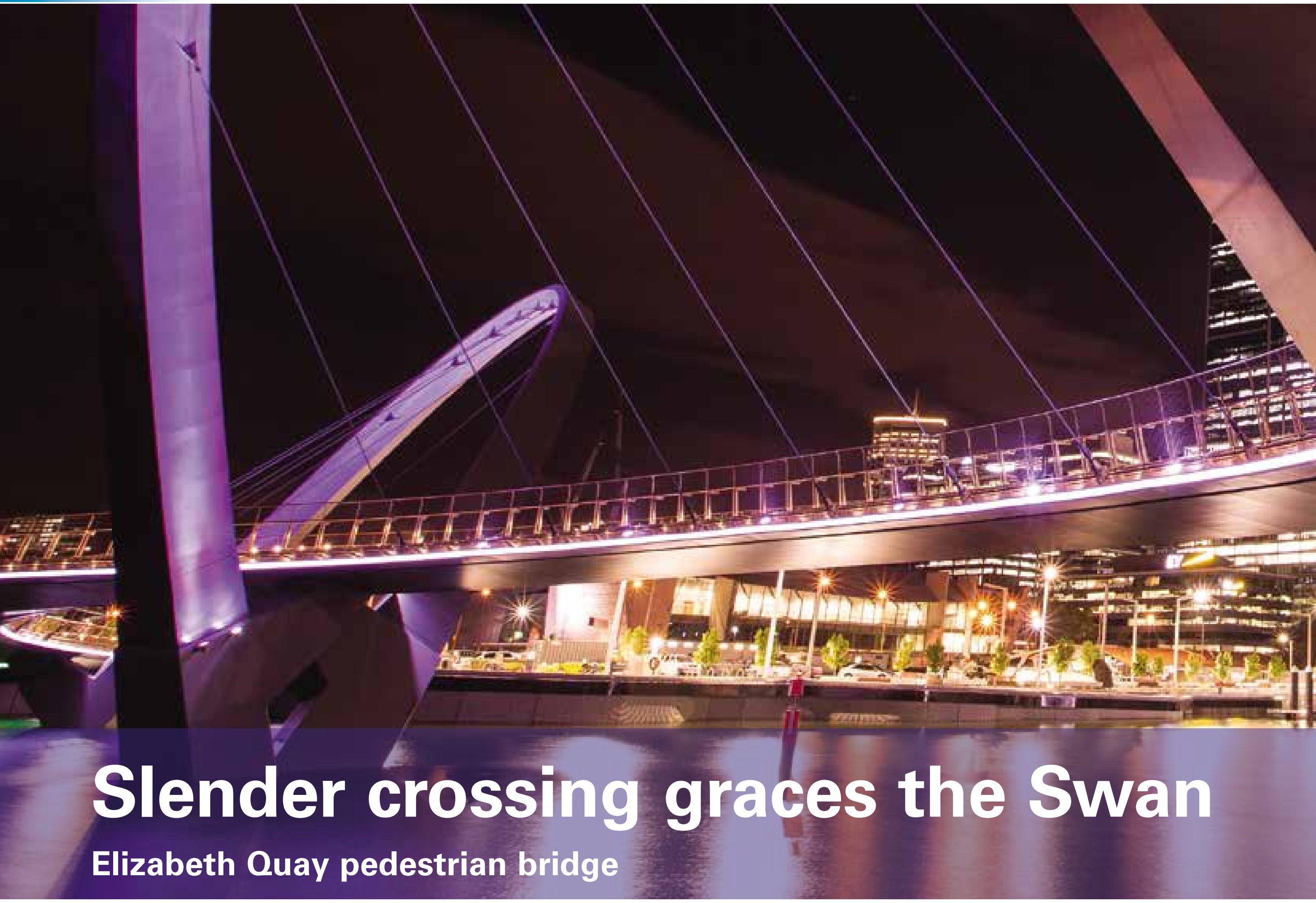


Slender crossing graces the Swan

Elizabeth Quay pedestrian bridge

A steel-intensive approach created a striking new 110 metre bridge connecting the west promenade with a new island along the Swan River in central Perth slender enough for ferries to pass underneath whilst providing a relatively level crossing for pedestrians and cyclists in a constrained location.

