

# Sydney Opera House

Conservation Management Plan Overview

Team SIX



# Understand the Place / 背景理解

## The Builders

Architect : Jorn Utzon

Structural engineer : Ove Arup & Partners

Client : NSW Government

## Interval of Construction (1959-1973)

Groundbreaking : 1 March 1959

Construction started : 1 March 1959

Completed : 1973

## Program

Performing arts center

**Location**-Bennelong Point, Sydney NSW 2000 Australia

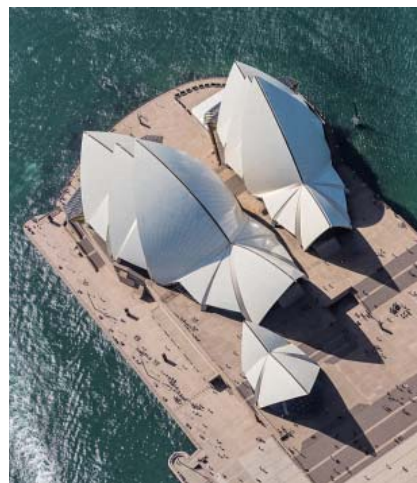
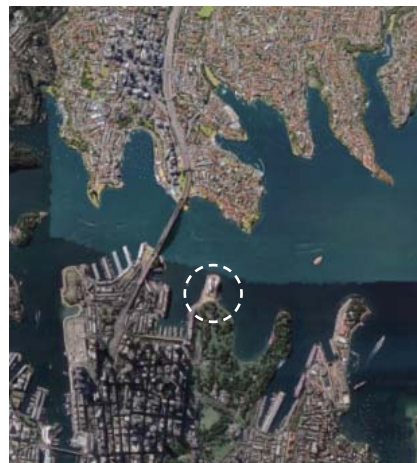
This area has formed from the deposition of alluvial materials scattered in the seawater and is not suitable to bear the weight of the opera house.

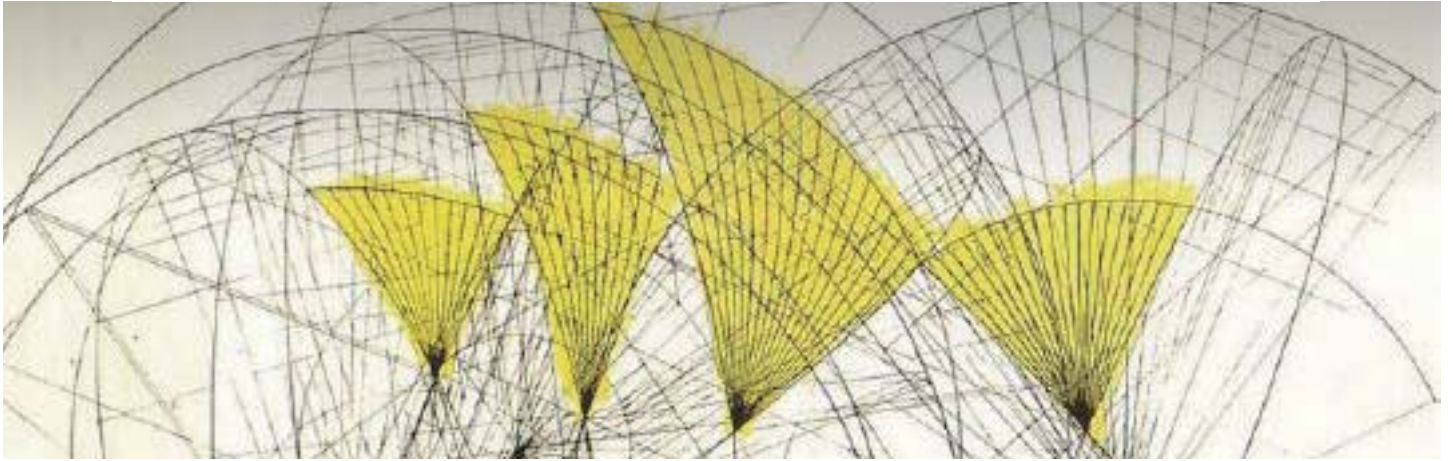
Due to weather factors and problems caused by the diversion of rainwater, Utzon has not yet prepared the correct structural drawings.

On the man-made peninsula in the southern part of Sydney Bay, with a total area of 2.2 hectares, it is supported by 588 concrete piers settled 25 meters below sea level. The buildings, with a length of 183 meters and a width of 120 meters, occupy 1.8 hectares of this area.

