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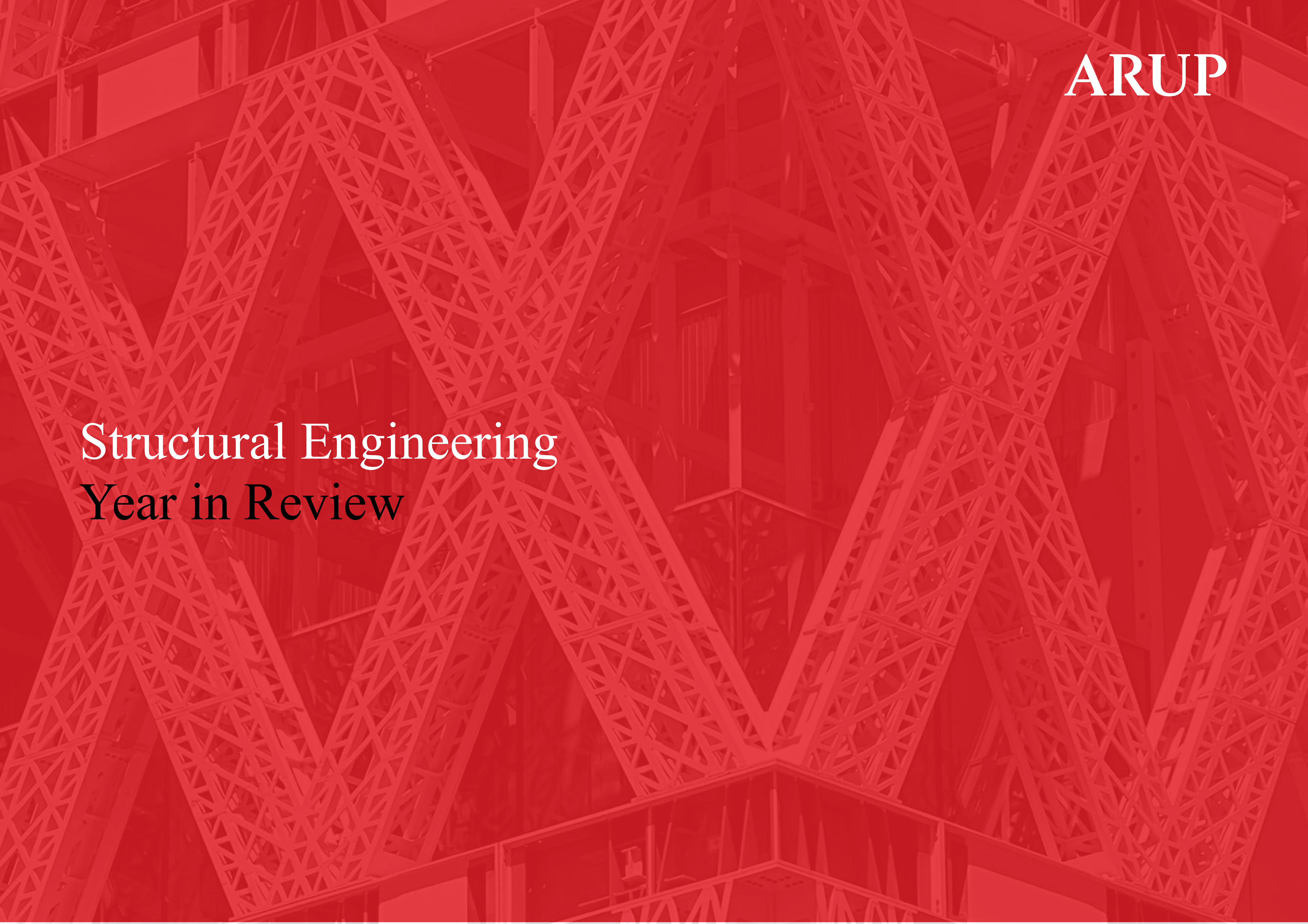
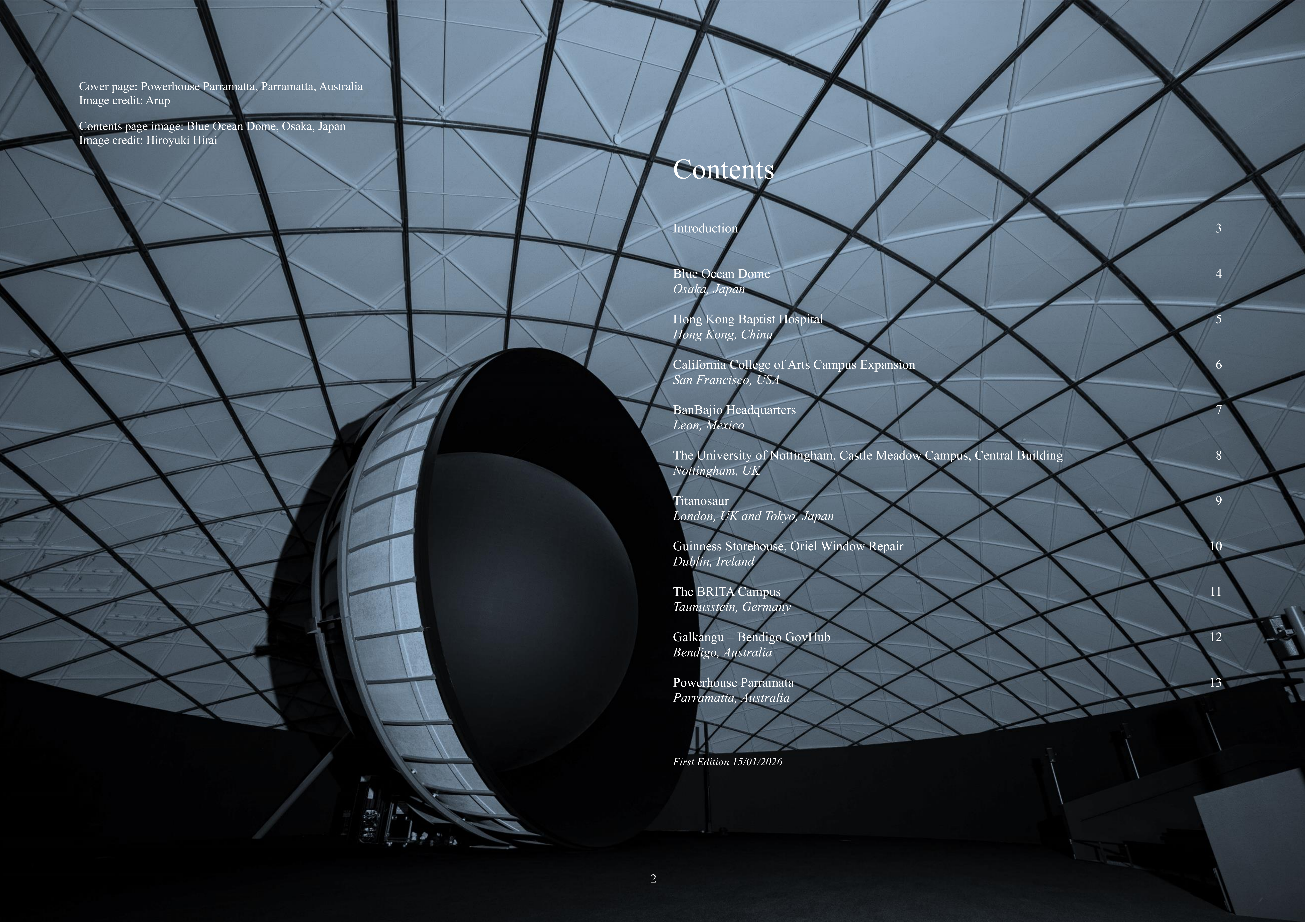


