability of the trees is ensured through the botanical analysis of the species and their geometry**
Value	**The flourishing trees help improve air quality, provide shade and reduce noise pollution**

T·PARK

2014, Hong Kong, China

T·PARK is a state-of-the-art sludge treatment facility specifically designed to provide an innovative and eco-friendly solution for the problem of sewage sludge disposal in Hong Kong.

As one of the most technically advanced facilities of its kind in the world it integrates a power station, a spa resort and a sludge treatment facility. With its architecturally distinctive wave-like façade, it is the first facility of its kind in Hong Kong, and one of the largest sludge incinerators in the world.

It utilises fluidised bed incineration technology, capable of burning 2,000 tonnes of sludge every day and uses the excess heat energy to generate electricity. At full operational capacity, an excess of 2MW of power is available daily.

What	**Combining sludge incineration, power generation, seawater desalination and wastewater treatment in a single facility**
Process	**Driven by the challenge to find a sustainable solution for the increasing amount of sludge disposal**
Value	**A showcase of sustainable building, setting a new standard for green infrastructure in Hong Kong and the world**

Lotte World Tower

2015, Seoul, South Korea

Rising to over 555m, the 123-storey supertall building is the tallest in South Korea and the fifth tallest in the world.

As the supertall tower is underlain by multi-directional faults and shattered rock mass, the client initially considered extensive treatment to the ground conditions.

We overcame this with an out-of-the-box solution, supported by simple calculations, overseas case studies and using the available borehole and testing data. Our design consists of a cost-effective hybrid solution of piled raft foundation. The raft provides overall foundation capacity, complemented by strategically placed short piles to mitigate potential differential settlement at the concerned portions of the tower.

What	**Applying a cost-effective hybrid solution of piled raft foundation to avoid the need for considerable ground treatment**
Process	**Adopting out-of-the-box thinking using available data, simple calculation and overseas examples**
Value	**Delivering a 555m super-tall building erected on on multi-directional faults and shattered rock mass**

Air Induction Unit

2015, Hong Kong, China

In hot and humid climates of cities like Hong Kong and Singapore, mechanical fans are commonly used in outdoor areas. However, they often only provide a localised high-speed air movement and there are ‘dead spots’ with no airflow for cooling.

The patented Air Induction Unit (AIU) is a displacement ventilation device designed to provide moving air for comfort, particularly in transient spaces such as metro platforms and semi-outdoor eating areas.

The device has a minimal and aesthetically pleasing blade-like design and works using the principle of induction. When connected to a ventilation system, the blade generates a small jet of air, which in turn entrains a large volume of surrounding air.

What	**A pioneering displacement ventilation device that moves air to provide comfort in transient spaces**
Process	**Utilising aerodynamic principles to induce a large-volume of continuous air flow with gentle speed**
Value	**AIU induces up to 15 times the amount of supplied air, making it highly energy-efficient**

HATS stage 2A

2015, Hong Kong, China

The Harbour Area Treatment Scheme (HATS) is one of the largest ever sewerage infrastructure projects in Hong Kong. HATS Stage 1 provides treatment to about 75% of the sewage from urban areas around the Harbour. HATS Stage 2, provides additional facilities to convey all remaining for treatment.

The scale of the project called for visionary, innovative and pioneering engineering solutions.

For example, Stage 2A comprises a network of interconnected deep tunnels at a total length of 21km located at depths varying from 70m to 160m below sea level. An innovative and state-of-the-art technology called Horizontal Directional Coring was adopted to investigate the geology and ensure successful delivery.

What	**Adoption of various state-of-the-art technologies to ensure successful delivery**
Process	**The scale of the project called for visionary, innovative and pioneering engineering solutions**
Value	**HATS serves 5.7million people and is one of the largest ever sewerage projects in Hong Kong**

Gifu Media Cosmos

2015, Gifu, Japan

This two-storey building houses a modern public library complemented by an art gallery, studio and workshop spaces under a flowing timber roof.

An innovative feature of the library is the 11 giant ‘globes’ suspended from the roof. Besides defining different zones for reading, resting and study, they also play an important role in the building’s overall sustainability performance as they enhance the airflow and bring in natural light.

