Frontiers of Architectural Research (2013) 2, 74–84

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Frontiers of Architectural Research

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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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Received 15 October 2012; accepted 12 November 2012

KEYWORDS
Chinese traditional architecture;
Copper hall;
X-ray fluorescence;
Geographic information system;
Architectural history

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.

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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Peer review under responsibility of Southeast University.

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http://dx.doi.org/10.1016/j.foar.2012.11.006

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

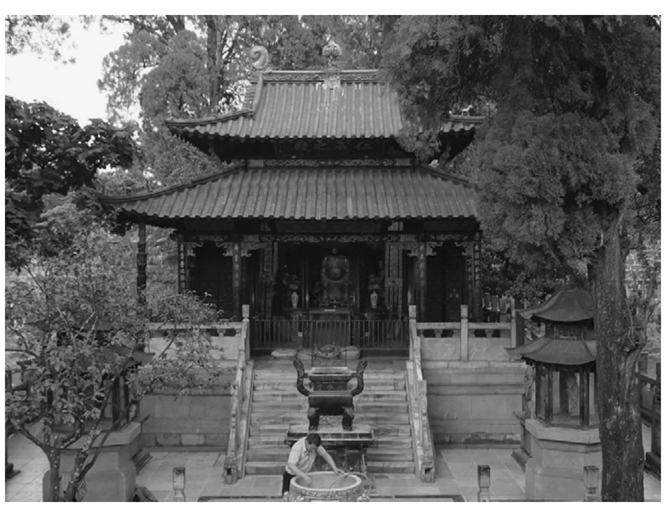

Figure 1 Photograph of the KCH.

Mountain in 1637 and was demolished in 1966. The current copper hall (see Figure 1) on the site of Taihe Gong was built in 1671 (during the early Qing Dynasty), when the famous General Wu Sangui occupied this prefecture, who rebelled the Qing court two years later. In our investigation, many carved inscriptions are found on the surface of the copper hall, which indicate that the copper hall was patronized by Wu Sangui, his high officials, and several wealthy local residents. Wu Sangui was probably the major patron because his name is written on a prominent position, that is, at the bottom of the ridge purlin, so that it can be easily read (Zhang and Zhou, 2009).

The KCH is surrounded by a brick wall. The presence of a copper hall, as well as the layout of the building complex, imitates of the famous Golden Hall of Wudang Mountain, which implies a significant Taoist meaning. However, the architectural style of the KCH is more indigenous, rather than simply being a copy of the Wudang copper hall. The plan of the KCH is 6155 mm by 6120 mm, which is the largest among all the surviving copper halls (see Figure 2).

2.1.2. Structure

The structure of the KCH is illustrated in Figures 3 and 4. The building stands on a large, two-storey stone platform. Except for the stone platform, all other components are cast out of copper. The KCH has two levels of eaves. The upper eave is supported by the four inner columns, which are higher than the outer columns. The inner and outer columns are linked by tie beams. Two layers of tie beams on top of each column bind the columns together. Bracket sets are placed on top of the tie beams, on the columns, and between the columns. Above the bracket sets are the purlins, which support the rafters and roof tiles. Aside from the inner and outer columns, four corner pillars support the lower eave. The four corner pillars are more elaborate than the other columns. Judging by their inscriptions, these pillars were probably erected at the same time when the copper hall was built.

Between the columns, there are lattice doors on all the four sides, but only the front lattice doors can be opened. To set the lattice doors in each bay, a group of frames are built in on the floor and beside the columns. The construction of the joints of the roof tile and the rafters for this structure differs from that of timber architecture because the roof tiles directly fit onto the rafter, without any mortar.

The inner surface of the lattice doors has a golden layer above it. Further analysis shows that the surface used to be gilt (Zhang and Zhou, 2009).

2.2. XRF analysis

To prevent damage to the historic building, no samples were retrieved from the KCH in accordance with the law on relic preservation in China. A portable XRF device (Niton XLt 898; Thermo Fisher Scientific Inc.) is used to conduct the on-site analysis. The device uses a 35 kV and 1.0 W Ag anode tube, with an analytical range from Ti to Bi. The testing for each point lasts from 20 s to 30 s (at least 5 s are required). Each piece under the bracket sets of the lower eave is tested. The bracket sets and the roof tiles of the lower level are randomly tested. The analyzed components of the lower level can cover all the types of materials in the whole