Structural Engineering
Year in Review



Cover page: Powerhouse Parramatta, Parramatta, Australia
Image credit: Arup

Contents page image: Blue Ocean Dome, Osaka, Japan
Image credit: Hiroyuki Hirai

Contents

First Edition 15/01/2026

> “Our work should be interesting and rewarding. Only a job done well, as well as we can do it – and as well as it can be done – is that. We must therefore strive for quality in what we do and never be satisfied with second-rate”

The Key Speech
Ove Arup, 1970

Introduction

Looking backwards

Structural engineering has been at the heart of Arup ever since the company began in 1946. The history of the firm is rich with structural engineering that pushes the boundaries of what’s possible, with projects spread around the world, from the Sydney Opera House to the National Aquatics Centre in Beijing (the Watercube), Sagrada Familia in Barcelona, Centre Pompidou in Paris, Lloyds Building in London and the Las Vegas High Roller. We create structures that form the centres of cities, host world class sports, become cultural icons, are homes for people and businesses, and provide places for worship.

Looking forwards

This yearbook presents ten projects from across Arup that demonstrate our members’ skill and enthusiasm to produce exceptional structural engineering that enhances the places we work and benefits the people who live there.

The projects are either recently completed, under design or under construction and were selected from those put forward for our global series of “What’s Hot” talks where structural engineers from around the Arup world share their work with their colleagues. Maintaining and developing a global community of structural engineers is a vital part of our culture and the way we work.

Blue Ocean Dome | Expo 2025 Osaka

Osaka, Japan

High tech long span structural engineering designed for reuse

Arup led the design of this unique pavilion built for the Expo 2025 Osaka, showcasing use of three unconventional materials to form three large domes

Authors Junichiro Ito, Junya Kobayashi

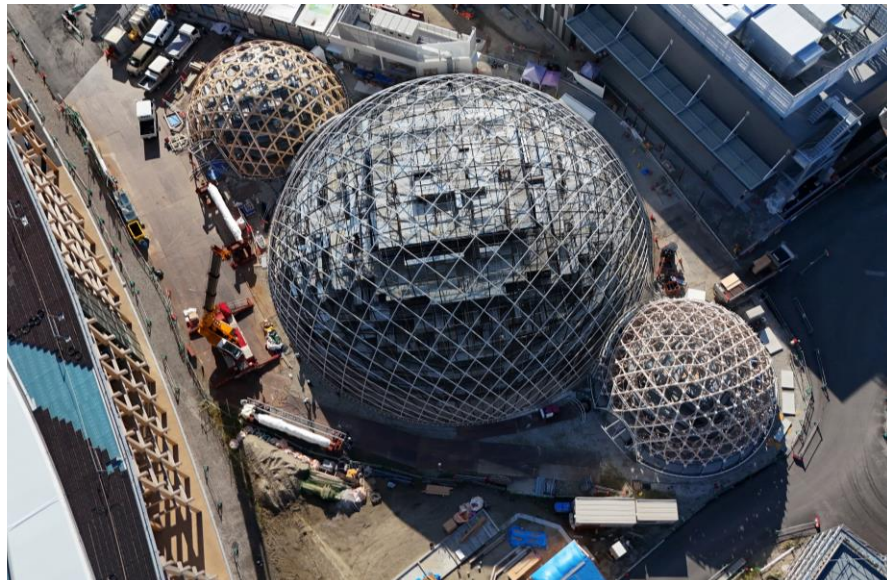
Collaborating with Shigeru Ban Architects, Arup structural engineers used pioneering materials to create the Blue Ocean Dome Pavillion. The Pavillion has been designed for deconstruction and relocation, extending its life beyond the duration of the Expo.

Ground conditions

As the site is on reclaimed land the Expo Association prohibited excavation to greater than 2.5 m and mandated consideration of soil settlement. Bearing capacity tests indicated a low capacity of 50 kN/m^2, and so a lightweight structural system was essential to realise domes, two with spans of 19 m and one larger dome spanning 42 m, without the need for deep piled foundations. To construct the domes three new structural materials were adopted:

19 m paper tube dome

Paper tubes have been used as a structural material on three previous Shigeru Ban Architects projects in Japan. For the paper tube dome, the tubes were made from 100% recycled paper, and a bespoke new ball joint detail developed to connect the tubes together. Unlike the steel ball joint used in previous paper tube structures, Arup engineers were able to design a 300 mm diameter ball joint from cross laminated timber.