The project was integral to the Western Australian Government's Elizabeth Quay development to revitalise central Perth comprising a 2.7ha inlet and 1.5ha promenade as a welcoming recreational precinct.

The 22-metre high cable-stayed bridge spans the inlet allowing for continuous movement around the Quay with the use of steelwork as a primary element affording the design flexibility to realise an eye-catching structure befitting the high profile location.

Project Manager and Associate with the project's principal engineers Arup, **Stewart Buxton** said that without the slenderness achieved through the use of structural steelwork, the bridge could not have been constructed in its current form to achieve the required slender design.

"With a deeper structural depth, the 'S' curves in the deck would have been steeper, diminishing the experience for bridge users having to walk further with the more exaggerated curves adding to torsional and flexural internal forces," he said.

"Steel was the material that best suited the slenderness requirements, providing the required strength and stiffness for its weight."

He said that the sinuous 'S'-shaped plan geometry of the bridge was required to achieve the minimum required length to clear the navigational channel and compliance with universal access gradient requirements.

"Adopting structural steel for the deck construction allowed the design team to significantly reduce the structural depth to minimise the deck length which, in turn reduced the offset between the centreline of the deck at the mid-span and the line passing through the centre of the piers that presented the greatest challenge for the structural steelwork," Mr Buxton said

"The offset between the applied loads of the deck and pedestrians and the centreline of the pier supports induced a significant torsion in the deck section which was exacerbated by the cable supports on the inner face.

"The offset also induced a misalignment of the lines of force in the cables with those of the arches. As such, the arches are subjected to axial compression from the structural strength of the arches combined with an inward bending due to the arch cables.

"This load combination was accommodated through the selection of the arch geometry and led directly to the, approximately, rectangular section that has been adopted."

He said therefore that the required construction tolerances were necessarily onerous and could only be achieved by collaboration and sharing of the resultant 3D structural models for the major structural elements.

Image: Michael Haluwana - Aeroture

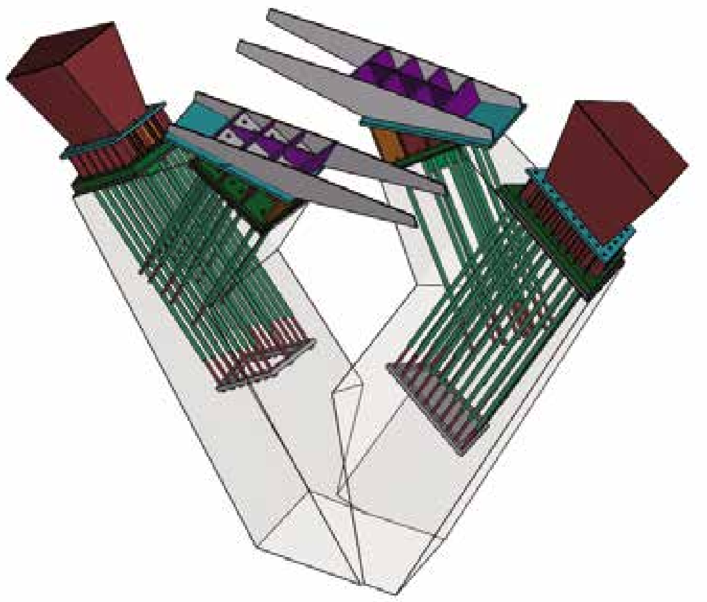
A seamless digital workflow resulted in complete coordination between the architects, engineers and fabricators via integrated design using parametric modelling tools to determine sculptural forms for arches' structural performance as developed in concept. The architect used Rhino and Grasshopper to converge quickly generating analysis models to assess and optimise the structural performance of developing bridge form.

1D finite element models were generated parametrically directly from Grasshopper to GSA using Arup's very own Salamander plug-in. The engineers extended the architect's initial Grasshopper scripts to generate all the internal steelwork necessary to describe the structure. This geometry was then referenced into Revit to populate the BIM model and produce the structural documentation. A fully detailed Strand7 analysis model consisting of 2D shell elements was also translated from the Grasshopper surface geometry which was used for final structural verification.