雪梨歌劇院的建造發想始於 1940 年代，當時戰後的雪梨沒有足以容納千人以上的表演廳。1955 年雪梨政府向全球發起設計比賽，烏松在從未造訪過雪梨的情況下，憑著幾個雪梨姑娘對家鄉的描述就繪製出這份設計圖，設計靈感來自撥了一半皮的橘子。

準備工作開始不久，地質學家發現建造地區一開始並沒有經過準確的調查，原本這個區域是由散佈在海水中的沖積物沉積而成，不適合承受歌劇院的重量。團隊需要在預算外多花錢，添購大量混凝土填充在不穩定的岩石中。也因天氣因素及雨水改道產生的問題，一連串的計畫需要執行和更改。





### Three points of the Utzon's design in the terms of construction

歌劇院的建造過程分為三階段進行，分別是底座、拱形殼以及玻璃幕牆和內部裝潢：

#### • Under-Broadwalk Structures / 步道平台下的結構

The Opera House is built on a narrow peninsula of land on the south shore of Sydney Harbour. The Western Broadwalk and Northern Broadwalk rest on steel reinforced concrete piers, which are embedded into the harbour floor. Granite aggregate slabs are used to clad the Broadwalks. **(Figure 1)**

歌劇院站立於最下方的步道平台，由於雪梨歌劇院座落於雪梨港南岸的狹窄半島上，因此結構部分由鋼筋混凝土澆灌並嵌入港口的地層（圖 1）。

#### • The Pedestals / 底座

The points from which the sail ribs rise from the podium, and connect to the foundation columns, are known as the Pedestals. **(Figure 2)**

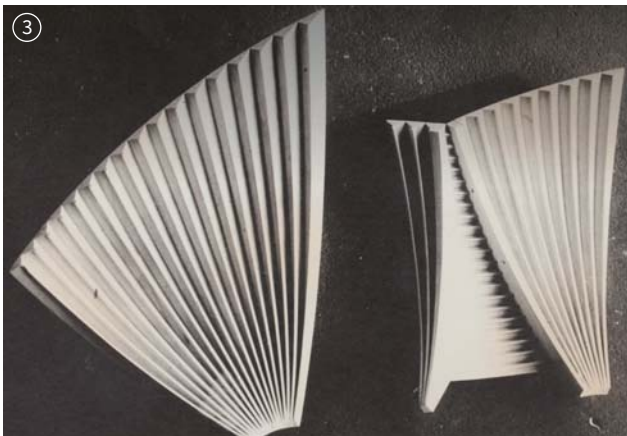
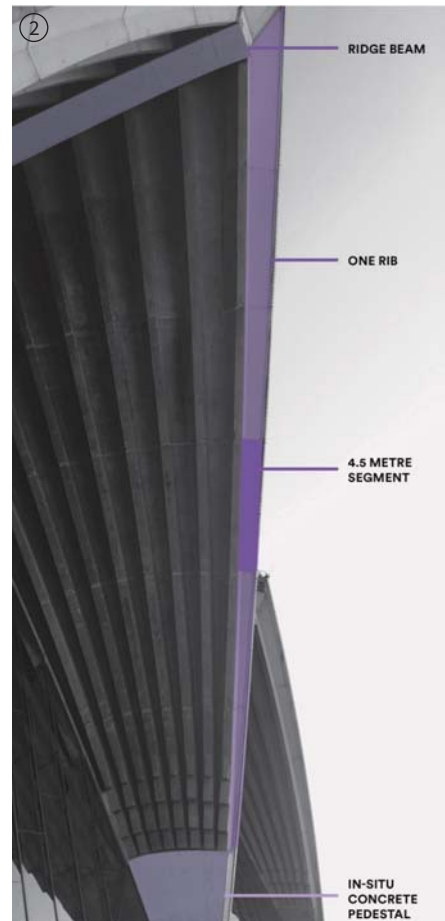
The Pedestals are made of reinforced concrete, cast in-situ, and can be seen on the building's exterior below the line of ceramic tiles.

歌劇院主體由折扇般的結構構成，其中分為兩部分，帆肋從平台升起並連接到柱礎的部分稱為基座（圖 2），基座由現場澆灌的鋼筋混凝土製成，暴露於外部的磁磚線以下。

#### • The Sails(Figure 3) / 肋帆 (圖 3)

During construction of the Opera House, the pre-cast rib **(Figure 4)** sections of the sails were cast with ducts to carry the steel stressing cables. In all, 4100 individual ducts with a total length of around 113 kilometres (70 miles) were created.