1.

42 m Carbon fibre reinforced plastic (CFRP) dome

To achieve the 42 m span of the largest dome, CFRP, was adopted due to its high strength to weight ratio – roughly five times stronger than normal structural steel - allowing the long span with minimal structural weight and avoiding the need for prohibited piled foundations. CFRP is a relatively novel structural material in buildings and has not previously been used as the primary structural material for an earthquake resistant building in Japan. To meet fire regulations for temporary buildings, the outer most layer of the dome, which supports the façade membrane, was made of steel, with the second and third layers of the gridshell formed from CFRP tubes.

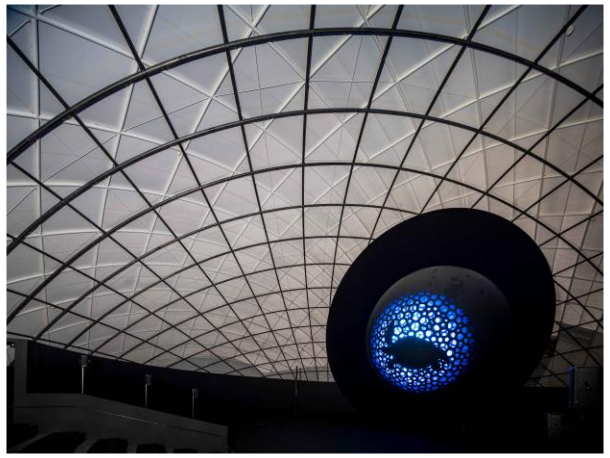
19 m laminated bamboo dome

Bamboo absorbs CO_2 when growing, like timber, but grows significantly faster – offering multiple benefits. One challenge the design team had to overcome was that no buildings in Japan have used laminated bamboo before, and its strength and characteristics were not clear, so use of bamboo required a rigorous series of tests in collaboration with suppliers and universities. The bamboo was laminated, which enhances its strength and stability while accommodating variations in its thickness, size and surface uniformity.

Considering the different characteristics of each dome, including the foundation, each dome was made independent by incorporating moving joints. The three domes are expected to be relocated to a new location after the Expo, therefore the design takes relocation into consideration.

2.

Client: ZERI Japan
Architect: Shigeru Ban Architects
Services: Structural, Mechanical, Electrical, Plumbing



3.

Image credits

1: Shigeru Ban Architects
2-3: Hiroyuki Hirai

1. All three domes under construction
2. The bamboo dome
3. The carbon fibre reinforced plastic dome

Hong Kong Baptist Hospital

Hong Kong, China

Redevelopment of a working hospital

Hong Kong Baptist Hospital consists of five main blocks, three of which (Blocks A, B and C) are proposed to be redeveloped whilst the hospital remains operational. The project is land locked and surrounded by busy roads

Author Ben Luk

Hong Kong Baptist Hospital is situated on a land locked site, surrounded by busy roads in Kowloon. As part of redevelopment three of the five blocks (A, B and C) are proposed to be demolished and rebuilt, requiring clever sequencing of structural work to maintain operation of the remaining hospital

Block A demolition

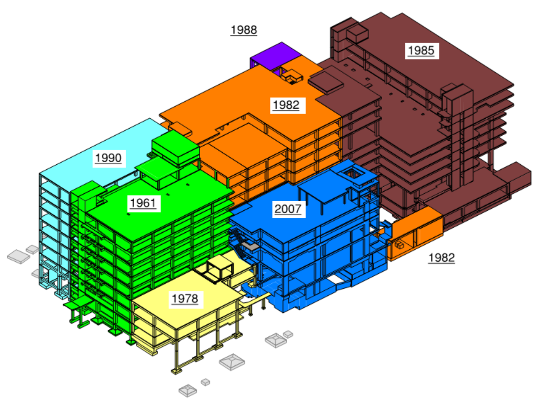
The first stage of work is the demolition of Block A to allow construction of a new 12 storey building with an additional three levels of basement. The demolition cut-line between Blocks A and B is constrained by two critical hospital operations: firstly, a means-of-escape staircase serving both blocks which is an original part of the Block A structure. Secondly, operating theatres to be retained during demolition sit within central portion of the combined Block A and B, and are also original part of the Block A structure. To allow the demolition of Block A whilst retaining both the escape stair and operating theatres, these part of the structure had to be strengthened and connected to the adjacent Block using structural stitch details.

Structural stitch details

To connect the retained area of floor slabs, each part of the retained floor in Block A is stitched to the adjacent floor in Block B by small steel components which are sized to be transportable in existing lifts. To reduce disruption to the hospital, the work areas are confined to alternate floors, where steel plates are used to stitch floor slabs accessed from above and steel angles are used to connect edge beams accessed from below. Where work was required in operational wards the affected area was hoarded off and sealed for noise, dust and infection control.

Staircase strengthening

For the staircase strengthening, a steel frame has been designed to envelope the whole staircase, and tie back at each level to existing floor beams in Block B. The connecting steelwork is tailored to suit the variation in existing concrete beam layout, size and level. All site connections are designed to be bolted to avoid hot works. Design of the steelwork was undertaken to the current Hong Kong wind code, which required a comprehensive checking of existing wind frames in Block B for the areas of Block A now supported by Block B.