Another innovative element of the design is the wooden lattice roof. Different approaches were tested with scaled models, ultimately leading to a layered grid shell in three dimension that could be built by local carpenters with local materials.

What	**Adopting giant globes and the development of a new construction method for timber grid structures**
Process	**Thorough testing of scaled models, followed by a cycle of reiteration and refinement**
Value	**Highly popular among the city’s population and a positive influence on the local community and economy**

Kai Tak District Cooling System

2017, Hong Kong, China

We enabled the planning of the first-of-its-kind seawater district cooling system (DCS) to serve the 320 new urban developments at the former Kai Tak airport site.

Through centralisation and the use of seawater for heat rejection, the DCS offers multiple advantages over conventional individual air-conditioning systems. It achieves savings of about 15-20% on overall installed capacity, while also reducing the material use and total plant space required.

We worked closely with the Electrical and Mechanical Services Department (EMSD) in Hong Kong, from concept to implementation, for 20 years to bring one of the most important sustainable infrastructures to the city.

What	**The first-of-its-kind seawater district cooling system in Hong Kong**
Process	**Working closely with EMSD for 20 years, from concept to implementation, to ensure delivery**
Value	**Saving about 15-20% of energy use, while also reducing the material use and total plant space required**

Queensferry Crossing

2017, Edinburgh, The United Kingdom

The Queensferry Crossing is Scotland’s largest infrastructure project for a generation and the longest three-tower, cable-stayed bridge in the world. Our work was fundamental to the development of the project. We significantly improved the cost-benefit ratio through the innovative use of new and existing bridges as an integrated pair of multi-modal crossings.

One of the key innovations is the use of real-time sensor data which protects travelers and employees by monitoring the impact of weather and motion and is one of the first bridges to have live ‘health checks’ for infrastructure. This Cloud-based system informs the maintenance regime and monitors the structural health of the crossing to support decision-making.

What	**Using real-time sensor data to monitor the impact of weather and motion**
Process	**A multidisciplinary approach of more than eight types of services spurred innovation**
Value	**Assuring long-term durability and enhancing the drivers’ experience and safety**

Hong Kong-Zhuhai-Macao Bridge

2018, Hong Kong, Macao and Zhuhai, China

The Hong Kong-Zhuhai-Macao Bridge (HZMB) represents a significant innovation in bridge construction, showcasing how modern engineering techniques can be used to create large-scale infrastructure projects that are durable, efficient, and environmentally friendly.

The world's longest sea crossing, stretching for 55km, consists of three cable-stayed bridges and linking roads in the three cities. It reduces the travelling time between Hong Kong and Macao/ Zhuhai from an hour's ferry ride to a 40-minute car journey.

The construction of the HZMB involved multiple innovative techniques, including automatic manufacturing technology, large segment offshore installation and non-dredged reclamation.

What	**The world's longest sea crossing that is durable, efficient and environmentally friendly**
Process	**Adoption of innovative techniques such as automatic manufacturing, offshore installation and non-dredged reclamation**
Value	**Reducing the travelling time between Hong Kong and Macao/Zhuhai from an hour's ferry ride to a 40-minute car journey**

Shanghai Urban Drainage Masterplan

2019, Shanghai, China

Shanghai’s population has tripled since 1990, leading to growing city flooding and river pollution, made worse by climate change.

We used remote sensing to scan greater Shanghai and built a machine learning tool to interpret the images and categorise the entire area in 12 categories of flooding protection need.

Our next-generation blue and green infrastructure will be integrated into all urban projects, from urban network systems to individual buildings. It will also be integrated with other critical infrastructure including transportation, water, energy, digital and waste, for urban planning, design and urban redevelopment.

The project demonstrates how human ingenuity and community priorities can be supercharged by the power of machine learning to achieve previously impossible things.

