

# An Engineering Walk around the Sydney Opera House

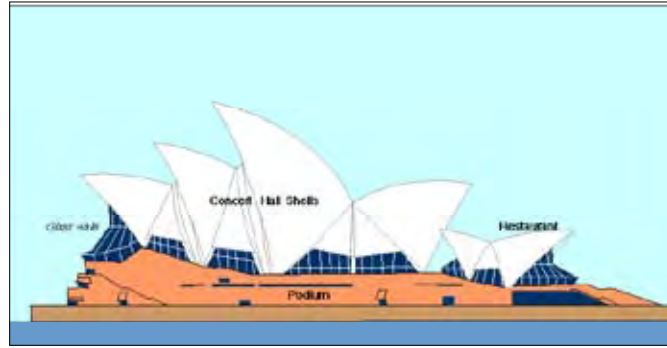
In a one to two hour walk around the outside of the Opera House you will see all the main features of its unique structural design. The narrative in the guide outlines how the concept that won Danish architect Jørn Utzon an international competition in 1957 became a reality.

The walk commences at the Opera House forecourt on Benelong Point. There are no restrictions on walking around or taking photographs outside the Opera House. Except at the times of performances, the only part of the interior accessible to the public is the box office area.

There are few places around the Opera house where you can sit down to read, so it's best to read the story before you start the walk.



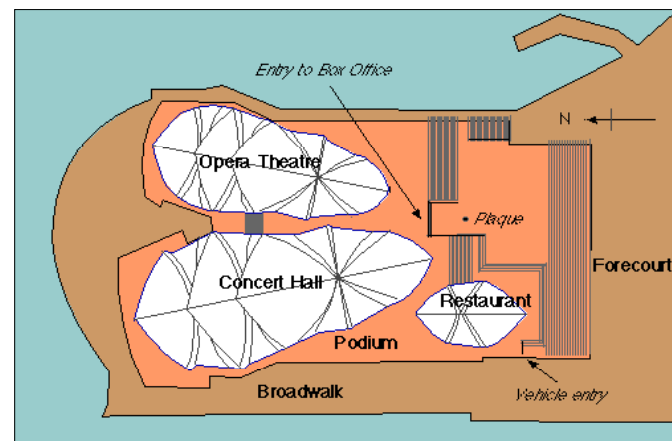
Self-guided walk



## How it began

In 1946 Eugene Goossens came to Sydney as Conductor of the Symphony Orchestra and soon began a campaign for an opera house on Benelong Point. The idea caught the imagination of the Premier of New South Wales, Joe Cahill, who in 1956 announced an international design competition for an opera house to be built by the government.

The design was to be for a multipurpose auditorium to seat around 3000, as proposed by Goossens, plus a smaller hall for around 1200. There were over 200 designs submitted in the competition. Utzon's winning design, little more than a series of sketches, differed from almost all other entries in having the two auditoria arranged side by side on the site. His entry was also unique in conceiving the commission as a giant symbolic sculpture.



In 1957 the government commissioned Utzon as architect and obtained a cost estimate of \$7.2 million. Utzon thought this was probably too low. By the time it was completed in 1973 the cost, entirely met by the proceeds of lotteries, was over \$100 million.

In mid-1957 the government, with Utzon's agreement, appointed the London firm of Ove Arup as consulting engineer for the project.

## The podium

**Start the walk in the forecourt and climb the steps of the podium to the platform in front of the entry to the two main auditoria..**

The Mayan temples of Mexico provided Utzon's inspiration for the podium. His concept was for spectators to walk up the steps, then enter the building to view a completed work of art in the theatre. All the preparation for the opera performance takes place beneath.

Visually the two theatres under the shells would be separate from the platform, as if cut with a knife. The shells would touch the platform only at the springing points, and the infill would be glass appearing to hang from the shells. As you stand on the platform, you see Utzon's concept realised in the completed building.