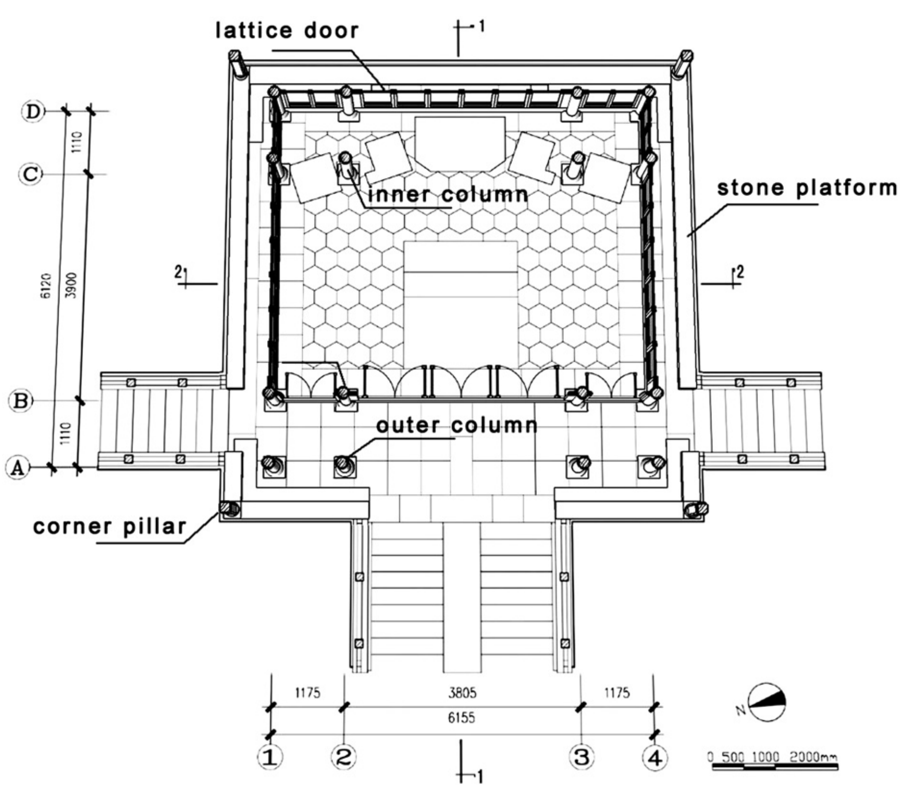

Figure 2 Plan of the KCH.

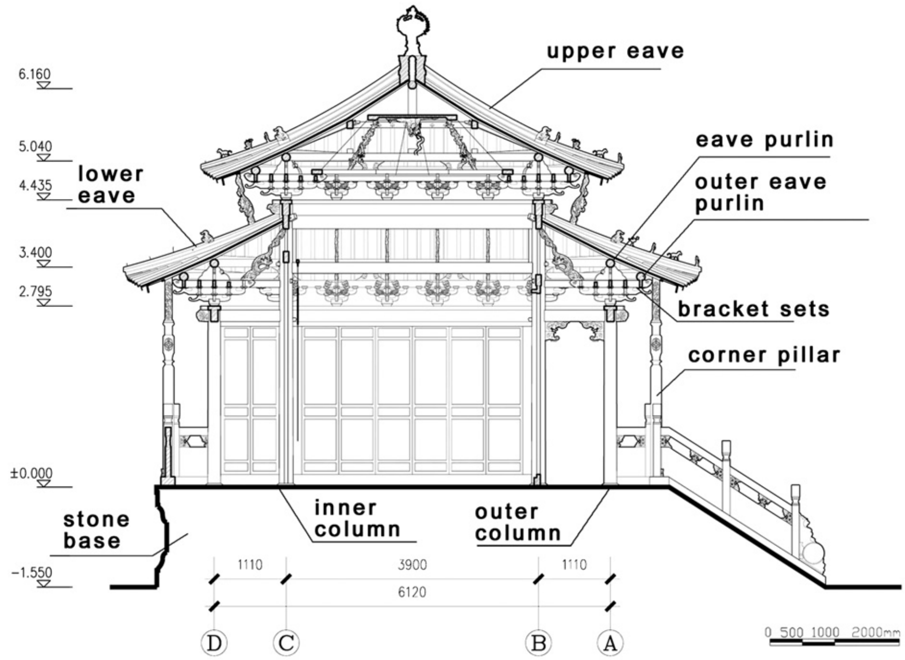

Figure 3 Section 1-1 of the KCH.

