Studies in Conservation

ISSN: 0039-3630 (Print) 2047-0584 (Online) Journal homepage: http://www.tandfonline.com/loi/ysic20

Installation of an environmental monitoring system in the Chapel of Our Lady Guia, Macao

Zhong Tang & Shibing Dai

To cite this article: Zhong Tang & Shibing Dai (2014) Installation of an environmental monitoring system in the Chapel of Our Lady Guia, Macao, Studies in Conservation, 59:sup1, S149-S152, DOI: 10.1179/204705814X13975704318876

To link to this article: https://doi.org/10.1179/204705814X13975704318876

Published online: 30 Sep 2014.

Installation of an environmental monitoring system in the Chapel of Our Lady Guia, Macao
建設澳門聖母雪地殿教堂溫濕度監測系統

Zhong Tang 湯眾, Shibing Dai 戴仕炳

Architectural Conservation Laboratory, Tongji University, Shanghai, China
中國上海同濟大學歷史建築保護技術實驗室

Keywords: Chapel of Our Lady Guia, Conservation, Modern techniques, Environmental monitoring system
關鍵詞： 澳門聖母雪地殿教堂、文物保護、現代技術、監測系統

Built in the early seventeenth century, the Chapel of Our Lady Guia (Our Lady of the Snow) is one of the most important heritage sites in the historic centre of Macao. Despite its small size, the Chapel remains a landmark of the region due to its location at the top of Guia Hill.

The mural painting in the Chapel was discovered during a renovation project conducted by the Macao Portuguese government in 1996. All the interior walls and ceiling are decorated with mural paintings. The themes are mainly Biblical characters and stories, decorated with plant and animal patterns, painted using Chinese painting techniques. This combination of Chinese and Western art and culture makes it an unusual work of art in southern China (Fig. 1).

The Chapel has been well preserved in the three hundred years since it was built. The structure remains intact and without any serious damage, though signs of deterioration have been observed on the murals in recent years. The Cultural Heritage Department of the Cultural Institute of the Macao S.A.R. Government therefore asked the Laboratory for Conservation of Heritage Architecture of Tonji University (LCHA) to study, record, monitor, and evaluate the environmental condition and conservation problems of the Chapel, and to devise an improvement plan for conserving the architecture [1].

The LCHA combined the study of historical construction materials and the building environment with modern specialist technologies to analyse and identify the causes of mural deterioration in order to devise a conservation methodology. These techniques included using three-dimensional laser scanning to survey accurately the current state of the Chapel and murals [2], high definition digital photography to

澳門聖母雪地殿教堂位於澳門東望洋山頂，建於17世紀早期，是世界文化遺產澳門歷史城區的重要組成部份。聖母雪地殿教堂規模雖小，卻因其地理位置特殊成為了澳門地標建築。

澳葡政府於1996年對教堂進行內部保護和修復工程時，發現了壁畫遺跡。壁畫作為建築的室內裝飾遍佈牆面與天花，主題為聖經故事和人物，還有一些植物與動物圖案，並運用了中國繪畫的技法繪製，整個畫面是中西文化和藝術的大融匯，在華南地區屬罕見之藝術作品（圖1）。

聖母雪地殿教堂建成三百多年來保存基本完好，整體建築未經過明顯的破壞，但近年發現壁畫有劣化的趨勢。為此，澳門特別行政區文化財產廳委託同濟大學歷史建築保護技術實驗室對聖母雪地殿教堂進行建築實錄、病害診斷、環境監測及評估、改進設計方案的研究[1]。

同濟大學歷史建築保護技術實驗室應用歷史建築材料和建築環境多方面的最新專業知識和技術，分析和確定壁畫劣化的原因，設計並建立保護措施。其中包括：使用三維激光掃描技術精確測繪教堂與壁畫的現狀[2]、以高度精密數碼攝影詳細記錄教堂內部空間，更分別整體和局部地記錄壁畫、使用數碼化傳感器收集壁畫及環境溫濕度的數據、熱紅外成像分析壁畫受潮的位置與程度、微波掃描測量牆體內部的含水量變化、貫入阻力測試牆體內部的材料特性等。