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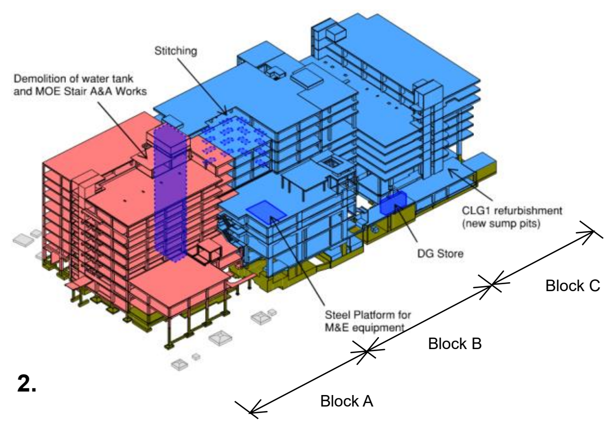


2.

3.

Client: Hong Kong Baptist Hospital
Architect: Rocco Design Architects Associates Ltd
Services: Structural, Civil, Geotechnical, Mechanical, Electrical, Public Health, Project Management

4.

1. Ages of different parts of the Blocks
2. Stitching to maintain temporary stability
3. The hospital before works started
4. Structural stitch detail

Image credits

1-2: Arup
3. Rocco Design Architects Associates Ltd
4: Arup

California College of Arts Campus Expansion

San Francisco, USA

Innovative use of mass timber in a seismic zone

In collaboration with Studio Gang, Arup played a key role in the incorporation of fully exposed timber by leveraging our material knowledge to achieve the client's design and sustainability objectives

Author Kion Nemati

To support diverse modes of learning and making, the California College of the Arts required additional space for classrooms and studios. Arup's structural solution delivers a podium supporting a series of pavilions through a novel steel–timber hybrid system. For a college dedicated to art, design thinking and making, Studio Gang's choice to express this structure was intentional: the materials and the way they receive and express natural forces were conceived as an integral part of the architectural expression, making the structure itself a visible embodiment of the design philosophy..

1.

The podium

A "Double Ground" podium structure utilizes traditional reinforced concrete construction on augercast piles. Above, the two pavilions. 3 storey and 1 storey are constructed from mass timber.

Pavillion structural system

A key design feature is the decoupling of the gravity and lateral systems. The gravity system comprises 3-ply CLT panels spanning to glulam beams and girders supported by glulam columns. The lateral system, a Mass Timber Eccentric Braced Frame (EBF), is offset from the gravity frame and wraps the pavilion perimeter. This separation simplifies the use of the novel seismic system which keeps gravity and lateral loads separate, a strategy supported by the peer reviewers.

Brace design

The dark braces visible along the perimeter are coated 12 inch square Douglas Fir glulam members, connected with steel dowels into knife plates and pinned to perimeter steel link beams. These braces are designed for the maximum expected seismic forces (overstrength) corresponding with full plastic deformation of the steel EBF links to enable the required lateral system ductility. Pin connections ensure braces carry axial loads only, simplifying design and avoiding brittle timber failure modes.

EBF design

EBFs require torsional stability at each end of the perimeter link beams to stabilize against

2.

"constrained-axis flexural torsional buckling" of the link. This is provided by concealed connections bracing against the gravity frame. Since CLT diaphragms were not codified at the time of permitting, the 4.5 inch concrete topping slab tied into the perimeter steel link beam serves as the diaphragm.

The gravity frame accommodates seismic drift with slotted seated beam and column base connections, allowing member rotation during lateral displacement.

Client: California College of the Arts
Architect: Studio Gang Architects
Services: Structural, Acoustics

1. Façade detail
2. California College of Arts Campus Expansion

Image credits

1-2: Jason O'Rear

BanBajío Headquarters

Leon, Mexico

A new headquarters for BanBajío, one of Mexico's major banks

An architecturally driven campus combining high rise and long span buildings

Author Jordan Woodson

Currently in preconstruction and designed by architect Benjamin Romano (LBR&A) the BanBajío Headquarters development includes a 170 meter, 40 storey, office tower, a geometrically complex amenities structure, a five-storey deep combined subgrade basement and an independent single story subgrade parking and entry plaza structure. The project began excavation in 2025.

Office tower

The office tower's exposed steel diagrid and exposed concrete shear walls are its defining features, both architecturally and structurally. Arup collaborated closely with LBR&A to achieve an architectural expression of the structure that aided the viewer in understanding the building's overall structural behaviour. The diagrid elements are a consistent size, with variations in steel wall thickness or concrete fill to increase element capacity as required for strength and stiffness. Diagrid nodal connections are fully exposed. Our structural detailing of these elements needed to be modelled for extensive review and approval by the architect. The slender nature of the tower allows 1 m deep floor trusses to span 15 m clear from façade to façade providing column free interiors for the office fit-out.

1.

Amenities building

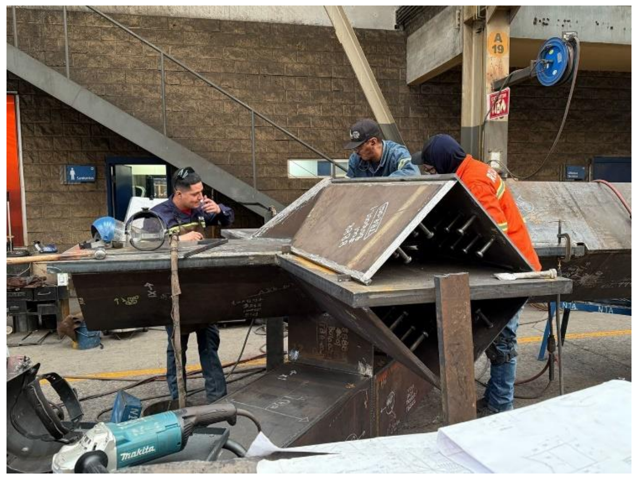
The amenities building presented its own structural challenges, in both its complex architectural form and the architects desire for 'no columns' while accommodating a wide range of programmatic spaces including a convention centre, food hall, auditorium, and conferencing. The structure is primarily exposed concrete, consisting of stacked long span deep beams and walls transferring load to the subgrade parking columns below. Steel was utilized in food hall and auditorium roofs where the long-span steel framing achieves increased openness and flexibility for each space.