Completed podium

Premier Cahill was anxious to start construction before the state election in 1959 so Arup advised separating the construction into two stages: Stage I, the podium, and stage II, all the rest. Australian firms were invited to tender for stage I and in February 1959 the contract was signed with Civil and Civic, which had submitted the lowest tender. On 2 March 1959 a ceremony marked the official start of construction. Utzon said that all the details of construction had now been worked out; the problems had been overcome; there would be no more alterations.

Civil and Civic finished their work the site in March 1963 with the concrete structure of the podium completed and the construction of the shells about to begin.



Utzon's model for the shells

## The shells

**Look into the restaurant to see the structure of the fan-like shells, built as a series of prestressed concrete ribs joined together to form arches.**

Each of the shells consists of a set of concrete ribs, joined together laterally by bolts and prestressing cables. The ribs themselves were built from precast segments, prestressed after erection.

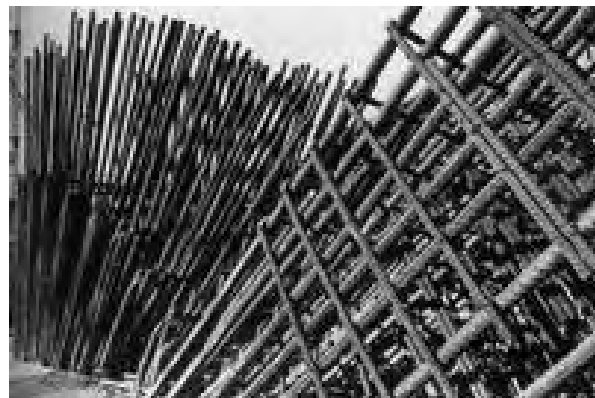
Utzon's original freehand sketches showed concrete sails that soared out and over the two auditoria. He imagined that these would be concrete shells, very thin in relation to their size – like egg shells – as had been used in other buildings around the world, and were known to be very strong. But thin concrete shells are only possible if their shape is appropriate, and Utzon's shapes were certainly

not appropriate, though this was not immediately obvious to either the architects or the engineers.

For four years Arup's engineers in London struggled with the design of the shells. They concluded that a practical design would be a double skinned shell with a strong internal steel structure. However serious structural problems with the design were still to be worked out.

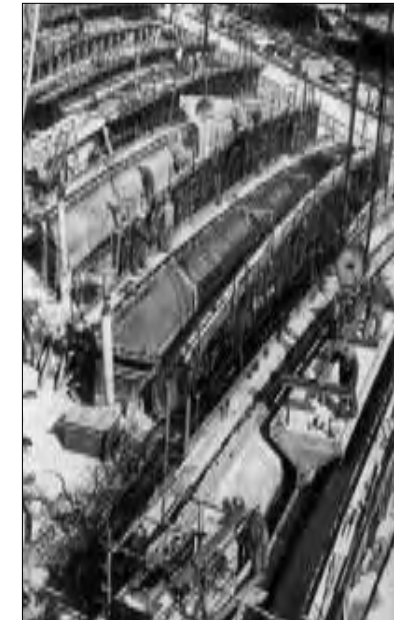
Then Jack Zunz, a senior Arup engineer who had not been involved in the project, proposed a different solution: build the shells as a set of arches formed from precast concrete ribs. At meetings in London late in August 1961, Utzon reviewed the alternative design concepts with Zunz and Arup. Utzon disliked the double shell concept because its main structural elements would be hidden from view, but the rib design appealed to him. But casting the ribs would be a major problem unless they could be geometrically all of the same shape. This had to be a sphere. Arup returned to Denmark with the problem unresolved.

Shortly afterwards, Utzon phoned Arup to say that he had found the solution. All the shells would be segments of a sphere of 75 metre radius. All of the concrete segments could be cast in the same moulds. By the end of September 1961 the way ahead was clear.



Steel reinforcement for a rib pedestal

In November 1961 the government, on Arup's recommendation, appointed the Australian construction company Hornibrook to build Stage II of the Opera House on a cost plus fixed fee contract. Hornibrook selected its NSW construction manager, Corbet Gore, to manage the project. Gore first briefly met Zunz and Utzon in Sydney during March/April 1962.



