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RESEARCH ARTICLE

# Materials analysis of traditional Chinese copper halls using XRF and GIS: Kunming Copper Hall as a case study

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## Abstract

This paper presents the framework and results of analysis of the building materials used in traditional Chinese copper halls. The analysis of the Kunming copper hall (KCH) is presented as a typical example. First, the historical building structure of the KCH is investigated. Results of X-ray fluorescence (XRF) spectrometry are presented and analyzed according to the units of each building component. The results indicate that the different components in the same building were cast out of different alloys such as bronze, brass, and red copper. Furthermore, the XRF results are loaded into the geographic information system (GIS) to examine the relations between the building components and their materials. The GIS analysis indicates that the different alloys were deliberately chosen according to the function of each piece in the structure. Finally, the reason and significance of this phenomenon is discussed from the perspective of architectural history and the history of science and technology.

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## 1. Introduction

Copper hall is a special type of traditional building in Chinese architecture. Copper halls imitate traditional Chinese timber architecture in terms of their structure, with all their components cast from copper alloys. When western travelers and missionaries introduced Chinese architecture to the western world at the end of the 19th century, they already noticed these shining copper halls. Although they did not have sufficient knowledge and technology to analyze the building materials at that time, these copper buildings were referred to as “golden

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temples”, “bronze shrines”, or “brass temples” (Baber, 1882; Baker, 1971). Joseph Needham originally thought that these buildings were cast out of bronze (Needham, 1971). Except for the term “golden temples”, all the other terms are inaccurate because some copper halls are made of bronze, others are made of brass, and two of them are a mixture of both. Bronze and brass are different copper alloys. The history and significance of the application of these two alloys in China is extremely different. Thus, the determination of the accurate composition of the alloys is significant to architectural history and the history of science and technology. Furthermore, if the alloys were deliberately chosen for each building or for each building component, the strategy and motivation for choosing the building materials is worth discussing to propose important theories on the application of building materials in architectural history as well as the history of science and technology. Finally, the results of the analysis will provide a necessary database for the preservation of the copper halls.

However, after the above mentioned initial attempts, no further research on the structure or the materials of the copper halls was conducted by Chinese or Western scholars for over a century. Up to date, China has six surviving ancient copper halls, which are dated from 1307 AD to 1755 AD, as shown in Table 1. These halls are located in different regions of China, and most of are located in the mountains. Previous scholarship did not obtain material samples for laboratory analysis, because the existing techniques were limited, and the material issue did not attract sufficient interest from historians. Further, all the copper halls are National Protected Cultural Properties. Thus,

sample collection from these may damage to the properties, although a few samples are occasionally permitted to be taken.

This study is part of a project on Chinese metal architecture started in 2006. Since then, all the surviving copper halls, as well as the monastery sites that used to have copper halls, are investigated. The history, structure, and building materials of each copper hall have been analyzed. A portable XRF device is used to conduct onsite analysis. Thus, no samples were taken from the buildings. The earliest copper hall is made of bronze (Cu-Sn, Cu-Pb, and Cu-Sn-Pb). Three halls are completely made of brass (Cu-Zn and Cu-Zn-Pb). One hall is made of both bronze and brass. The most complicated structure, the Kunming copper hall (referred to as KCH), is made of bronze, brass, and red copper (98% Cu). In this paper, the results of the XRF and GIS analysis of the KCH are presented as a case study to illustrate the framework and contributions of the entire project.

## 2. Materials and methods

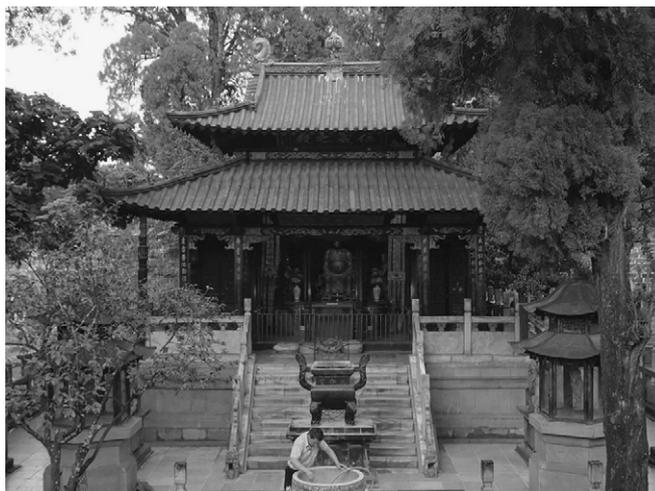
### 2.1. History and structure of the KCH

#### 2.1.1. History

The KCH is the main building of the Taihe Gong (Taoist monastery) located on the top of the Mingfeng Hill of Kunming (the capital of Yunnan Province in Southwest China). Before this copper hall was built, there used to be another hall that was originally built in 1602 during the Ming Dynasty. However, the former hall was moved to Jizu

**Table 1** Surviving copper halls in China.

| Site                                  | Year of construction | Material                      | Religion |
|---------------------------------------|----------------------|-------------------------------|----------|
| Xiaolian Peak, Wudang Mountain, Hubei | 1307                 | bronze                        | Taoism   |
| Tianzhu Peak, Wudang Mountain, Hubei  | 1416-1418            | brass                         | Taoism   |
| Wutai Mountain, Shanxi                | 1605-1607            | brass                         | Buddhism |
| Taishan Mountain, Shandong            | 1613-1614            | bronze and brass              | Taoism   |
| Mingfeng Hill, Kunming, Yunnan        | 1671                 | bronze, brass, and red copper | Taoism   |
| Summer Palace, Beijing                | 1755                 | brass                         | Buddhism |



**Figure 1** Photograph of the KCH.

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