What	**Application of remote sensing and machine learning to interpret and address flood protection needs**
Process	**Close collaboration between our water engineering, flood risk management and Advanced Digital Engineering teams**
Value	**A comprehensive flood mitigation strategy, informed by a machine aided assessment and classification process**

Landmark 81

2019, Ho Chi Minh City, Vietnam

Landmark 81, Vietnam's tallest building, rises to 461m with 81-storeys and three levels of basement. The shape of the building resembles a bundle of bamboo canes to reference the area's agricultural past and the nation's much revered home-grown resource.

It was built in an area with exceptionally poor-quality soil, presenting a number of challenges. The design solution adopted an innovative thick raft supported on barrette piles. This allowed for maximum flexibility for the subsequent development of the design even as the foundation was being constructed – a necessary requirement imposed by the fast-track design and construction programme.

What	**Using an innovative barrette pile solution in soft soil for the tallest building in Vietnam**
Process	**Leveraging our deep knowledge in high-rise development, combined with our out-of-the-box thinking**
Value	**Overcoming exceptionally poor soil conditions and enabling flexibility for the fast-track design and development programme**

FORESTA Acoustic Panel System

2019, Global

We worked with Italian bio design firm Mogu to develop FORESTA, a bio-degradable mycelium-based acoustic panel system with proven acoustic properties. It’s a world-first to use mycelium for this type of product.

The components of the prefab FORESTA system are made of fast-growing, completely renewable raw materials that can be reused or composted at the end of their life cycle, therefore helping businesses move away from the ‘take-make-waste’ system towards a circular economy model.

Apart from the cutting-edge innovation embedded in the bio-fabrication, the system’s timber components are manufactured with latest technologies in timber processing.

What	**Development of a modular acoustic panel system made from bio-degradable mycelium**
Process	**Collaboration with a start-up, combing established technical expertise with new material technologies**
Value	**Offering an innovative, truly sustainable solution for acoustic comfort for office spaces**

MX3D Bridge

2019, Amsterdam, The Netherlands

This large-scale 3D-printed steel bridge, is a 12m long digital design masterpiece with curved, raw steel balustrades that belie its high-tech origins.

Printed in stainless steel, the bridge is the culmination of a long-running dream that welds traditional steelwork and advanced digital modelling into an inspired, structurally sound piece of public urban infrastructure. Computational design and 3D printing come together to streamline both the design and production process.

The use of advanced parametric design modelling, which allowed designers to explore new shapes through coding, significantly accelerated the initial design process.

What	**Delivering a world's first, 12m long 3D-printed steel bridge**
Process	**Collaboration with a start-up, combing expertise in advanced digital modelling and 3D printing**
Value	**Offering a glimpse into how state-of-the-art robotic welding technology could shape our cities in the future**

Hybrid Outrigger System

2020, patented in China

We developed an innovative hybrid outrigger system – it combines strengths of steel and stiffness of concrete, resulting in a hybrid form using concrete walls and steel bracings. The system also comes with a structural ‘fuse’ that behaves as rigid under wind action; while in case of severe earthquakes, this ‘fuse’ component will yield and dissipate energy to protect the building.

The system has been successfully applied in the two 350m high towers in the Raffles City Chongqing in China. Substantial cost savings were achieved through 10% reduction of total steel consumption and acceleration of the construction schedule by four months.

What	**A patented hybrid outrigger system that uses concrete walls, steel bracings and a structural ‘fuse’ to provide stability**
Process	**Extensive analyses were carried out using the elasto-plastic finite element analysis and laboratory joint tests**
Value	**Significant reduction of steel consumption and acceleration of the construction schedule**

Neuron: AI Smart Building Console

2020, Hong Kong, China

We have developed Neuron, the first-ever AI-enabled smart building solution in Hong Kong.

Neuron is an app that integrates our insights into the built environment with emerging digital technologies, all in one platform. It utilises 5G and the internet of things (IoT) to gather real-time ‘sense data’ from equipment and systems. Building information modelling (BIM) is used to display these complex data sets through a cloud-based, centralised management console. Neuron’s ‘brain’ uses AI and machine learning to analyse, optimise and automate operations.

It can save up to 30% on electricity consumption for a typical existing commercial building and can be easily integrated into any buildings and tailored to meet different needs.