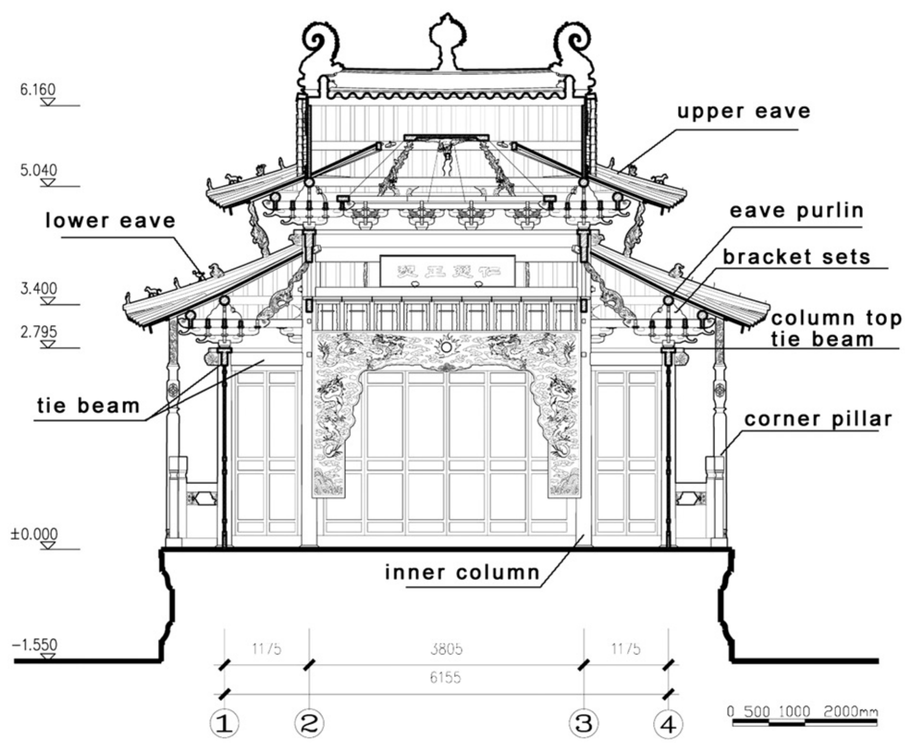

Figure 4 Section 2-2 of the KCH.

building. Therefore, although the components from the upper level of the KCH have not been tested, their composition could be inferred from the same type of components of the lower level. For example, the bracket sets from the upper level are probably identical to the bracket sets from the lower level because they are of the same size and style and are completely interchangeable. Each piece of the components is tested twice to three times to obtain a reliable result. Some components are tested more than three times to obtain the average result.

2.3. GIS analysis

To indicate and examine the relation between the building components and their materials, each building component is assigned an exclusive number in ArcGIS. The XRF results are