而肋帆部分則是由預鑄的鋼筋混凝土部件組成（圖 4），每個高度的斷面都不盡相同，且內部以空心管道乘載鋼應力的纜索，整個歌劇院共有 4100 條獨立管道，總長度約為 113 公里 (70 英里)。



# Statement of significance / 重要性闡述

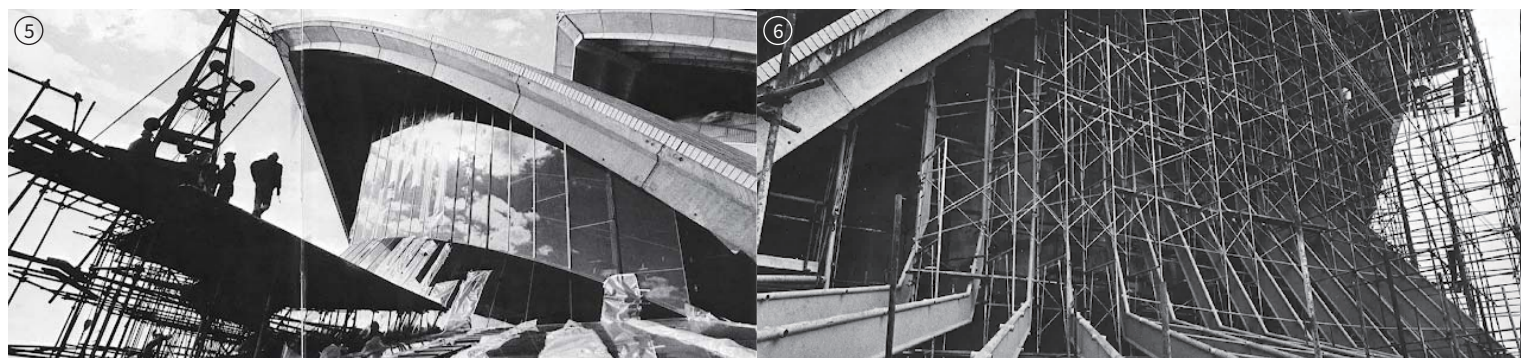
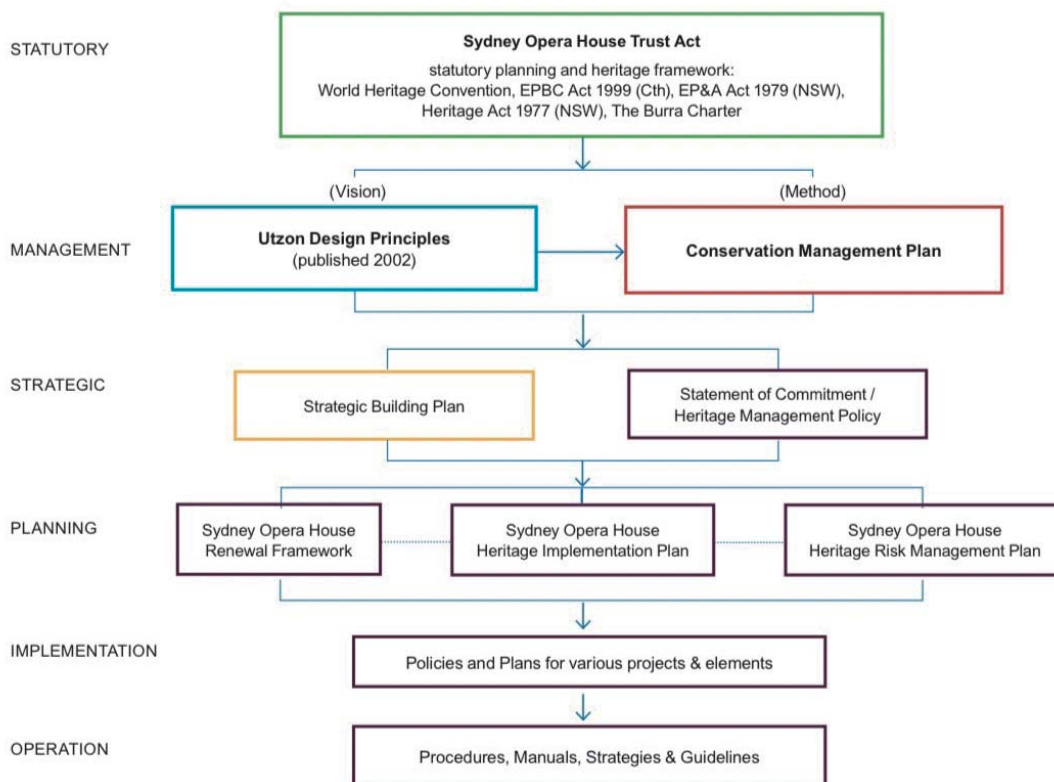
While the unconventional design of the opera house initially diverged from the spatial requirements typical for such venues, subsequent adjustments were made to address issues related to reverberation time. Nevertheless, it is indisputable that, both in terms of concrete construction and technical innovation, the opera house held a pioneering position at that time.