What	**The first-ever AI-enabled smart building solution in Hong Kong**
Process	**Integration of insights into the built environment with emerging digital technologies on a single platform**
Value	**Potential to save up to 30% on electricity consumption for a typical existing commercial building**

Chapel of Sound

2021, Beijing, China

The Chapel of Sound is a boulder-shaped concert hall that features a semi-outdoor amphitheatre, an outdoor stage, viewing platforms and supporting spaces.

Due to the complex geometry, the coordination of architecture and engineering was facilitated by digital technologies such as computational fluid dynamic analysis, acoustic simulations and 3D modelling software. Based on these tools, we generated structure and MEP drawings as well as 3D models for the contractor.

The construction process posed the ultimate challenge, with thousands of uniquely shaped timber plates fitting together like a jigsaw. Additionally, 10,000 rebars, each with different shapes, were bent and secured in place.

What	**Unique shape and function, requiring an innovative approach to design and delivery**
Process	**Use of digital tools to foster collaboration among architects, structural and acoustic engineers and the contractor**
Value	**A highly praised example of design that successfully combines functionality with striking aesthetics**

Admiralty Station

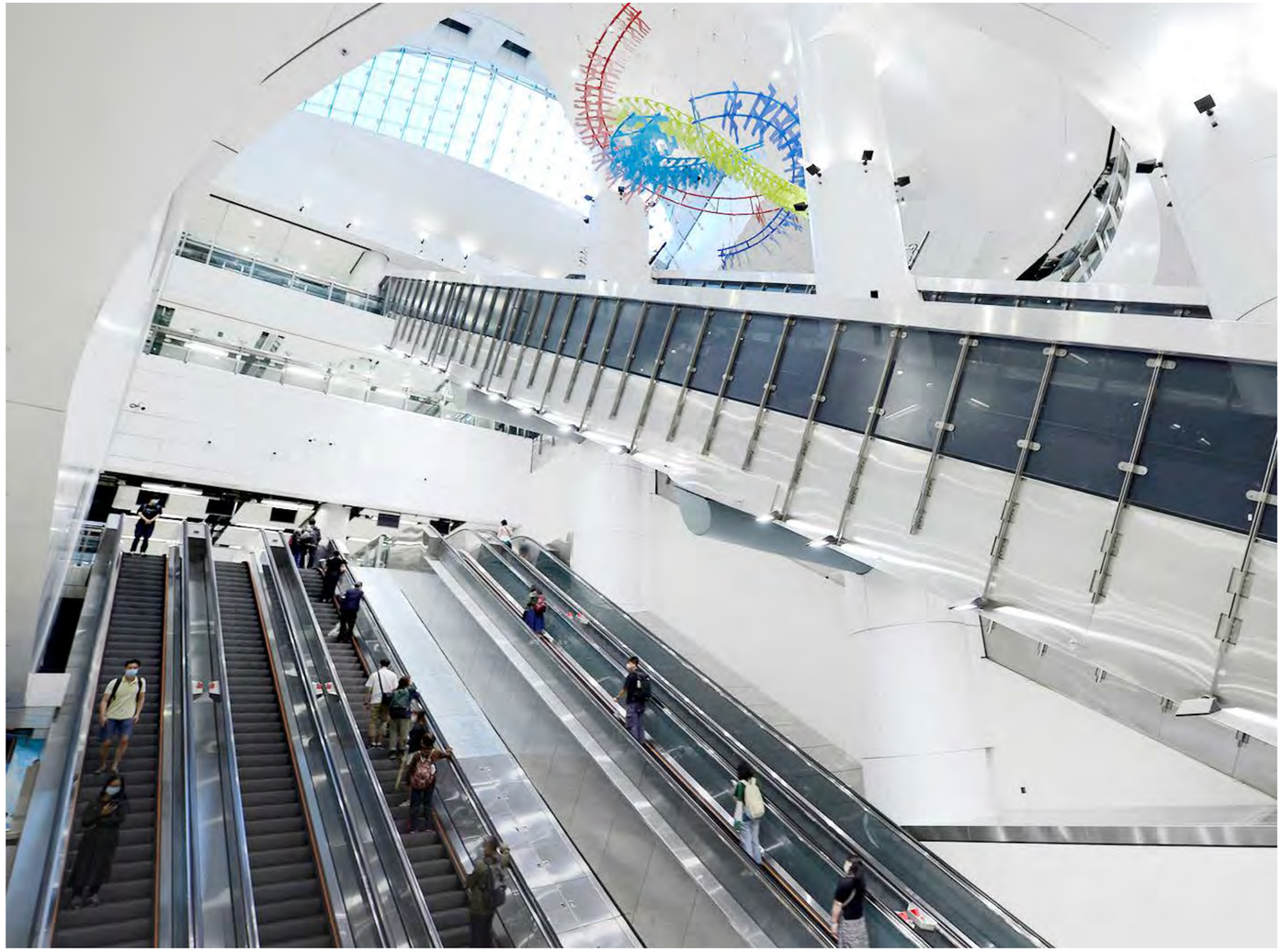
2021, Hong Kong, China

Our involvement in Admiralty Station focused on connecting the fourth metro line while minimising disturbance to existing metro lines.

To address the complex arrangement and constraints related to the railway facilities, we carefully designed a phased sequencing of works that involved removing solid rock beneath the box and inserting a permanent structural framework. This approach set a precedent in Hong Kong.

By adopting real-time monitoring and a computerised jacking system, the contractor effectively controlled any undue movements induced by the construction and underpinning works, thereby ensuring passenger comfort and smooth operation of the running metro lines.

What	**Adoption of an innovative underpinning approach, including real-time monitoring and a computerised jacking system**
Process	**Implementation of a pioneering approach to address the highly complex station arrangement**
Value	**All works were delivered without impacting existing railway operations and with minimal disruption to the community**



Little Island

2021, New York City, The United States

This artificial island covers a public area of 9,800m^2 and is supported by 132 pot-shaped structures making it suspend above the water. Its complex curved and undulating form, different from a typical pier, posed significant challenges in the design, fabrication and erection processes.