The project features several other technically demanding structural design including a masted canopy with tripod columns at the front entry bridge, a pyramidal column below the food hall roof landing on the cylindrical parking ramp, feature stairs and atria, and a long-span triangular truss at the top of the tower's diagrid housing the building's water tanks and mechanical equipment.

This project highlights Arup's technical expertise and close interdisciplinary coordination, particularly in delivering expressive, architecturally integrated structural solutions that fully align with the client's vision.

2.

Client: LBR&A
Architect: LBR&A
Services: Structural



3.

1. The main tower with diagrid
2. The amenities building
3. Mock up of a diagrid node

Image credits

1-3: LBR&A

The University of Nottingham, Castle Meadow Campus, Central Building

Nottingham, UK

Replacing a landmark tensile roof to extend the life of a listed building

Giving a new lease of life to an innovative and iconic building in Nottingham.

Author Stuart McNash

The Central Building at the Castle Meadow site was designed by Arup and Hopkins Architects in 1993 as part of a large-scale office development in Nottingham for the Inland Revenue Service.

The entire development set the industry standard for sustainable design at the time due to its use of off-site manufacture, innovative natural ventilation techniques, being the first project to achieve maximum BREEAM points. All buildings on the site were awarded Grade II listed status in 2023, highlighting their importance.

Fabric roof design

The large tensegrity tensile fabric roof over the Central Building originally housed a café and gym spaces built around a sports court in the middle. The roof was formed from 5 PTFE (polytetrafluoroethylene) canopies, hung from a complex steel structure including large, curved steel trusses suspended by a cable net tied to four large steel pylons at the corners of the building, long spanning "occuli" trusses at the sides of the building and raking perimeter columns. The roof was considered to be one of the most complex structures of its type in Europe when completed.

Roof replacement

A condition survey concluded that the existing PTFE roof membrane required replacing with a new PVC alternative. Using existing archive information held at Arup, measured surveys, LiDAR scans and by working closely with specialist contractors, analysis models were quickly created to assess the impact of the proposed deconstruction and reconstruction sequence and alterations to the structure. This analysis identified elements of the structure that would become unstable as the fabric was de-tensioned as well as the high-strength tension bars and connections which would become overstressed due to the replacement membrane.

Arup worked closely with the contractors to design suitable temporary works to prop elements of the frame during construction, design remedial strengthening works to the structure and develop a suitable monitoring regime for the structure during the works.

The completed works are believed to be one of the most complex tensile fabric replacement schemes attempted to date.

Client: G F Tomlinson & The University of Nottingham
Architect: Bond Bryan Architects (new scheme), Hopkins Architects (original designers)
Services: Structural, Building services, Civil, Geotechnical, Fire, Façade, Sustainability, Specialist materials

1.

2.

1. Amenity building with original roof material removed
2. Amenity building with new roof installed

Image credits

1-2: G F Tomlinson

Titanosaur

London, UK | Tokyo, Japan

Seismic assessment of a dinosaur

Using structural analysis and design to enable a prehistoric giant to travel to East Asia

Author Chris Neighbour

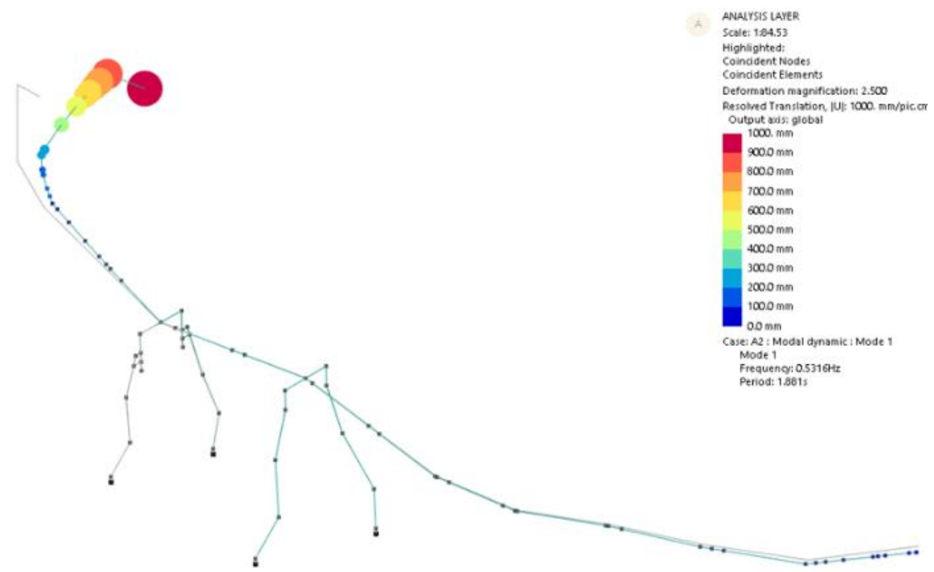
The Natural History Museum approached Arup in 2024 to evaluate the seismic resilience of their touring Titanosaur model, to account for requirements in the more seismically active countries where it will be exhibited.

The model

The 28 m long model comprising a steel skeleton clad with a glass fibre reinforced polymer/resin cast was previously developed and supplied by a specialist manufacturer in South America.

Analysis

To assess the performance of the model under seismic loading, a structural analysis model of the steel skeleton was constructed in GSA. Gravity loading was applied to represent the weight distribution of the resin casting with seismic loading based on the tour locations. Arup engineers from our Japan office visited the model on location in Tokyo to measure critical section and connection geometry. Natural periods of vibration were measured using smartphones attached to the model. One particular focus of the review was the spigot connection which joins the neck and tail; this connection is unusual in form as it relies on the transfer of force via bearing between overlapping hollow sections.



1.