As a testament to its architectural significance, the Sydney Opera House was officially recognized as a UNESCO World Heritage Site in 2007, a mere 34 years after its completion. Remarkably, it stands as one of only two World Heritage Sites designated while the architect was still alive, underscoring the 'youthfulness' of this prestigious accolade.

However, in the CMP (Conservation Management Plan) process for the Opera House, relevant regulations were already enacted prior to 2000, including the Sydney Opera House Trust Act and the Conservation Charter. Utzon's design principles were also documented in 2002, well before the initiation of the preservation management plan. This indicates that the assessment and documentation of the Opera House began much earlier, yielding certain accomplishments.

雖然這樣的特殊造型與歌劇院所需求的空間其實有一段差距，後續也因為殘響時間的問題而有所調整，但不可否認的是，無論是在混凝土或施工技術的層面，歌劇院都在當時具有非常領先的地位，也正因如此，歌劇院於 2007 年被劃定為世界遺產，此時距離落成僅過去 34 年，世界上僅有兩個世界遺產是在建築師還在世時被劃定的，雪梨歌劇院就是其中之一，這兩件事均體現了這個世界遺產的“年幼”。

然而，我們可以看到歌劇院的 CMP 流程中，早在 2000 年前相關的法令就已經頒布，包含雪梨歌劇院信託法及布拉憲章，Utzon 本人的設計原則在 2002 年也整理完成，之後才開始進行保存管理計畫，可見其實對於歌劇院的測試和紀錄很早以前就已經開始並且獲得一定的成果。



3 Sydney Opera House Conservation Management Plan Overview

## Structural Engineering & Technical Innovation / 結構工程及技術突破

Sydney Opera House was a project with such extreme technical challenges, where the design and construction took place over an extended period and which, for the entire period, was played out under a public and political spotlight.

雪梨歌劇院的設計及結構超越了當時的時代技術，因此面臨了極大的挑戰，也使其成為了公眾及政府的焦點。

Engineering and technological feats developed during the design and construction of the Opera House include:

歌劇院設計和施工期間的工程和技術成就包括：

- Ove Arup designed folded concrete beams to support the podium structure (Figure 1, 2)

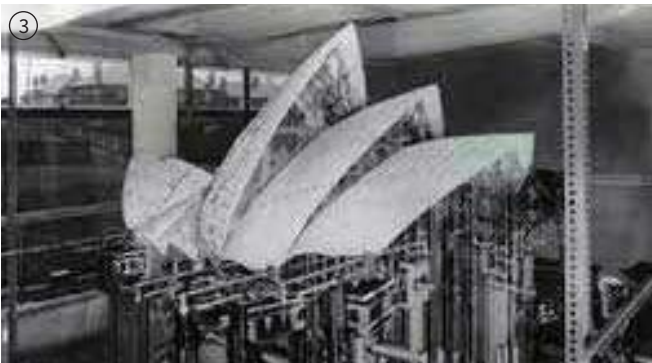
結構團隊為此設計了折疊混凝土梁以支撐裙樓結構 (圖 1,2)

- One of the first buildings in the world to make use of computers in design (Figure 3)

世界上最早使用電腦進行設計的建築之一 (圖 3)

- Ove Arup & Partners were a pioneer of wind tunnel testing for building, during the design of the sails.

在肋帆的設計過程中採用了風洞測試



This is now common practice in design for large buildings all over the world

現在仍被大型建築所採用的技術包括：

- An adjustable mounting and assembly arch was invented for the project. This removed the need for mass scaffolding to support the structure during construction. (Figure 4, 7)

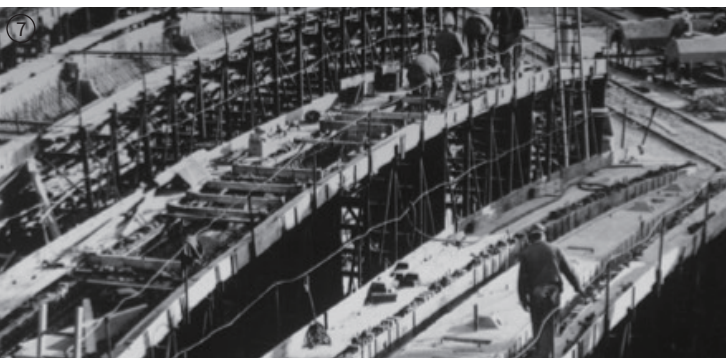
承包商為此設計了可調節的組裝拱門，減少的施工期間的鷹架需求 (圖 4,7)

