A magic cube

THE BEIJING NATIONAL Aquatics Centre, also known as the ‘Water Cube’, will be one of the most dramatic and exciting venues to feature sporting feats for the Beijing Olympics in 2008. Enclosed within the blue bubble walls are the pools for the Olympic swimming and diving competitions, along with seating and facilities for 17 000 spectators.

It has five pools, including one with a wave machine and rides that are six times the size of an Olympic pool. There is also an organically shaped restaurant area carved out of the bubble structure.

Designed specifically for the 2008 Olympics in Beijing, after the event it will continue as one of Beijing’s premier recreation centres.

The US $100 million dollar project sits next to the glowing bird’s nest of the spectacular main stadium designed by Herzog & de Meuron – the two opposing shapes sitting together in yin yang harmony.

THEORY BEHIND THE WATER CUBE

The structure was inspired by cells and soap bubbles. The skin of the swimming centre, which covers both the inside and outside of the structure, is clad with over 100 000 m² of ETFE foil cushions – making it the largest ETFE-clad structure in the world.

ETFE (ethyl tetra fluoro ethylene – a strain of fluoro polymer) is a tough recyclable material with a durability of more than 20 years. It weighs just 1% of an equivalent-sized glass panel. This plastic material is strong, lets in more UV light than glass, and thoroughly cleans itself with every rain shower. It is also a better insulator than glass and is much more resistant to the weathering effects of sunlight.

The design of the structure is based on a common natural pattern, the most effective sub-division of three-dimensional space – the fundamental arrangement of organic cells and the natural formation of soap bubbles. Arup based the structural design on Weaire and Phelan’s (Irish physics professors at Dublin’s Trinity College) proposed solution to the problem of ‘What shape would soap bubbles in a continuous array of soap bubbles be’?

This problem was both initially posed and tentatively answered by Lord Kelvin at the end of the 19th century, but it would be one hundred years before the Irish professors proposed a better one.

Arup structural engineers realised that a structure based on this unique geometry would be highly repetitive and buildable whilst appearing very organic and random. Indeed, such space filling patterns are regularly observed in biological cells and mineral crystals and they are probably the most common structure in nature.

Though seemingly fragile, in fact the structure is very robust and the ductile space frame that is generated from this geometry is ideally suited to the seismic conditions found in Beijing.

THE STRUCTURE

The Water Cube is essentially a structure made from an organic network of steel tubular members and clad with translucent ETFE pillows. The huge complex measures 177 x 177 x 31 m.

The cube is composed of a series of steel tubes welded to round steel nodes, which vary according to the loads placed upon them. There is therefore a huge variety in sizes, with around 22 000 steel members and 12 000 nodes in total. If all the steel members were lined up in a row the line would travel for more than 90 km!

The two internal compartments and the roof structure are designed around a steel space frame never previously used for an architectural or engineering construction.

Four thousand bubbles make up the Water Cube, some as large as 7.5 m wide. The roof comprises seven bubbles and the walls 16 bubbles, which are repeated throughout. The key to the randomness of the façade is that the repeating cells are made up of two different size cells, which give this effect when cut by the building surface planes.

The square shape of the complex reflects the Chinese philosophies of the square representing Earth, and circles representing the heaven. The resulting structure is a very simple regular building form, but with very complex geometry in the façade which creates a transfixing and beautiful effect.

GIANT GREENHOUSE

Beijing has an extreme climate. It can swing from –13 °C in winter to around 36 °C in summer.

The Water Cube is designed to act as a greenhouse. This allows high levels of natural daylight into the building and, as swimming pools are predominantly heating driven, allows the scheme to harness the power of the sun to passively heat the building and pool water. It is estimated that this sustainable concept has the power to reduce the energy consumption of the leisure pool hall by 30%.

Swimming centres require a lot of heating, but by cladding the building in high-tech ETFE cushions, it is a very efficient greenhouse. Twenty per cent of the solar energy falling on the building is trapped within the building and is used to heat the pools and the interior area. This is equivalent to covering the entire roof in photovoltaic panels.

By cladding the building in ETFE cushions, the centre will be well lit during the day, with appropriate levels of internal daylight, visual connection and visual comfort. Up to 55% savings on lighting energy
use can be achieved in the leisure pool hall, with smaller savings expected in other areas.

**THERMAL MASS HEAT STORAGE**

The use of thermal mass heat storage ensures that heating by the sun during the day is offset by overnight cooling. The thermal mass of the swimming pool water and heavy weight surfaces surrounding the pool effectively store the excess heat during the day and re-emits this heat at night, minimising the variation in load.

**SHADING DESIGN**

Variation shading of the facades ensures that fabric heat loads are minimised in summer but maximised in winter when the solar heat gain is most beneficial. This is achieved by patterning the various layers of the façade with translucent painted ‘frit’ and by ventilating the heat out of the cavity in summer and containing it in winter. The location and pattern of these translucent elements have been developed to respond to the daylight and thermal requirements of the various building uses adjacent to the façade, from leisure pools to sports pool, even at one stage an ice rink.

To reduce the energy consumption of the centre, the design has incorporated many energy recovery systems, including:

- Heat recovery from warm exhaust air for warming up the cold outside air (fresh air supply)
- Heat recovery from chillers for space and pool water heating
- Heat recovery from ice-making machines (for the ice rink) for air in building and pool water heating

**LIGHTING DESIGN**

Lighting design has also been a challenge. It is not ideal to have lighting in the middle of a pool as it creates glare for the spectators. Arup designed two structures for either side of the pool that direct light at ideal angles. The structures can be lowered onto the floor for maintenance, and they are also flexible enough for lights to be added or removed at will.

**WATER**

Even the water cycle has not been ignored in this incredibly sustainable building. With rainfall such a precious commodity in China, water in the centre will be recycled. Even rainwater falling on the giant roof will be collected, stored and re-used.

Swimming centres consume a large amount of water for sanitary purposes and from the pool filtration system backwash. This precious resource will be recycled to reduce water consumption. Used water is collected from showers and hand-wash basins and recycled as grey water for toilet flushing, water features and irrigation.

Rain water falling from the giant roof is collected and stored in underground tanks before filtered and treated for hot water services. The aim is to reduce the reliance and pressures on local receiving water, municipal water supply system and discharging direct to the sewer system.

**A STRONG TRACK RECORD**

To design a building never attempted before, Arup drew from its best practice knowledge of aquatic centres from around the world, including those used for the Sydney Olympics and Manchester Commonwealth Games. Arup’s involvement in other high profile projects in Beijing, including the stadium, CCTV tower, the international airport and interchange, also gave the team an advantage.

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**KEY PLAYERS**

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<th>Role</th>
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<tr>
<td>Client</td>
<td>Beijing: State-Owned Assets Management Co</td>
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<td>Three Gorges Corporation</td>
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<td>Consortium Leader</td>
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