Restraints

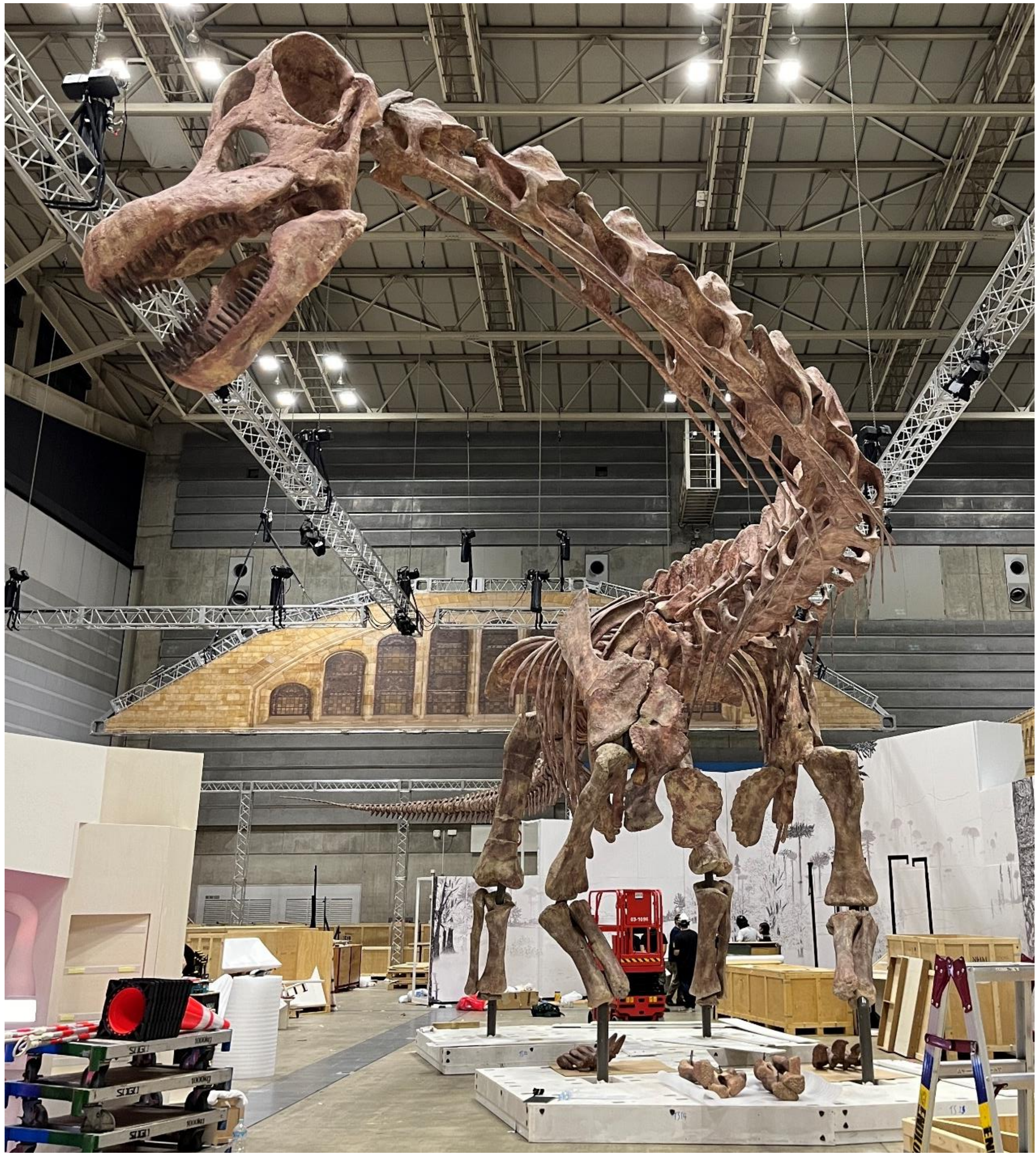
Our studies led to the development of restraint details which incorporated load cells to measure the force carried at each support position. The design of the restraints incorporates built-in adjustability to cater for differing structural restraint positions in each exhibition space the Titanosaur will visit.

Client: Natural History Museum
Services: Structural, Seismic

1. Finite element analysis model
2. Titanosaur model

Image credits

1: Arup
2: © The Trustees of the Natural History Museum, London



2.

Guinness Storehouse | Oriel Window Repair

Dublin, Ireland

Investigation and restoration of a stone façade to a historic building

Using curiosity and technical ability to preserve a heritage structure that is the home to Ireland's world famous brewery.

Author Conor McGrath

While modest in scale compared to many of Arup's structural projects, the restoration of an oriel window at the Guinness Storehouse in Dublin exemplifies the enduring need for detail focused, highly skilled structural engineering, particularly in the context of historic preservation and refurbishment of existing buildings.

Oriel window deterioration

The Guinness Storehouse, as for numerous early 20th-century buildings, is affected by what is commonly known as Regent Street Disease: the corrosion and expansion of embedded steel framing behind masonry façades. At the oriel windows along the eastern elevation of the storehouse, this had led to severe cracking and displacement of granite lintels, posing a significant safety hazard directly above the building's main exit.

Adding to the complexity, the cantilevered steel supports behind the windows had undergone substantial structural modifications in a previous refurbishment. This raised an important diagnostic question: were the cracks a result of corrosion in the steelwork, or was there a more serious issue involving structural deformation due to the past interventions?

To answer this, we dismantled the first of the affected windows, stone-by-stone, and by measuring the response of the structural framing behind to this unloading, we could determine that water ingress was the root cause of the issue.

Restoration

The adopted solution involved replacing the corroded steel with new stainless-steel elements, precisely fabricated to match the original detailing. Importantly, the lessons learned from this intensive investigative repair on the first window enabled us to develop a less intrusive method for the remaining windows, allowing the steel replacement to be completed without dismantling the stonework, significantly improving efficiency and cost-effectiveness.

This project is a testament to the importance of craft and detailing in structural engineering. While digital tools allow us to undertake increasingly ambitious projects, there will always be a need to understand the intricacies of how a building is constructed.