This integrated approach meant that architectural and structural refinements could occur in parallel without losing element-to-element connectivity or resulting in the separation of modelling parts which avoided timely rework at each design update.

The flexibility in fabrication with steel allowed the main load carrying arches to be precisely shaped and aligned to match the imposed loads from the cables supporting the main deck structure. Off-site fabrication led to very fast assembly, improved quality and clearer work zones onsite that improved safety with various trades working onsite simultaneously.

"A seamless digital workflow resulted in complete coordination between the architects, engineers and fabricators..."



It was determined that arch and deck sections be fabricated with 'coffin' box construction after extensive consultation was undertaken with Arup's bridge construction and fabrication experts in London and Brisbane to enhance torsional stiffness, a primary requirement for such an aggressively cantilevered structure, whilst minimising structural mass.

Mr Buxton said the 'coffin' construction involved the traditional fabrication of the base plates, side plates and their associated stiffeners through clear access to all sides.

"The top plate was fabricated in two halves separately in a similar manner. The central stiffener was designed as a full depth plate that protruded through the top plate, and the top plate was detailed to over-hang the side plates," he said.

"These details permitted the closing welds to seal the box at the central spine and the side plates and to construct the required section."

He said careful welding was required to avoid locking-in thermal stresses into the welded plates. The internal, longitudinal stiffeners were re-designed to continue between the transverse stiffeners. The transverse stiffeners also required coordination to avoid clashing between the stiffeners for the top and bottom plates; the stiffeners were offset longitudinally to achieve this.

At the cable connections, the transverse stiffeners were notched to enable the passing through of the longitudinal stiffeners.

Assembly was carefully considered to ensure the cable outrigger plate could extend through the top flange to transfer adequately the cable force into the box and a closing weld could be made from the top. The through-thickness properties of 'Z'-grade plate required careful consideration and incorporation with this construction sequence. Spreader plates were detailed at stiffener ends to accommodate local stress concentrations.

By identifying and documenting the welding sequence, particularly the design of the closing welds, the required splice locations and coordination of the various stiffeners in the congested space, the steel detailing achieved the required arrangements to realise the slender design.

He said that the high level of attention given to coordination and tolerances throughout fabrication directly improved the constructability of the bridge with the value of the planning and constructability assessments demonstrated by the arches being fixed to the piers within two millimetres of the documented position.

ASI fabricator Civmec supplied the two arches for the bridge including four 'arch to pier stub connections' undertaking shop detailing, fabrication, trial assembly, surface treatment, weld and painting inspections and testing, and delivery to site. As each arch weighs approximately 82 tonnes, delivery of arch modules to site required implementing a traffic management plan liaising with all authorities to obtain permits and requisite on-road escorts.