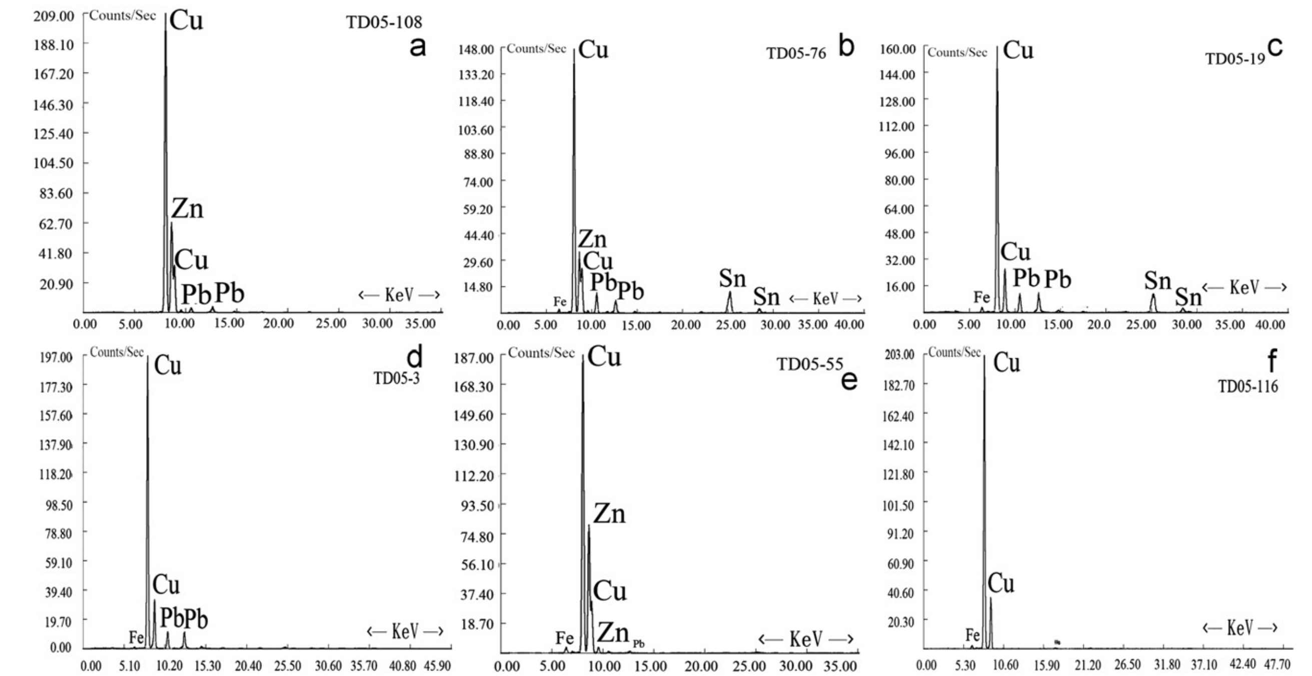

Figure 5 Energy-dispersive spectra: (a) leaded brass (Cu-Zn-Pb); (b) leaded gunmetal (Cu-Zn-Pb-Sn); (c) leaded bronze (Cu-Pb-Sn); (d) leaded copper (Cu-Pb); (e) brass (Cu-Zn); (f) red copper (Cu).

then added in as values. The distribution of brass, bronze, and red copper in the analyzed components of the KCH are illustrated by Figure 6(a) and (b) by classifying the percentage of Zn and Sn. In the figure, the components in yellow are made of brass, those in green are of bronze, and those in red are of red copper.

3. Results

3.1. XRF analysis results

The XRF results are summarized in Table 2. Given the space limitations, not all the data are listed in this paper, but each type of analyzed component is listed at least once. Elements with more than 2.0% are recognized as components of the alloys. Otherwise, these elements are considered impurities. For example, only materials that contain more than 2.0% Zn are considered to be brass. Six kinds of copper alloys are used in the KCH: leaded bronze (Cu-Pb-Sn), leaded copper (Cu-Pb), leaded gunmetal (Cu-Zn-Pb-Sn), leaded brass (Cu-Zn-Pb), brass (Cu-Zn), and red copper (Cu), which can also be sorted into three groups: bronze, brass, and red copper. Furthermore, the four corner stones of the stone platform are made of iron. These corner stones are used to strengthen the corner of the stone base by pinning the stones together.

Au and Hg are found in some of the components of the structure (marked with *), which indicates that the surface of those parts used to be gilt. However, the gilded layer prevents the X-rays from reaching the copper alloy beneath it. Thus, the accuracy of these points is affected.

The typical energy dispersive spectra of the leaded brass, leaded gunmetal, leaded bronze, leaded copper, brass, and red copper of the KCH are shown in Figure 5.

3.2. GIS analysis results

The following observations can be made from Figure 6: First, among the analyzed components, most of the major structural components such as the columns, plinth, tie beams, and the column top tie beams are made from bronze. Second, the components that have a secondary function in the building structure, such that the door frames, the lattice doors, and the thresholds, are made of brass. Third, the roof tiles are made of red copper, including the plain tiles and the water-drop-shaped tiles that have no structural functions. Meanwhile, all the pieces of the bracket sets as well as the corner pillars and their plinths are made of brass. Therefore, the logic of the distribution of the different kinds of copper alloys is evident. The clear diversity in the use of bronze, brass, and red copper is based on the function and position of the building components.

In traditional Chinese architecture, the components are manufactured under modular and regularization, especially those that exist in large quantities. Therefore, usually there are no differences between the same components occur in the same building, so that they are interchangeable. The XRF results for the columns, plinth, frames, and lattice doors from the lower level of the KCH prove that the same type of components from different parts of the building are made from the same kind of alloy, except for a few exceptions. Therefore, the randomly analyzed bracket sets, roof tiles, and rafters can represent the remaining parts of the structure.