- The Opera House is the first large-scale example of glass used as a structural load bearing material in a building. (Figure 5, 6) (圖 5,6)

歌劇院是第一個在建築中使用玻璃作為承重結構的大型案例

- An innovative epoxy resin process developed to bond the rib segments together. This achieved the smooth concrete effect that was vital to Utzon's design for exposed surfaces.

新開發的環氧樹脂用於將預鑄的肋帆部件接合，這對烏松裸露的光滑表面設計至關重要



# Data Collecting of Concrete Conservation

/ 混凝土保存的資訊蒐集

## The Data of Concrete Conservation Data Would Benefit

混凝土保護的數據將受益於：

- Facilitate understanding of concrete and dissemination of knowledge  
促進對混凝土的理解和知識的傳播
- Influence future research  
影響未來的研究
- Address knowledge gaps  
消弭知識差距
- Create a long term strategy for preventative and remedial maintenance for the Opera House  
制定預防性補救性維護的長期策略
- Build digital management tools to support concrete conservation  
建立數位化的管理工具以支持混凝土保護計畫



## Introduction of Data Collecting Methods / 數據的蒐集方法介紹

Practical investigations and non-destructive testing methodologies were developed based on the identified knowledge gaps and priorities. These included condition assessment of the concrete under the tile lids, studies on the environmental impacts on the roof pedestals, and inspection of the concrete in the Northern Broadwalk under-structure.

根據已知的知識差距和優先事項執行了實際調查和非破壞性的檢測方法。其中包括對混凝土下方的磁磚狀況進行評估、研究環境對屋頂基座的影響，並檢查北邊步道平台的下層混凝土結構。

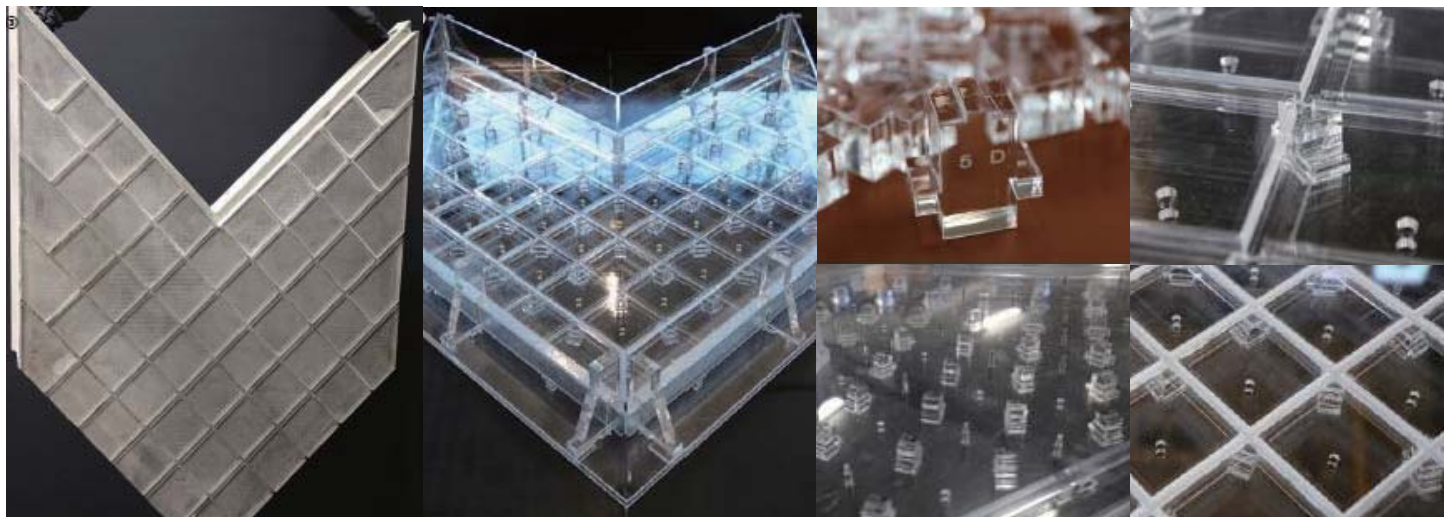


## Non-Destructive Testing Methodologies

非破壞性測試方法

### Tile Lids / 磁磚座

- Ground penetrating radar  
探地雷達
- Ultrasonic pulse echo imaging  
超音波脈衝回波成像
- Robot for inspecting the sails  
檢查肋帆的機器人
- Remote-sensing vibrometer  
遙感測振儀
- Vibration speakers  
振動揚聲器