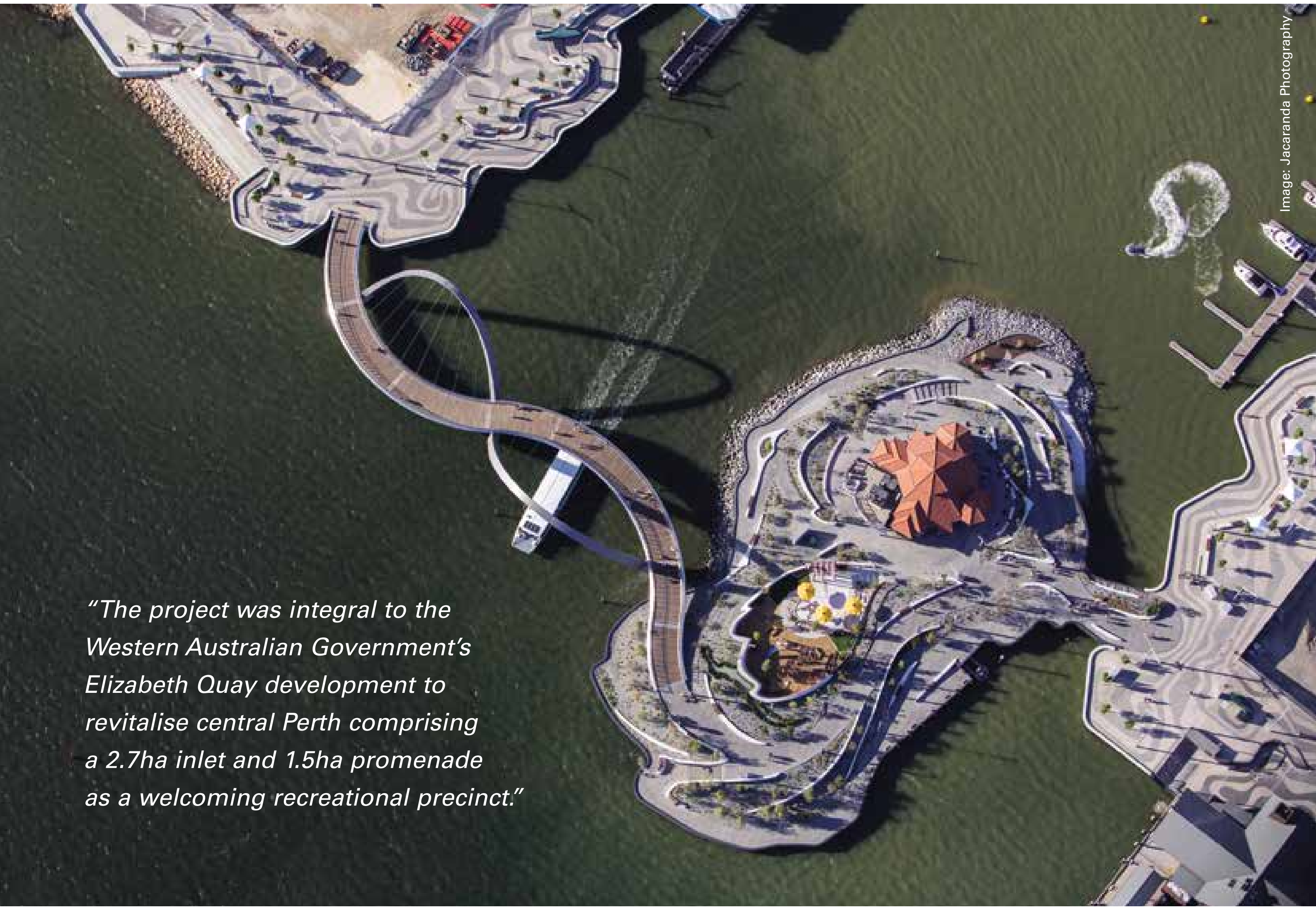


Image: Jacaranda Photography

The curved geometry of the bridge arches required Civmec to adopt complex steel fabrication methods which involved implementing a 3D model to roll the steel plates to the required curvature.

Deputy Operations Manager at Civmec's Henderson facility, **David Power** said that the arches were required to be twisted and curved so the traditional fabrication method of rolling the steel components and then welding these together could not be utilised.

Civmec instead designed a new methodology with each of the arches fabricated in three separate pieces to achieve a total length of 84 metres from end to end and 34-metre height from the point of radius to AS 5100 for box girder fabrication.

"Due to the curved and twisted shapes of the arches, standard jigs could not be used so customised adjustable jigs to shape the plate had to be developed to successfully hold the pieces in place for welding," he said.

"Additionally there was uncertainty as to whether the jigs would be able to hold the pieces in place effectively without movement to achieve the extremely tight tolerances so we developed a method to attach the customised jigs exactly as per the arch design to steel plates, welded together and onto the workshop floor to minimise the chance of movement during fabrication.

"The shop detailing drawings were also highly complex due to the requirement of different weld preps on every joint, twist lines to be provided for every plate section and internal stiffeners to be incorporated."

Mr Power said the design required the fabrication to achieve an extremely high quality finish.

"Our welding of the joints for the steel components was undertaken using a full pen welding method which left excess weld metal on the surface that was carefully ground flush by hand," he said.

"Welds were subjected to various testing conditions such as corrosive solutions, impact testing, physical impact, tensile testing and crack tip opening displacement testing. The welds were assessed post testing for various signs of failed weld integrity including: level of nitrates, weight loss, signs of openings or cracks. The weld procedures were modified and retested based on the results of the tests."