Casting rib sections

Zunz took charge of the detail design for the shells at Arup's London office, and kept in close touch with Gore, who was in Sydney working out how to construct the shells.

In 1963 the Sydney media learned that parts of the podium would need to be demolished so that footings could be built for the heavy concrete shells. Arup, on a visit to Sydney said in an off-guard moment to a reporter 'It's only one of a million troubles. The Opera House is being built on a trial and error basis.'



Lifting a rib section

The first rib section was placed in position in November 1963, the last in January 1967. Altogether there were 224 ribs made up of 2194 separate precast sections.

## The tiles

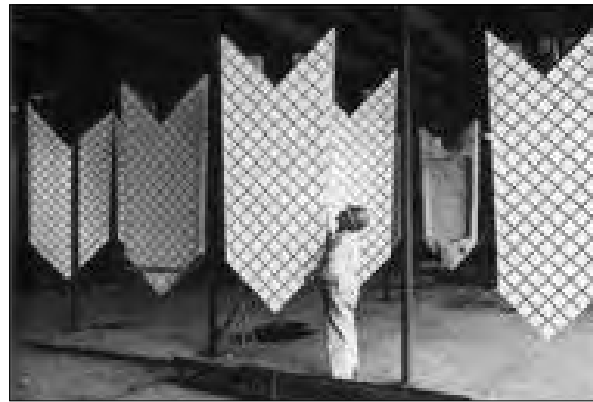
Now take a close-up look at the tiles.

There are over a million tiles on the surface of the shells. All of them were made by Höganäs in Sweden, just a short distance from Utzon's home in Denmark.

In Utzon's original design for the Opera House, the outer surfaces of the shells were to be completely covered by white tiles. Later, he considered many alternative possibilities for the tiling, with combinations of matte and glossy tiles, white, black and various colours. Höganäs produced all the sample tiles.

At that time it was planned to place the tiles individually on the completed shells. Once it had been decided to build the shells in spherical form from precast rib sections, Utzon proposed that the tiles should be set in precast panels, called 'tile-lids'. Höganäs had developed and marketed a system for cladding buildings with precast tiled panels, which demonstrated the practicality of the concept. Hornibrook conducted many experiments at the Opera House site to perfect the construction technique.

On the construction site, the tile lids were cast by placing tiles in the base of a mould and pouring concrete on top. The completed lids were fixed to the shell ribs by bronze brackets and bolts.



Curing tile lids on the construction site

## The vehicle concourse and folded slab

Walk part way back down the steps towards the forecourt, then follow the sign pointing through the glass doors to the box office. Just near the sign is a bronze model, based on one made by Utzon, that shows how the shells are all formed from segments of a sphere. Inside, you can see the concrete beams that support the stairs and platform. In the box office foyer there are toilets, and information desk and a small shop. Now walk down the stairs from the foyer to the vehicle concourse.



Michael Lewis, manager of Arup's Sydney office, Arup and Zunz

Utzon planned that vehicle access to the Opera House should be completely separated from pedestrian access. His original design for the vehicle concourse included a central line of columns, but he asked Arup if a single span would be possible. Arup's answer was predictable. Utzon wanted the depth of the concourse beams be kept to a minimum, and the depth of the beam section to be uniform across the span.

Arup's design solution was a set of prestressed concrete beams, with a T section at midspan, changing to a channel section at the ends. The contractors, Civil and Civic, experienced great difficulties with construction, and their contract ended in arbitration. In the end, Utzon achieved the visual effect he was seeking.

## The glass walls and the bar areas

Walk along the broadwalk towards the harbour. Inside the podium are three public performance spaces, the drama theatre, playhouse and studio, along with offices, services and back-stage facilities. Walk around to the end of the concert hall.