Client: Guinness Storehouse Ltd
Architect: Howley Hayes Cooney
Services: Structural

Image credits

1-2: Arup
3: Excerpt from original building drawings

1. Cracking to Oriel Window
2. Internal remediation works
3. Original window detail

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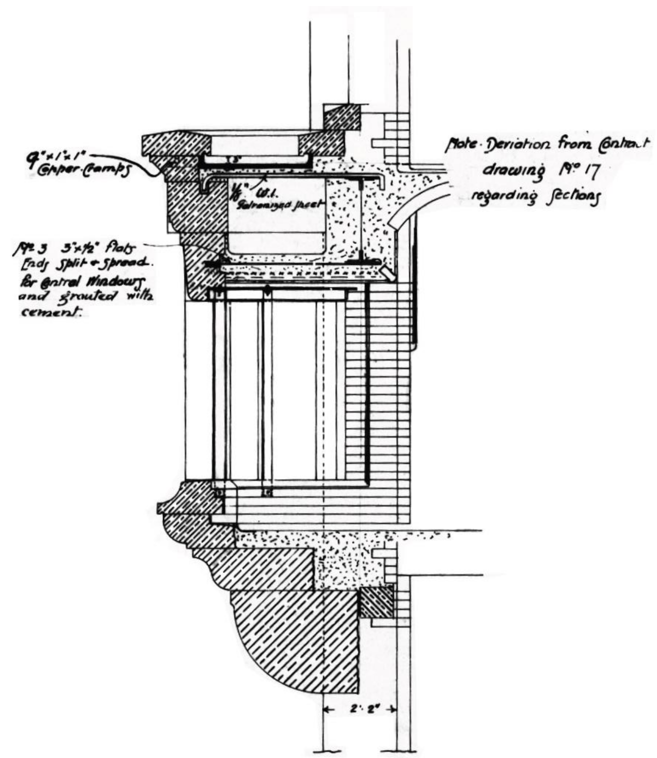


3.

The BRITA Campus

Taunusstein, Germany

Simplified complexity in timber, steel, concrete

Meeting the needs of a growing company with a highly sustainable design that fits into the surrounding landscape the new BRITA campus provides a home for the internationally renowned drinking water solutions company.

Author Susanne Buchner

The BRITA Campus is a series of interconnected buildings located in Taunusstein, northwest of Frankfurt, Germany. Arup provided a multidisciplinary team across all design stages, developing our competition winning design comprising of an in situ concrete basement and ground floor, with a timber-concrete composite superstructure with architecturally expressed steel balconies and exterior circulation space. The buildings are stabilised by reinforced concrete stability cores

Timber Concrete Composite

Ribbed timber concrete composite slabs (TCC-slabs) use glulam downstand beams to span up to 8.1 m between a central in situ concrete spine beam and perimeter glulam façade beams. The TTC-glulam-beams sit on top of the central spine beam, allowing a route to distribute services between the ribs above the spine beam.

1.

The timber column to timber beam connections at the perimeter are achieved with Sherpa connectors, whilst the timber to concrete connections use bespoke details to accommodate the differing tolerances between materials. An in-situ concrete ring beam was provided at the perimeter of the slab for robustness and to mobilise diaphragm action in the floorplates.

Steel Façade

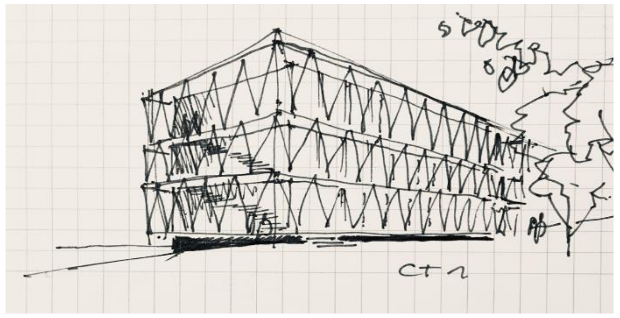
The façade features external steel balconies and circulation space. The supporting steel frame is connected via a thermal break to a concrete ring beam. The outer face, comprised of inclined steel members, was built from modules, speeding up on site construction whilst achieving the original architectural vision.

2.

Simplifying complexity

The complexity of bringing together three different structural materials to achieve an elegant architectural vision was achieved through collaborative working. In the midst of Covid restrictions when only two people were allowed to meet - the structural engineer and architect would meet in rooms with open windows to develop the design using paper, pens and sketching, resolving tricky details and achieving Total Design.

Client: BRITA GmbH
Architect: Arup
Services: Architecture, Structural, Mechanical, Electrical, Public Health, Fire Safety, Building Physics, Acoustics, Project Management; Lighting Design, Energy Concept Design, Landscape Architecture



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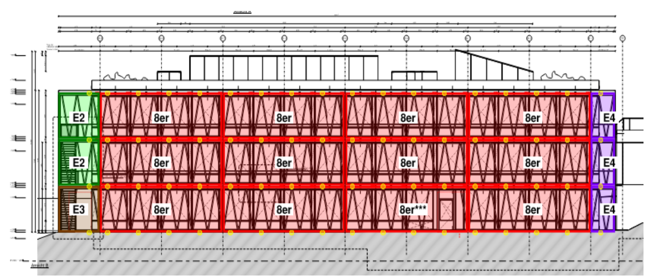

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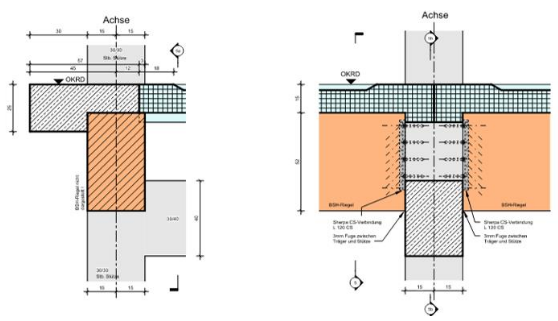

5.

