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Foster & Partners’ Khan Shatyr Entertainment Centre

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The Khan Shatyr Centre during construction in Astana, Kazakhstan

With temperatures soaring to 40°C in summer and sliding down to minus 35-40°C in winter, Astana, Kazakhstan’s capital, has an extreme climate.

This unforgiving environment calls for some imaginative solutions for its buildings and never more so than in its latest “giant tent”, the Khan Shatyr entertainment centre by architect Foster & Partners and structural engineer Buro Happold.

Tipped to be the capital’s tallest structure at 150m, its form was chosen for both environmental and structural criteria and to maximise accommodation. The building will have 100,000sq m of interior space comprising 40,000sq m retail, 18,500sq m leisure and sports facilities, 21,000sq m car parking and 20,500sq m back- of-house services — all enclosed beneath a vast cable net structure and 19,000sq m of ETFE foil cushions.

The project is complicated by the difficulty of accessing the capital and therefore of transporting prefabricated materials, and also by the small window of opportunity when work can be carried out on site. Building work is near to impossible during winter, so most site work is restricted to the summer months.

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Credit: Foster & Partners and Buro Happold
Perspective rendered view (with cable net removed).

As Foster partner Filo Russo quips: “It would be easier to build in the South Pole, where the temperatures are more consistent.”

Foster’s appointment in February 2006 to design the entertainment centre wasn’t unexpected. The president of Kazakhstan, Nursultan Nazarbayev, was already pleased with the progress of the now completed Pyramid of Peace & Accord, the 62m-tall pyramid also designed by Foster & Partners that sits at the eastern end of the town’s main axis. So for another iconic building to be sited in the same key axis in Astana, Foster’s was an obvious choice.

Incredibly, the original brief was for a much taller building — 200m rather than 150m high. In plan, it is elliptical rather than an exact circle, with a 20m-tall in-situ concrete base which will house most of the retail. Concrete was specified for its thermal mass and good insulation properties.

Attached to the base will be a huge steel tripod mast rising 100m from the ground to its architectural “hat” at the top, to which cables will be connected and fixed to the building’s perimeter, creating a huge cable net structure. This was considered to be the most efficient and economical way to cover such a large area since it requires only one central column, which is then enclosed by a giant roof.

Clamped to the net using aluminium extrusions will be the ETFE cushions inflated with air. These were chosen for their transparency and as they can accommodate a high thermal range. Additionally, the material will wear extremely well in the tough weather conditions. Ben Morris, founder and director of consultant Vector Foiltec, claims it has a design life “in excess of 100 years”.

Work began on site in 2006, with the driving into the ground of the huge bored piles that will take the tripod’s bases. The steel sections for the tripod have been prefabricated in Turkey and transported to the site, where it took four cranes to erect the 2,000-tonne structure during two weeks at the end of last year. The work was timed to avoid the worst of the high winds that often occur in winter. The cable net is now being attached to the top ring.

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Given the scale of this structure and the amount of building work still to do, the team faces a tough challenge to complete the project for the opening deadline of this summer.

Khan Shatyr's tripod mast

The final roof design features a cable net supported by a steel tripod mast. The tripod comprises a 60m-tall vertical back leg and two 70m-long splayed front legs.

Each leg is constructed from tubular steel trusses that are triangular in section and formed from sections of between 25mm and 60mm thick.

The three-legged mast provides a stable ring in the air for the cables to be fixed to on site. It was considered that a single mast would have been too difficult to handle on site at this enormous scale.

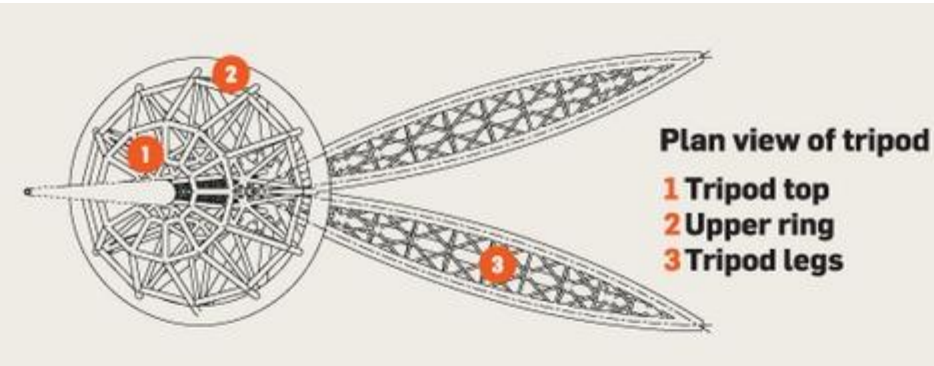
Where the three legs meet, there is a central 7m-high "hub" constructed from 150mm-thick plate.

A 20m-diameter top ring is then fixed. This is made from a circular section 1.6m in diameter and 40mm thick; its function is to gather the cables together.

"The ring is designed to rock a little," says Mike Cook, Buro Happold's director of structural engineering.

"It's important for cable net structures to be able to move a bit as this allows the fabric to change shape and is more efficient".

On top of this sits an architectural "hat", an inverted cone constructed from insulated aluminium panels. This provides a ventilation zone at the top of the tent and a light feature at night.