經過初步研究，發現聖母雪地殿教堂內部壁畫是直接在石灰上繪製的濕壁畫，而石灰材料在溫度和濕度變化時會出現膨脹與收縮，這很可能是導致石灰基壁畫表層起皮脫落的原因。教堂內部的溫度與

Correspondence to: Zhong Tang, College of Architecture and Urban Planning, Tongji University, Room A209, Wenyuan Building, 1239 Siping Road, Shanghai, China. Email: tangzzzk@163.com

聯繫人：湯眾 同濟大學建築與城市規劃學院 中國上海市楊浦區四平路1239號文遠樓A209室 電郵：tangzzzk@163.com

DOI 10.1179/204705814X13975704318876

record the details of interior space as well as the overall and detailed views of the murals, digital sensors to collect the temperature (T), and relative humidity (RH) of the murals and the environment, infrared imaging to study the distribution and extent of moisture in the murals, microwave scanning to detect the change in water content, and a penetration resistance test to study the characteristics of the material of the internal walls.

Preliminary studies indicated that the murals were painted onto a lime ground while it was still wet. The present flaking and detachment of the paint layer from the lime ground may have been caused by the expansion and contraction of the lime ground in response to fluctuations in T and RH. The changes in T and RH inside the Chapel were complicated. Aside from seasonal and diurnal changes, the operation of air conditioning and visitors also affected the indoor environment. In addition, the distribution of T and moisture level varied in different positions and depths in the paintings. Therefore, it was necessary to install a system for collecting, storing, and analysing the environmental data relating to T and RH [3].

Based on the spatial composition and the mural distribution in the Chapel, the design layout of the T and RH monitoring system was 32 sensors in six groups in different locations. Three groups of sensors were installed at the narrow and long corridor and the front hall; one group at the worship hall; one group at the sacristy where a relay device was added to transmit far-end signals, and one group was installed outside the Chapel. Each group had more than one sensor to record the data [4].

As it was not convenient to collect data on-site regularly, the system was designed to be an unattended automatic remote monitoring system. The operation status of the sensors and the data collected were transmitted through a wireless network and stored on a main computer for regular data transmission through mobile communication 3G network to an internet server. A Dell OptiPlex 760 computer (specifications: Intel E5300/2.6 G Hz, Intel Q43 Express mainboard, 2G RAM DDR2 800, Samsung SSD 840 EVO 120GB solid state hard disk) was used for data collection, storage, and transmission. The cooling and safety protection of this host computer were enhanced.

It was necessary to consider the special requirements for a heritage building while selecting the hardware for monitoring: small size, high stability, and low power consumption were the criteria for consideration. Since the Chapel was not suitable for installation of the large T and RH sensors currently available in the market, the LCHA developed wireless sensors for the project. The sensors were made from the SHT series digital T and RH data collection chip with