1. Timber downstand to concrete spine beam detail
2. The BRITA Campus
3. Architectural sketch
4. Modularisation of the steel façade
5. Ring beam and timber to concrete connection details

Image credits

1-2: Arup
3: Arup / Tim Ahlswede
4-5: Arup

Galkangu – Bendigo GovHub

Bendigo, Victoria, Australia

A state-of-the-art workplace and community hub, in timber

Accommodating 1,000 employees and reflecting First Nations culture, the Galkangu-Bendigo GovHub welcomes the community, exemplifying sustainable design.

Author Mark Ayers

Arup's client, Development Victoria, had a vision to create an exemplar building that would provide a single point of access for government services, revitalise Bendigo's city centre, and deliver economic benefits to the community. The result was Galkangu – Bendigo GovHub, a state-of-the-art workplace and community hub located in regional Victoria, Australia.

Our multidisciplinary team worked collaboratively with Lyons Architects to develop a design solution that was a first for Victoria, with exposed timber soffits and frames. our expertise in structural and fire engineering ensured the timber structure is compliant and safe in a design first for the State of Victoria.

Mass timber

Galkangu became Australia's largest mass-timber building constructed entirely from Australian-sourced glue laminated timber (glulam) and cross-laminated timber (CLT) The innovative use of renewable timber material reduced embodied carbon by 20% compared to traditional construction methods.

The exposed timber structure is a cornerstone of the project's sustainability strategy, and was achieved using 2,733 m³ of cross-laminated timber (CLT) and 1,000 m³ of glulam components. Timber elements were prefabricated offsite and installed in only 70 days. This efficient construction method not only minimised emissions but also reduced disruption on-site, showcasing the benefits of precision engineering and sustainable practices. The project also upskilled the local workforce and instilled confidence in timber construction, significantly expanding the potential, breadth and capability of Australia's timber industry.

Sustainable design

The building's exceptional sustainability performance earned it a 6-star Green Star rating, setting a new benchmark for sustainable timber building design in Australia. Galkangu – Bendigo GovHub serves as a valuable community asset and workplace that enhances wellbeing while minimising its environmental footprint.

Client: Development Victoria
Architect: Lyons
Services: Structural, Fire, Acoustics, Building Services, Façade, Civil, Vertical transportation design, Lighting design, ICT infrastructure design

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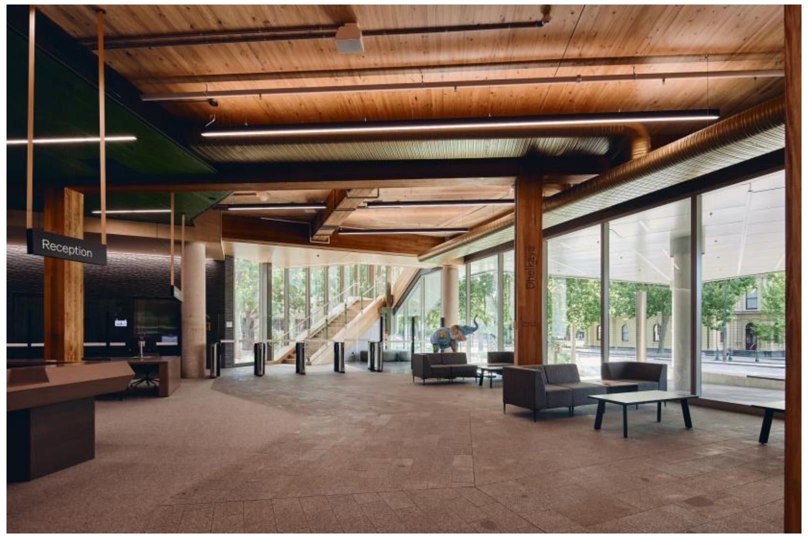

3.

1. Galkangu-Bendigo GovHub under construction
2. Completed façade
3. Interior

Image credits

1: Icon-Fairbrother JV
2-3: Peter Bennetts

Powerhouse Parramatta

Parramatta, New South Wales, Australia

Steel lattice exoskeleton for a science and technology museum

Powerhouse Parramatta is one of the most architecturally and structurally complex projects currently underway in Australia. It stands as an exemplar of design excellence. As the first major cultural institution in New South Wales to be built in Western Sydney, it will also become the leading science and technology museum in the Southern Hemisphere

Author Kengo Takamatsu

Funded by the New South Wales (NSW) Government, Powerhouse Parramatta combines a striking architectural design with cutting edge structural engineering.

The exoskeleton

A defining feature of the architecture is the structural exoskeleton. This lattice structure serves not only as a striking visual frame but also supports expansive column-free spaces across multiple levels and is engineered to withstand a 1 in 2,500 year seismic event. These seemingly conflicting goals, openness and robustness, have been resolved through a design that is elegant, lightweight, and refined, yet structurally strong and resilient. The exoskeleton's lattice patterns directly express the building's structural logic, combining large-scale bracing arrangements such as V, X, and N forms with finer elements such as chords and diagonals functioning as laced columns.

Exhibition spaces

A central idea in the project brief was to create a museum where the structure itself is on display, celebrating engineering as part of the visitor experience. The largest of the seven exhibition spaces, Exhibition Space 1, is a remarkable column free volume space equivalent to 15 Olympic sized swimming pools. The full northern elevation of this space can open directly to the public domain overlooking the Parramatta River. Via a supersized mechanical hoisting door.

In partnership with Infrastructure NSW and Lendlease, Arup have provided full multi-disciplinary design services for the project. More than 20 disciplines and over 240 Arup staff have contributed to the project.

1.

Client: Lendlease
Architect: Moreau Kusunoki (Lead design) and Genton (Local architect)
Services: Structural, Civil, Flood, Fire, Façade, Mechanical, Hydraulic, Electrical, Vertical transportation, ICT, Security, Blast, Acoustics, AV, Venue Planning, ESD, Façade Access, Pedestrian flow, Waste Management, Wind, and Traffic.

2.

1. Powerhouse Parramatta
2. Detail of the lattice exoskeleton

Image credits

1-2: Arup

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