Plan view of tripod

How the roof's ETFE cushions work

Describing the ETFE element of the entertainment centre, Ben Morris, founder and director of Vector Foiltec, cites Buckminster Fuller's prophetic vision of enclosing Manhattan under an energy-saving "bubble".

"We are beginning to see the rise of the mega-building, climatic enclosures enveloping small towns — mainly because they are being built in unpleasant climates," he says.

By cladding the the project's cable net structure with 19,000sq m of ETFE foil cushions, Morris says a comfortable microclimate will be created within.

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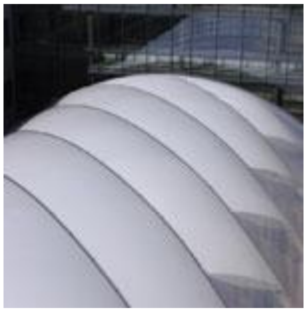


Credit: Foster & Partners and Buro Happold
ETFE provides flexibility.

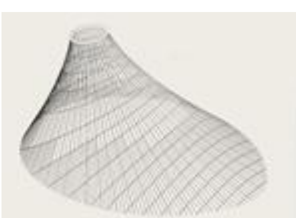
The foil cushions will comprise three layers assembled together, with the middle layer inflated. Given Astana's extreme climate, it is important that the structure provides high insulation, and by inflating the cushions with air the material can accommodate a high thermal range. During winter, the landscaped areas within the centre will be kept to 15°C, rising to 30°C in summer. Fritting on the outermost foil layer will also provide solar shading. Each cushion will be about 3.5m wide and up to 30m long (the length depends on the spacing of the circumferential cables), and they will taper as the radial cables converge towards the cone.

The flexibility of the ETFE material also makes it well suited to deal with the cable net's range of movement. As the structure deflects, the cables move closer together and the cushions change shape — from an eye shape to an almost cylindrical shape. This movement prohibited the use of continuous cushion edge extrusions parallel to the hoop cables which would have created rigid collars. Instead, alternating circumferential cushion joints were specified, allowing the entire envelope to move like an accordion.

The prefabricated foil cushions have been made in China. They have been numbered and labelled to be transported to the site by train. The ETFE cushion panels are connected to the cables using a system of aluminium clamping plates. These are able to tolerate the movements of the cables under wind and snow loads. Morris anticipates that the installation of the foil cushions onto the cable net structure, which can only be done during summer and autumn, will take between three and four months.

The roof's cable net structure

The cable net comprises 192 radial cables and 16 circumferential cables. To improve handling, cable diameters were kept below 76mm, while to provide strength, cables are generally installed in pairs, which also facilitates the clamping between radial and circumferential cables.



The cable net is highly pre-stressed.

The radial cables run between the top ring and the concrete plinth around the perimeter. These carry the roof weight as well as the weight of any snow, which is considerable in Kazakhstan winters. The circumferential cables are used to stabilise the radial ones by pulling against them, and they also restrain the roof under wind loads.

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The cable net is highly pre-stressed during erection to ensure stability under all load conditions.

Project team

Clients Sembol Construction, Architect Foster & Partners
Local architect Linea Tusavul & Gultekin Architects
Structural & services engineer Buro Happold
Local structural engineer Ozun Proje & Arce
Local services engineer Vemeks Engineering
ETFE consultant Vector Foiltec
Main contractor Sembol Construction
Cables Montage Services
Steelwork Samko Engineering Contracting
Lighting consultant Claude Engle
Fire consultant Istanbul Technical University

How Tensile Structures Work

By Project Engineer Mike Sefton:

Buro Happold has been involved in the design of several custom-built fabric structures including the Millennium Dome (now the O2 Arena) in Greenwich — the largest structure of its kind in the world. The Dome consists of a huge cable net measuring 320m in diameter and clad in 80,000sq m of tensioned PTFE coated glass-fibre fabric.

Tensile structures began to be more widely used in the 1960s. Supported by some form of compression or bending elements such as masts, the structures normally have a tensile membrane made of doubly curved fabrics with the larger schemes requiring cable netting for extra support. Their design makes them ideal for use in covering large areas such as exhibition spaces and sports stadiums as they are lightweight and economical.

Having designed the Dome, you might think that we would use the same design strategies on Kazakhstan’s Khan Shatyr entertainment centre, but the two structures actually work in quite different ways so aren’t directly comparable.

The centre’s design came from the idea of creating one vast roof which would house many venues and which would have a real feeling of space. So often in similar schemes there is a sense of individual, boxed-in buildings but by having one large “tent” accommodate them all, we could create a clear, open environment.

A major challenge with the project was to keep the temperature inside the space even in a climate with extreme weather conditions. We need visitors to be able to move from venue to venue inside the structure without experiencing dramatic changes in temperature.

Another challenge was the asymmetry of the design.

To work to a perfect circle creates a full radial symmetry but when you’re dealing with a cone shape that is also on a lean, you only have one line of symmetry — down the central line. This means every cable anchor and cable has a different geometry as they are all at different angles.

Tensile structures are all about anticlastic surfaces — surfaces that have opposing curvatures. Flat tensile designs just don’t work, so if you are considering using a tensile structure, you have to accept that it must have curves.

Mike Sefton is Buro Happold’s project leader of the Khan Shatyr entertainment centre.