Utzon resigned from the Opera House project in 1966 and the government appointed a new, Sydney-based team of architects, Hall, Todd and Littlemore. The main auditorium, originally intended for both concerts and opera, then became a concert hall, and the stage machinery, already delivered to Sydney, was never installed. The



Lewis, Gore and Skipper Nielsen, Utzon's site representative

smaller auditorium was adapted for staging grand opera. The new team, not Utzon, were responsible for the design of the interiors. In conjunction with Arup's as structural engineers, they also designed the glass walls with steel supporting structures that enclose the ends of the shells. Utzon had proposed a plywood supporting structure for the glass walls; the government's refusal to allow Utzon to contract with the Sydney firm Ralph Symonds for development work on the plywood structure was just one of the conflicts that led to Utzon's departure.

## Seeing more of the Opera House

**Before you leave, climb the stairs of one of the galleries at the base of the glass walls. Look inside to the foyers. If you visit the Opera house in the evening when there is a performance you can enter the building and climb the stairs alongside the auditoria to the foyers and see from inside the stunning views of Sydney Harbour at night.**

**Every day there are guided tours that include the foyer areas and the interiors of the opera theatre and concert hall. Advance booking is not essential. There are occasional guided tours of the backstage areas.**

## The engineers

### Ove Arup

Arup was born in Newcastle-upon-Tyne of a Norwegian mother and Danish father. He graduated from the Royal Copenhagen Technical College in civil engineering and began a lifelong career working with architects on the design of buildings. He commenced work in Hamburg with the Danish firm Christiani and Nielsen, and later moved to London, where he eventually established his own firm. Sir Hugh Casson recalled Arup as a man 'who was never one to let facts become the enemies of imagination'.

### Sir Jack Zunz

Gerhard Jacob (Jack) Zunz was born in Germany, but migrated to South Africa as a boy, graduating from the University of Witwatersrand in civil engineering. He began work for Arup in London in 1950, and in 1954 returned to South Africa to set up a branch of the firm. Zunz rejoined the London office in 1961 and almost immediately became involved in the Opera House project.

### Corbet Gore

Dundas Corbet Gore was born in Goodiwindi, Queensland. After engineering studies interrupted by war service with the RAAF in Europe he graduated in Civil Engineering from the University of Queensland and joined the construction company Hornibrook. Gore became Hornibrook's first manager in New Guinea in 1950, and later moved to Sydney as construction manager for New South Wales. In 1961 he was appointed as Hornibrook's construction manager for the Opera House. Zunz said of Gore 'For sheer skill, coupled with an ability to manage people and for getting the Opera House shells built, he deserves all the credit'.

## ASHET self-guided tour brochures

This brochure is one of a series describing self-guided tours to places of engineering and technological interest in the Sydney area. All of the brochures are published in pdf form on the ASHET website [www.ashet.org.au](http://www.ashet.org.au) where they may be viewed and downloaded for printing on a desktop printer.

The full set of brochures is as follows:

### **The Sydney Harbour islands**

Self-guided tours by ferry

### **Ryde to Tempe: discovering the history and industrial heritage of Rhodes, Concord, Canterbury and the Cooks River**

Self-guided cycle tour

### **Sydney's colonial fortifications**

Self-guided tours

### **Sydney Harbour Bridge**

Self-guided walk

### **The engineering heritage of Sydney's maritime industries**

Self-guided tour by ferry

### **Steam at the Powerhouse**

Self-guided visit to the museum

### **Parramatta River bridges**

Self-guided tour by RiverCat

### **Sydney Water: A day tour of the water supply dams south of Sydney**

Self-guided tour by car

### **Engineering and industry on three Sydney Harbour islands**

Self-guided tours of Fort Denison, Cockatoo and Goat Islands

### **An engineering walk around the Sydney Opera House**

Self-guided walk

ASHET, the Australian Society for History of Engineering and Technology, was formed in June 2003. Its objects are to encourage and promote community interest and education in the history of engineering and technology in Australia. For more about ASHET, visit the website [www.ashet.org.au](http://www.ashet.org.au).