## Roof Pedestals / 屋頂基座

- After reviewing recent inspection reports, it was determined that reductions in surface thickness and minor carbonation and chloride ingress did not represent a threat to the structural condition of the pedestals.  
審查最近的檢查報告後，確定表面厚度的減少、輕微的碳化以及氯化物的滲入並不會對基座的結構狀況造成威脅
- Some areas of decreased coverage in specific localized areas, which may be treated on a case-by-case basis. In the initial part of this work, the main aim was to reduce, if not completely eliminate, the rain runoff reaching the back faces of the pedestals.  
某些局部覆蓋率下降的區域可以根據實際情況進行處理。這個項目的最初目標是減少（如果不能完全消除）基座背面的雨水逕流。



## Concrete Under-Structure / 下層結構的混凝土

- While extensive inspection and repair works have been carried out on the Northern Broadwalk before the comprehensive study in August 2015, the records of these activities were limited. Site visits performed by the University of Sydney team in August / September 2015 visually inspected selected beams and columns to provide a framework for monitoring and documenting typical structural elements in this area. This was not further pursued by the University team once it was identified that Arup had established a similar framework for their regular inspections.  
雖然在 2015 年 8 月進行全面的研究前，已對北邊的步道進行廣泛的檢查和修復工作，但留下的紀錄有限。雪梨大學團隊於 2015 年 8 月至 9 月進行了實地考察，親眼檢查了選定的梁和柱，為監測和紀錄該區域的典型結構元素提供了一個框架，但並未進一步推進，直到結構團隊建立了類似的定期檢查框架。



# About the team / 團隊

## The Sydney Opera House Trust / 雪梨歌劇院信託基金

The Trust is constituted as a body corporate under the *Sydney Opera House Trust Act 1961*. It consists of 10 members **appointed by the Governor of New South Wales on the nomination of the Minister for the Arts**.

該信託基金是根據《1961年雪梨歌劇院信託法》組成的一個法人團體，由新南威爾斯州州長根據藝術部長的提名任命的十位成員組成。

### • Building and Heritage Committee / 建築及遺產委員會

The Building and Heritage Committee is a sub-committee of the Sydney Opera House Trust, with a delegated authority to oversee and monitor building, conservation and heritage matters.

建築及遺產委員會隸屬於信託基金之下，被授權監督及監控建築、重視保存和遺產。

### • Conservation Council / 保存委員會

The Conservation Council is an advisory committee to the Sydney Opera House Trust and includes members from the Trust, management, and independent advisors from the NSW Heritage Office, NSW Department of Planning and Infrastructure, and industry representatives from the Indigenous, heritage and architectural communities.

保存委員會是信託基金的諮詢委員會，其成員包括信託基金成員、管理階層、新南威爾斯州遺產辦公室的獨立顧問、新南威爾斯州規劃及基礎設施部門以及原住民、遺產和建築社區的行業代表。

### • Eminent Architects Panel / 傑出建築師小組

The Eminent Architects Panel, chaired by the NSW Government Architect, advises the Trust on architectural design matters and includes five highly experienced and award-winning architects. Jan Utzon, son of Opera House architect Jorn Utzon, is a member.