We harnessed advanced 3D design techniques and digital solutions to achieve the project's ambitious vision while optimising constructability and enhancing performance spaces. A 'Cairo pentagon' pattern was used to rationalise the geometry.

The complex fabrication and assembly work for these elements were carried out off-site. We also produced 3D models that provided detailed specifications for the off-site fabricator and created digital 3D rebar models for the intricate petals.

What	**Harnessing advanced 3D design and prefabrication techniques to achieve the project's unique aesthetic**
Process	**Utilising the 'Cairo pentagon' pattern to rationalise the complex and undulating form**
Value	**Delivering an iconic urban oasis on the Hudson River for the public to enjoy**

Davao High Priority Bus System

2022, Davao, The Philippines

This study aims to replace 7,000 jeepneys with a modern bus system in the third most populous city in the Philippines. It involves developing a new service plan for over 1,000 buses, including battery electric buses, operating along 29 routes. Various bus facilities, bus priority lanes, intelligent transport system elements and pedestrian improvements will be introduced.

Our work has been recognised as a pioneering effort, deploying over 380 battery electric buses, marking the largest-scale deployment in Southeast Asia to date. Our planning and design work in refining the 600km High Priority Bus System network and associated facilities strategically serve rural populations, opening up more growth opportunities and services.

What	**Facilitating the transition from polluting jeepneys to a comprehensive network of electric buses**
Process	**Working in close collaboration with policymakers, operators, users and other stakeholders**
Value	**Enabling the shift to a more sustainable mode of transportation while opening up growth opportunities and services**

Cayanga Solar Power Plant

2022, Cayanga, The Philippines

Mapping out terrains for solar farms is no easy task. Numerous factors such as orientation, slope angle and shadow considerations must be taken into account to design the most optimal panel layout that will yield the highest electricity output at the lowest cost.

We have developed an integrated digital workflow that combines in-house expertise in applied geology/ geomorphology, GIS, remote sensing, solar energy and digital skills to tackle these challenges effectively.

Our working prototype assists our clients in quickly assessing the suitability and annual yield of solar farms in various hilly locations.

