

# Construction of Local and International Projects using ETFE

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## **Introduction:**

In 2001, the Eden Project in England was the largest ETFE structure in the world comprising 30,000sqm of Texlon ETFE pneumatic cushions. Due for opening in 2008, the Beijing National Aquatic Centre incorporates over 100,000 sqm of Texlon ETFE and therefore formalises the technology as one of the most versatile 'new' construction technologies available.

## **Background:**

The use of pneumatic cushions as a roofing or cladding material first hit the public stage at the 1970 World Expo in Osaka Japan where several large spaceframes were clad in pneumatic cushions made from Polyester. However for various reasons, the system never really established itself as a viable technology.

The origins of ETFE in construction date back to the early 1980's when a small group of sailing enthusiasts were looking for alternative materials to make sails out of. ETFE was one of the materials assessed and quickly rejected because of its material properties. However, the group realised that the same properties that made it unsuitable for yacht sails made it ideal for use in the building construction industry but only when used in a certain fashion. From these humble beginnings the Vector Foiltec group was founded.

Today, Vector Foiltec have completed over 500 projects in more than 30 countries – more than 95% of all the ETFE structures in the world. Vector Foiltec are the world's largest ETFE specialist contractor and have been responsible for obtaining local authority approvals for the technology in every country that ETFE has been utilised.

## **Why ETFE?**

ETFE is quite a peculiar material to work with as it has specific properties which, if they are not respected and the implications analysed can lead to disastrous results. Experience therefore plays a large part in building with ETFE. However, some of the key benefits of the technology include:

- Longevity – lifespan in excess of 25 years
- Inert – does not react with acids, alkalis, solvents etc
- Low skin friction – similar to PTFE but since it is an extruded material is also ultra-smooth
- Excellent thermal properties
- Cost competitive when compared to other solutions

The last item is an interesting one for the LSAA forum as we generally do not count ourselves as 'lightweight structures'. The main reason being that Texlon ETFE pneumatic cushions are a panelised system as opposed to a tensioned membrane – we are therefore more often compared to glazing than to fabric structures.

## **Beijing National Aquatic Centre:**

The design brief required the building to be a world class leading building that achieves the theme of Beijing Olympic Games – Green Games, High–tech Games and Peoples games.

The project itself represented a massive undertaking for the company. The scheme called for approximately 100,000sqm of some of the largest Texlon ETFE pneumatic cushions ever attempted. To do this, new ways of making the cushions had to be invented as well as figuring ways to strengthen the cushions to achieve the spans & loads required. Technical limitations in the material production led to multi–layer cushion configurations previously only used on a handful of projects and never on this scale. To give some idea, the total tonnage of raw ETFE material used for this project was 90 tonnes – in 2005 when we were awarded the project, the global production of ETFE resin suitable for architectural use was only 100 tonnes. Since then of course, supply has increased significantly!

Shortly after being awarded the contract, Vector Foiltec were then notified that the base structure was changing to a fully site welded frame from a bolted scheme that was originally envisaged by Arup Engineers. This represented a major issue as the programme would not allow site measurements of steelwork followed by overseas fabrication and transit times. Site measurement was deemed critical to give the wrinkle–free appearance.

The erection of the steelwork was also an extreme feat of engineering. Being completely site welded, at times there were up to 2,000 welders on site even during the depths of a Beijing winter. One can only imagine the amount of power required to pre–heat the steelwork for 2,000 welders in –10 deg C weather. The entire steel structure was erected using a birdcage scaffold system which will surely be included in the next Guinness Book of Records!

In response to all of these challenges and other logistical concerns, Vector Foiltec opened a purpose built ETFE cushion fabrication facility in Beijing in 2006. Here we manufactured purpose built machines capable of not only generating the cushion sizes required for the project but also maintaining the strict quality control required for long term cushion viability. The facility was also designed so that site measurements for the cushions could also be taken off the base site steelwork and incorporated directly into the cushion manufacturing parameters to ensure a good and wrinkle free fit.

Another key technical challenge faced by Vector Foiltec was the use of a flat roof on the project. One of the material characteristics of ETFE is that it has up to 400% elongation at break. One of the defining design criteria of an ETFE system is that a cushion must not be allowed to fill with water or snow during deflation. As a deflated cushion fills with water, the material would stretch – thereby making the cushion deeper and able to accommodate more water until eventual failure. Therefore the trick is to not allow this eventuality to occur in the first place – either through risk management associated with the air supply or by other means. This problem was eventually solved by several methods including inflation unit redundancy, backup power systems and locally reinforcing critical areas.

Installation on the site was another challenge. It was originally envisaged that teams of rope access installers would abseil down the facades to install the technology – this is our standard installation technique. However, while refining the design we realised that in China site labour is not the cost center that it is in other cultures. Our standard details try and be as efficient as possible with regard to site labour. For this project, labour was not a key issue and so the details and work practices could be revised accordingly. Three methods of training for installation teams and methods of installation were developed specifically for China :

1. Horizontal cushions were installed from the main steel structure. Debris nets were installed to allow work to continue below.

2. Exterior vertical cushions were installed using a custom made platform
3. Interior vertical walls cushions were installed using lightweight scaffold.

At the peak of installation we achieved an installed rate 2500m<sup>2</sup> per day. Steel and other trades could not provide sufficient work areas for a continuous work flow. It was therefore critical for the Head Contractor to involve the ETFE contractor in the development of sequence of installation and minimum work areas. There are several methods by which the ETFE subcontractor can accelerate the schedule including the use of innovative construction methods that do not require birdcage scaffolding.

**Summary:**

Overall, this project is one Vector Foiltec have been proud to be associated with. We applaud both the vision of the Architects and the courageousness of the client to build what will undoubtedly be one of the most outstanding pieces of Architecture in the world for many years to come.

**Facts:**

1. Total ETFE façade area 102,000 m<sup>2</sup>
2. Building footprint – 177.77m x 177.77m
3. External wall height 33m
4. Custom Silver print was applied to the foils to reduce solar heat gain
5. Prints pattern densities were tuned to the activities for internal spaces; more light/solar energy allowed into the building at circulation areas, less light/solar energy allowed entering building at competition hall.
6. All external foils are blue.
7. Double wall façade and roof.
8. External roof cushions use four layers of ETFE to create three air chambers.
9. Internal ceiling cushions use four layers of ETFE to create three air chambers.
10. External facades walls use three layers of ETFE to create two air chambers.
11. Internal perimeter facades walls use three layers of ETFE to create two air chambers.
12. Internal walls use two layers of ETFE foils to create one air chamber.
13. Three internal rooms are created using double walls of ETFE cushions.
14. Volumes of air enclosed in the building weigh more than the building.
15. ETFE double wall system reduced plant equipment sizes by 40%.
16. Approximately 1million cubic meters of handled air.
17. Design temperatures external –12 degrees Celsius internal temperature +33 degrees Celsius.

18. Observed temperature in the ceiling cavity reached 44 degrees Celsius during construction.
19. Cavity acts as insulator .
20. Maximum Structural span 110m.

**Owner:**

Beijing State Owned Assets management Co., Ltd.

**Design Consortium:**

Lead of the design consortium: China State Construction Engineering Corporation

China State Design International

PTW Architects

Arup Sydney

Design and Build façade consultant and contractor

Vector Foiltec

General Contractor:

China State Construction Engineering Corporation

**Summary**

Various aspects of the construction of the EFTE component of the Beijing Watercube and other projects are discussed by means of the following slides.



