傑出建築師小組由南威爾斯州政府的建築師主持，就建築設計事宜向信託基金提供建議，其中包括五位經驗豐富且屢獲殊榮的建築師，包含烏松的兒子也是成員之一。



# Context / 脈絡

## The Burra Charter / 布拉憲章

### First drafted in 1979 / 首次起草於 1979 年

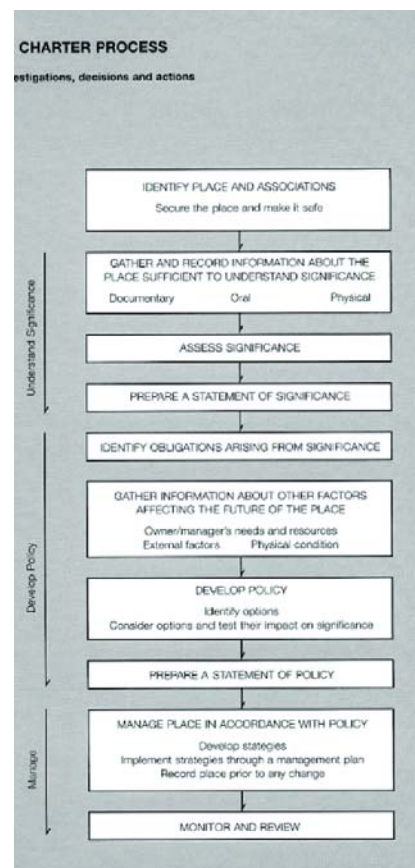
- Australian heritage movement  
澳洲遺產運動
- The green bans  
綠色禁令
- The founding document of Australia ICOMOS  
澳洲 ICOMOS 的成立文件

## The Venice Charter / 威尼斯憲章

- 'Places' refer to 'Monuments'  
"地點" 取代 "遺跡"
- Less applicable to Australian heritage concerns  
不太適用於澳洲的遺產問題
- An Antipodean pastoral town with a gruff name vs. the genteel European renaissance city of Venice  
一個有著粗魯名字的澳洲田園小鎮 vs 歐洲文藝復興時期優雅的威尼斯小鎮

## Question / 問題

- European conservation thought ex. Indigenous heritage  
歐洲保存思想，例如原住民遺產
- Still gives precedence to tangible and physical forms over meanings and associations  
仍優先考慮有形和物理形式，而不是意義和聯想





# Keeping it Modern / 現代性維持

## Improving Knowledge Management / 改善知識管理

Developments in technology have introduced new hardware, software and communication technology, which has progressively changed the way work is carried out and archived. Records range from hardcopy, microfilms and microfiche, to digital entries, leading to a lack of universal archive.

Keeping track of accumulated knowledge over a long period of time is challenging, since archive systems are not designed for efficient retrieval of information, especially where essentially the same project has been running intermittently for nearly 60 years.

As result of the Concrete Conservation Project, the considerable value of the knowledge of past projects held in Arup and Opera House archives, and retained in the memories of current and retired staff is now being captured in a single location, along with the importance of passing on this knowledge to future generations.

由於技術的發展引入了新的硬體、軟體和通訊技術，逐漸改變了工作的執行和歸檔方式，記錄範圍從硬拷貝、縮微膠捲和縮微膠片到數位條目，導致缺乏通用檔案。

追蹤長期累積的知識具有挑戰性，因為檔案系統不是為有效檢索資訊而設計的，特別是在本質上相同的項目已間歇性運行近 60 年的情況下。

在混凝土保存的最後，結構團隊和歌劇院檔案中保存的過去項目具有巨大的知識價值，以及保留在現任和退休員工記憶中的知識，現在都被集中在一個地點，除此之外將這些知識傳授給後代也同樣重要。

## Communicating Knowledge / 溝通資訊

The project steering committee met regularly throughout the project to share information and ideas, and support the project team with expert advice and guidance. Progress was also reported to the Sydney Opera House Conservation Council at their regular meetings.

專案指導委員會定期舉行會議以分享資訊和想法，並為專案團隊提供專家的建議和指導，在例行會議上也向雪梨歌劇院保存委員會報告進展。



## Training next generation / 訓練下一世代

The craftsmanship demonstrated in past patch repairs carried out in areas of the pedestals and on the tile lids will be useful in informing future repair strategies. It was important to document this information in a visual medium so that the techniques could be demonstrated to assist in training the next generation of trades staff.

過去在基座和磁磚座上進行的修復技術將有助於向未來的修復策略提供資訊，將這些資訊記錄在視覺媒體中非常重要，以便展示這些技術來幫助下一代行業人員的培訓。

# Demonstrative Reference / 示範性參考

## Concrete Conservation Frame Work Implementation / 混凝土保存框架的實施

In the two years since that project concluded, the Opera House and its partners have continued in the study of concrete conservation and development of condition monitoring techniques. The team continues to work at the leading edge of technology in the field and is working with industry and academic experts to develop the systems in line with the vision for what is possible.