What	**Using algorithms to determine the optimal orientation, slope and shadow factors of each solar panel**
Process	**Challenged by the lengthy process of terrain assessment, our geotechnics and digital teams collaborated to find a solution**
Value	**Assisting clients in quickly assessing the suitability and annual yield of solar farms in various hilly sites**

HAUT

2022, Amsterdam, The Netherlands

HAUT is the tallest revolutionary timber-hybrid residential building in the Netherlands. Our design principle for HAUT was ‘timber where possible, concrete and steel when necessary’.

HAUT serves as a shining example of how innovative sustainability can contribute to the future of buildings, where zero carbon and nature-inclusive design become the norm.

The tower features an Aquifer thermal energy storage system, sensor-controlled installations and low-temperature underfloor heating, making it one of the most climate-friendly high-rise residential buildings in Europe. A rooftop garden and nest boxes for birds and bats enhance the site’s biodiversity.

What	**Netherlands’ tallest timber-hybrid building, following a ‘timber where possible, concrete and steel where necessary’ approach**
Process	**Driven by the municipality’s emphasis on the importance of sustainable design and high architectural quality**
Value	**Reducing the total embodied carbon footprint by half compared to a conventional building**

Quay Quarter Tower

2022, Sydney, Australia

The Quay Quarter Tower is the world’s first upcycled skyscraper. Built in 1976, the original AMP Centre had reached the end of its usable lifespan. However, instead of opting for demolition and starting anew, the project team, together with the ambitious client, set out to reach an ambitious goal: to reuse as much of the existing building and set a lofty new standard for adaptive reuse in architecture.

Our adaptive retrofit design retained 65% of the original building’s floorplates and structure and 98% of the original structural walls and core. This equates to an approximate savings of 12,000 tonnes of embodied carbon.

What	**Retained 65% of the original building’s floorplates and structure and 98% of the original structural walls and core**
Process	**Comprehensive reuse of the structure and the retention of embodied carbon were integral to the client’s design vision**
Value	**Setting a new standard for sustainable building design with the comprehensive reuse of the structure**

11 Skies

2023, Hong Kong, China

We designed a comprehensive sustainability framework for this project, featuring solutions that brought added value to energy efficiency, and the health and wellbeing of building users.

We also collaborated with the Hong Kong Polytechnic University to introduce the first application of two AI-driven indoor air quality and thermal comfort monitoring and controlling systems, allowing automatic and responsive adjustment to air management.

Another highlight is the largest photovoltaic and thermal (PVT) installation in Asia with a total of 252 hybrid solar PVT panel modules, covering an area of over 400m^2.

What	**Pioneering AI technology to enhance energy efficiency and improve the health and wellbeing of building users**
Process	**In collaboration with the Hong Kong Polytechnic University, we developed AI-based machine learning algorithms**
Value	**Improving accuracy and responsiveness of ventilation control system which optimises energy efficiency and indoor air quality**

Lib Earth House model A

2024, Japan

Japan’s first 3D printed earth prototype house exemplifies circular economy construction, using soil – a widely available local resource – as its primary material. This approach reduces transportation and processing costs, carbon emissions and environmental impact, offering a sustainable alternative to conventional construction.

To ensure successful 3D printing, we developed an algorithm that considers printer capabilities, material properties and construction sequences. For example, it takes into account what the printer can do, such as how thick and wide it can make each layer, and how big an item it can print.

What	**Japan’s first 3D printed earth prototype house using soil as primary material**
Process	**Development of an algorithm to capitalise on printer capabilities, material properties and construction sequences**
Value	**Reduced transportation and processing costs, carbon emissions and environmental impact**

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About Arup

Arup is the creative force at the heart of many of the world's most prominent projects in the built environment and across industry. Working in more than 140 countries, the firm's designers, engineers, architects, planners, consultants and technical specialists work with our clients on innovative projects of the highest quality and impact.

About Arup University

Arup University, as a unique part of Arup, ensures the firm delivers excellence in everything we do for the benefit of our members, our clients and the communities we serve. We continuously strive to push the boundaries to formulate solutions, and assist our clients in understanding the megatrends that are shaping the future of the built environment, identifying new opportunities and developing innovative ideas.