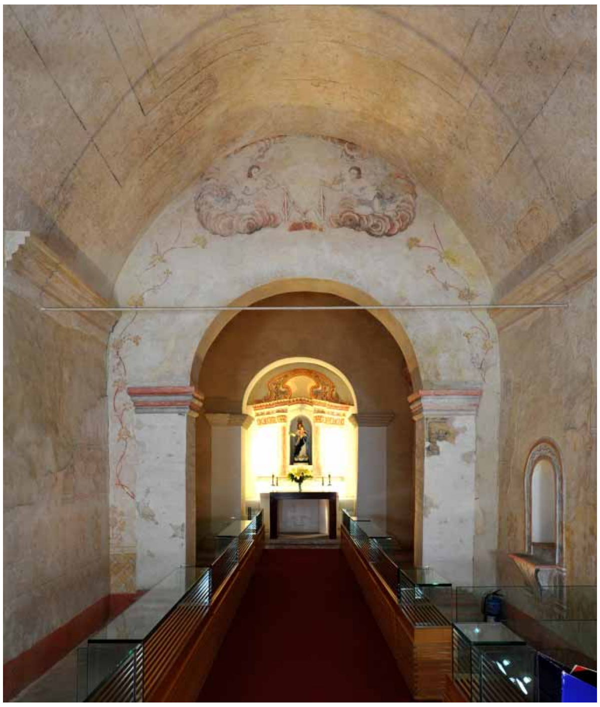

Figure 1 Murals inside the Chapel
圖 1 教堂內壁畫現狀

濕度變化情況比較複雜，除了室外季節晝夜交替對室內的影響，室內空調的運行和遊客的進出也會使其發生變化。另外，平面與剖面上不同的位置有不同溫濕度分佈，所以有必要為此建立一個環境溫濕度監測系統來採集、存儲及分析環境溫濕度的數據[3]。

溫濕度監測系統根據教堂的空間構成和壁畫分佈位置設計而成。傳感器分六組32處佈置，包括在教堂較為狹長的門廳和前殿置三組；在教堂拜殿置一組；在教堂聖器室置一組並添加中繼器以傳遞遠端信號；另外在室外也有一組，而每組佈置都設有多個傳感器收集不同位置的溫濕度變化數據[4]。

由於不便經常赴現場採集數據，整個監測系統設計成可在無人值守的環境下自動運行和作遠程監測。各個傳感器的工作狀態以及所得數據首先通過無線網絡傳輸並存儲於主機中，再定時由主機經移動通信3G網絡傳遞至互聯網伺服器。設備採用戴爾OptiPlex 760電腦系統（規格為英特爾E5300/2.6 G Hz, 英特爾Q43 Express主版，2G 隨機存儲 DDR2 800, 三星SSD 840 EVO (120GB) 配置固態硬盤）作為數據採集、存儲和傳輸，這設計能加強主機的散熱和安全防護。

設備選型要充分考慮文物建築的特殊要求，以小型、穩定、低功耗為標準。由於聖母雪地殿教堂不適合使用體積較大的市售溫濕度傳感器，因此同濟大學歷史建築保護技術實驗室自行研發專用無線傳感器，採用SHT系列數字溫濕度採集芯片，配合Zigbee無線傳輸模塊組成數據採集變送傳感器。

Zigbee wireless transmission module. The SHT sensor utilised patented CMOSens technology to integrate a thermo-humidistat comprising a single-capacitor humidity sensor, and a bandgap temperature sensor, a 14-bit A/D converter, and a two-wire digital connector. These sensors were small, had low power consumption, were fast in response, simple to connect and strong in interference resistance, thus meeting the requirements of reliability and long-term stability for monitoring.

As the spatial arrangement of the interior of the Chapel is very simple, the sensors installed were placed in such a way as to minimise their visibility (Fig. 2). Original decorative lines and existing steel reinforcing bars were used to install and secure them. The main computer was placed in the position of the original choir chair in the hall above the entrance of the Chapel, which was not open to the public. A separate entrance to this area facilitated maintenance.

The monitoring system has undergone fine-tuning and test-running since the hardware was installed. T and RH data were collected every 10 minutes by the 32 sensors. From April to October 2013, nearly a million pieces of data were collected. This indicated that the interior T of the Chapel ranged from 15.1°C to 29.3°C while RH ranged from 67 to 100%. Detailed analytical studies will be carried out by building environment specialists after the monitoring system has been in operation for a sufficient period of time.

The weather in Hong Kong, Macao and Southeast Asia region is relatively high in T and RH, and air conditioners are widely used in urban areas. The rapid alternating cycles of cooling/heating and dehumidifying/humidifying has a great impact on building heritage. The T and RH monitoring system installed in the Chapel will be used for long-term environmental monitoring inside and outside the Chapel and studying the effect of environmental changes on heritage conservation. It can also be used as a reference for the conservation of similar built heritage.