自該計畫啟動以來的兩年裡，歌劇院及其合作夥伴繼續研究混凝土保存和狀態監測技術的發展。該團隊持續致力於該領域的技術前沿，並與產業和學術專家合作，開發符合可能性願景的系統。

### • Condition Monitoring / 狀態監測

Several outcomes of the Concrete Conservation Project have facilitated the progression of the Concrete Conservation Framework: 混凝土保存計畫的多項成果促進了混凝土保護框架的進展：

1. exposure to a range of inspection techniques using established and emerging technologies.  
接觸一系列現有的及新興的檢查技術
2. ongoing engagement with the “Arup Originals” and other experts in concrete.  
與「Arup Originals」和其他混凝土專家持續接觸
3. recognising that it is essential to monitor and categorise concrete condition.  
認識到對混凝土情況進行監測和分類至關重要
4. application of Building Information Management technology for data storage and analysis.  
應用建築資訊管理技術進行資料儲存與分析

### • Concrete Inspections / 混凝土檢查

Non-invasive techniques are being explored to the extent possible so as to avoid impact to heritage fabric.

Monitoring techniques may include:

探索非侵入性技術可能以避免對遺產結構產生影響，監控技術包括：

1. systematic building rainfall inspections  
系統化的建築雨量檢查
2. internal borescope inspections  
內部管道鏡檢查
3. tomographic inspections  
斷層檢查
4. analysis of sail and podium stormwater drainage performance  
肋帆及底座雨水排放性能分析
5. structural waterproof membrane inspections  
結構防水膜檢查
6. aerial drone high resolution and infrared inspections  
空中無人機高解析度和紅外線巡檢

The drone carries sensors and cameras capable of monitoring:

無人機能夠攜帶的監控感應器和攝影機：

1. tile adhesion  
瓷磚附著力
2. tile cracking deterioration  
磁磚開裂惡化
3. organic growth  
有機生長
4. tile to tile grout erosion  
磁磚之間的灌漿侵蝕
5. lid to lid sealant failure  
磁磚座之間的密封劑失效
6. rainwater leak detection  
雨水外洩檢測

- **Tile sealants and grouting / 磁磚密封劑和灌漿**

Rainy day inspections have identified a risk of sealant failure in some areas, and localised repairs have been undertaken to address rainwater leaks. Subsequent drone, infrared and visual aerial drone leak detection inspections have been trialled and will target subsequent borescope investigations.

雨天檢查發現某些區域有密封劑失效的風險，並已進行局部維修以解決雨水洩漏問題。後續無人機、紅外線和可視無人機洩漏檢測均已試用並將針對後續管道鏡進行調查。

- **Broadwalk Remediation / 步道修復**

In 2017, Arup found that localised concrete repair is unlikely to materially increase the service life of the concrete structure, and more extensive works will be needed as the structure approaches its life expectancy.

2017年，結構團隊發現局部混凝土修復不太可能實質地延長混凝土結構的使用壽命，隨著預期壽命的接近，將需要更全面的工程。

- **Continued Collaboration with External Experts / 與外部專家的持續合作**

Since the project was completed, these experts who provided oral histories during the project have continued to participate in the formation of the Concrete Conservation Consultation Group.

專案完成後，這些在專案期間提供口述歷史的專家繼續參與混凝土保存諮詢小組的組建

- **Use of Building Information Modelling Technology / 建築資訊模型技術的運用**

The system has been configured to record the concrete condition, testing and treatment history for all building elements. Various complementary monitoring techniques will be applied to testing the same qualities in the roof sails and podium.

該系統已配置為記錄所有建築元素的混凝土狀況、測試和處理歷史，各項互補的儲存技術將有助於測試屋頂帆和底座的相同品質。

## Contents and Collections / 相關內容及資料蒐集

### Stakeholder / 利害關係人

The concrete conservation project brought together engineers, students, academics, heritage specialists and concrete industry professionals.

A group of exceptional people – some of whom worked on the original construction of the building – volunteered their time to share oral histories with the project team.

These first-hand accounts of the construction of the Opera House have become an invaluable resource for the current and future custodians of the building.

混凝土保存計畫匯集了工程師、學生、學者、遺產愛好者和混凝土行業專業人士。一群傑出人士（其中一些參與了建築物的最初建設）自願花時間與專案團隊分享口述歷史。這些關於歌劇院建設的第一手資料對建築物現在和未來的保管人而言無疑是非常寶貴的資源。

### University of Sydney / 雪梨大學

Due to the multidisciplinary approach taken in the project, heritage conservation students were exposed to engineering concepts related to concrete structures, and engineering students became familiar with conservation principles relevant to 20th century concrete structures.

This provided a special experience for the students to gain an understanding on how their specific disciplines fit and contribute to address real world problems.

由於該計畫採用了多學科方法，遺產保存的學生們接觸到了與混凝土結構相關的工程概念，工程學的學生們也熟悉了與20世紀混凝土結構相關的保存原則，這為學生提供了一次特殊的經歷，讓他們了解他們的特殊訓練如何適應並有助於解決現實的問題。