PROJECT TEAM

Client: Metropolitan Redevelopment Authority

Main Contractor: Decmil Australia, Structural Systems and Hawkins Civil Joint Venture (DASSH)

Structural Engineering: Arup

ASI Steel Fabricator: Civmec (arches)

Decking Structural Steelwork: Phillips Engineering

ASI Steel Distributor: BlueScope Distribution

ASI Steel Manufacturer: BlueScope

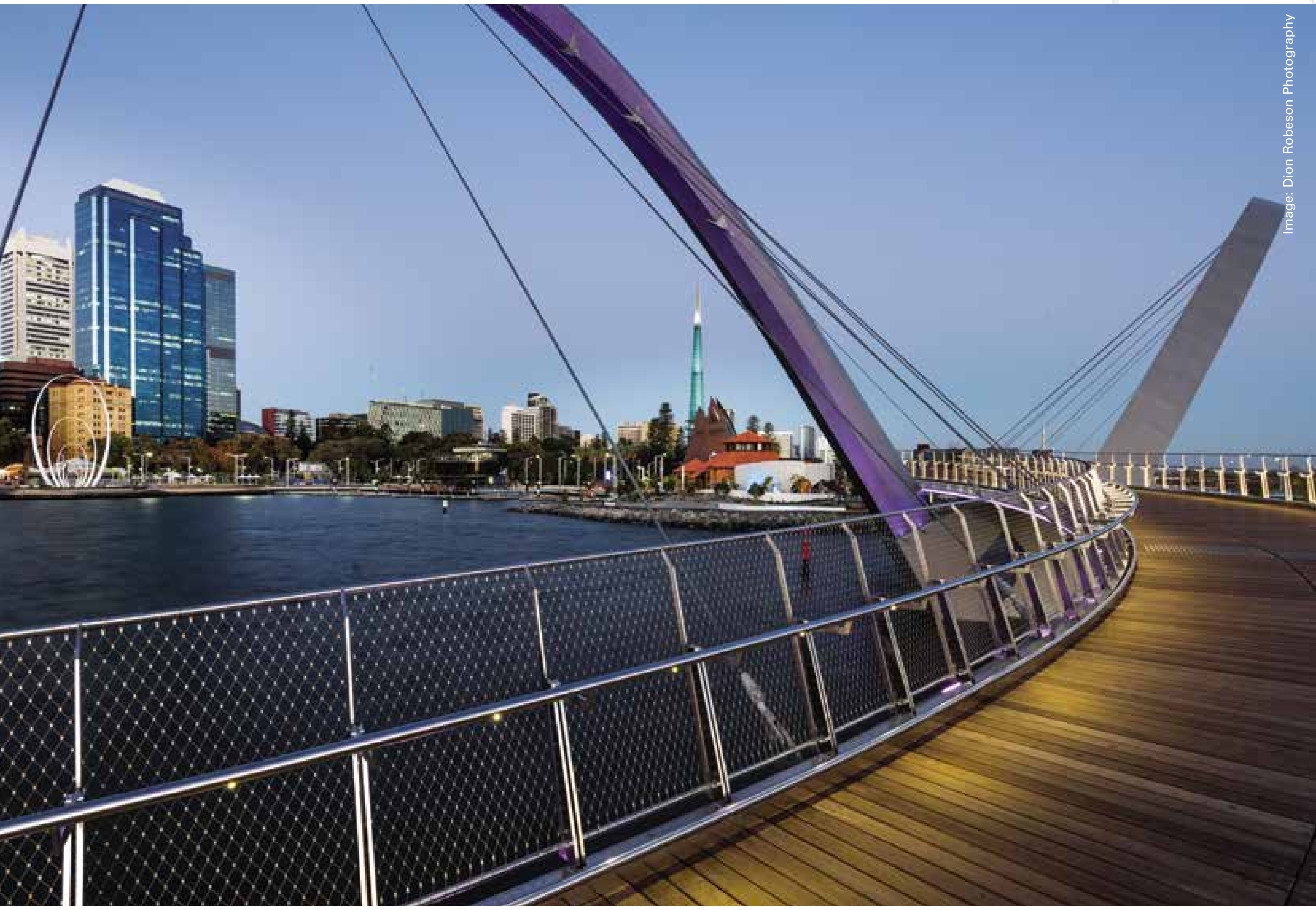


Image: Dion Robeson Photography