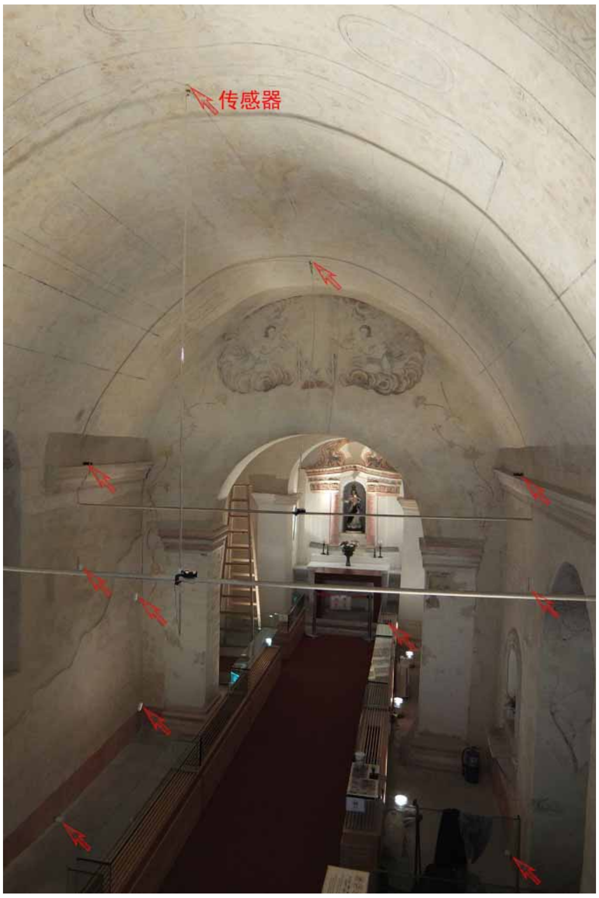

Figure 2 The locations of the installed sensors
圖 2 部份感測器安裝位置

SHT系列傳感器採用互補金屬氧化物半導體過程微加工專利技術，將一個電容式聚合體測濕元件和一個能隙式測溫元件組成溫濕度傳感器、一個14位A/D轉換器及一個二根信號線數字接口無縫結合，使傳感器體積小、功耗低、反應速度快、接口簡單、抗干擾能力強，並符合高度可靠和長期穩定的監測要求。

聖母雪地殿教堂的內部空間非常簡潔，傳感器的現場安裝需要因地制宜，盡量減少對室內觀瞻的影響（圖2）。在建築裝飾線腳和後期加固鋼筋等現有構件上放置和固定傳感器，主機則放置在教堂入口門廳上方的原唱詩席，此處不對遊客開放，並且另有獨立出入口，便於日常維護。

目前系統硬件已大致安裝完成，正在調試和試行運作。32個傳感器每隔10分鐘採集一組溫濕度數據，從2013年4至10月的半年多時間內已經斷續採集近百萬組數據。目前錄得的室內溫度最低為15.1°C，最高29.3°C；相對濕度最低為67%，最高接近100%。詳細的數據分析結果要在系統正式持續運行一個階段以後，由科研團隊中的建築環境專家進行專業研究後才能得出。

港澳地區以及東南亞地區的環境溫度及濕度較高，而現代城市生活普遍使用空調，這種冷暖乾濕

快速交替的環境對建築文物影響非常大。本文通過在澳門聖母雪地殿教堂建立溫濕度監測系統，對教堂內外的溫濕度環境進行長期監測，力求找出環境變化與文物保護的關係，為類似的建築文物保護提供參考和借鑒。

References 參考文獻

[1] 戴璐：〈澳門東望洋山聖母雪地殿壁畫考察報告〉,《文化雜誌》2009年春，第70期，頁1-52。
[2] 湯眾：〈空間信息採集中的三維激光掃描技術應用〉，載於《2006年全國高等院校建築數字技術教育研討會論文集》（廣州：華南理工大學出版社），頁159-162。
[3] 湯眾、張鵬：〈寧波市保國寺文物建築科技保護監測系統設計〉，載於余如龍編《東方建築遺產》（北京：文物出版社，2007），頁69-72。
[4] 湯眾：〈文物建築綜合信息系統構建探索—以圓明園為例〉，載於Re-relic編委會編《數字化視野下的圓明園》（上海：中西書局，2010），頁139-142。