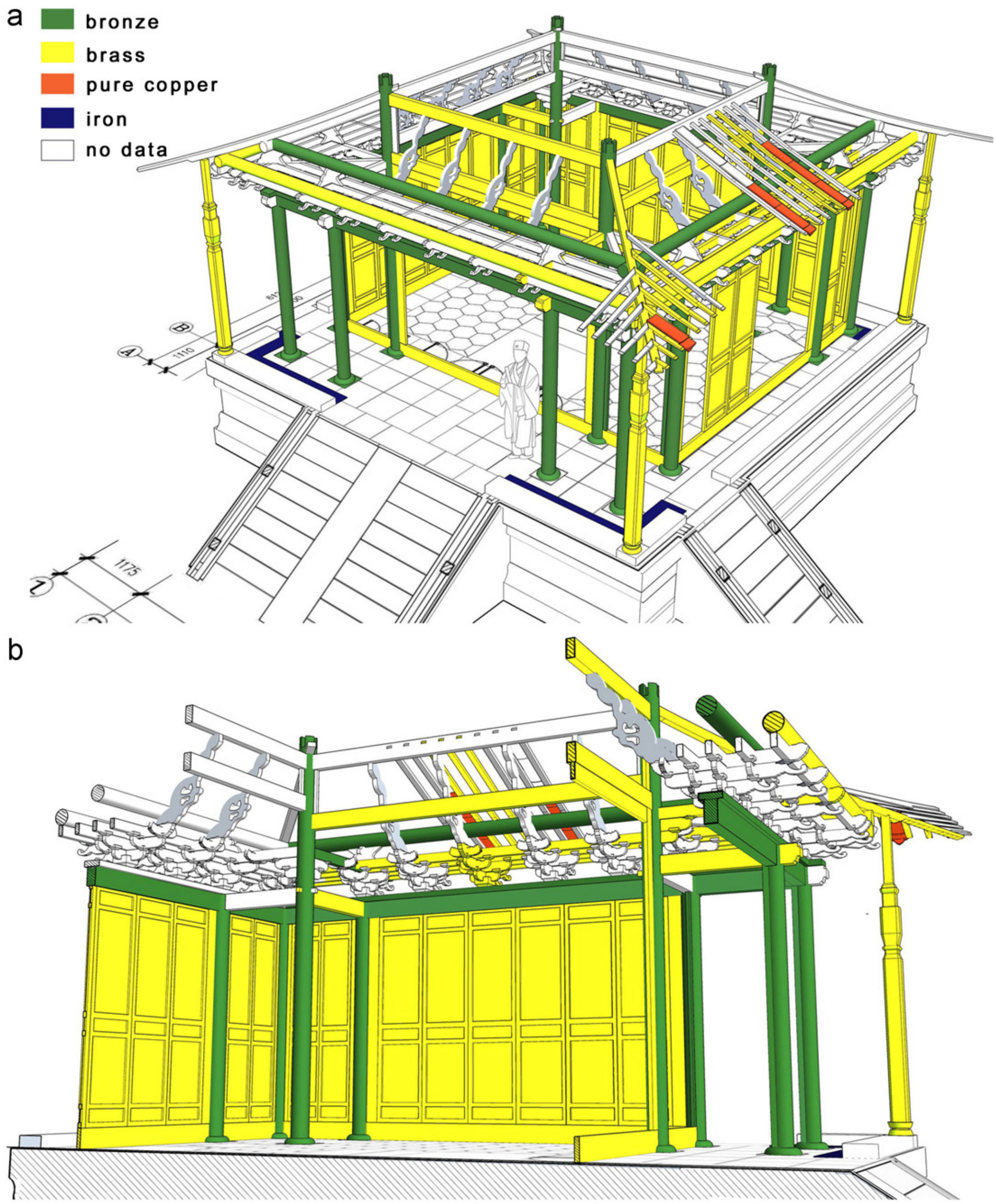

Figure 6 GIS alloy map of the XRF results for the KCH: Perspective view of (a) the entire building and (b) the 1–1 section.

From this perspective, the distribution of the copper alloys in the entire building can be inferred even though not every single piece in the KCH has been tested, as shown in Figure 7. (The colors in the figure only indicate the types of the alloys, not the surface color of the components. The roof ridges and the gable board have not been tested, so they are left blank).

4. Discussion

4.1. Bronze and brass

According to Chinese metallurgical history, the country has a long tradition of casting bronze vessels (since the 11th century BCE) and coins. Although brass has been used to cast statues (especially in the Buddhist monasteries) as early as the arrival of Buddhism in China, the most common type of copper alloy before the 16th century has always been bronze. China officially began to use cementation brass to cast copper coins in 1522 AD and began using speltering brass in 1621 AD (Zhou et al., 1994; Bowman et al., 1989). After 1522, brass replaced bronze as the major copper alloy in China. The copper hall in E'mei Mountain (constructed in 1602–1603, with only a few surviving pieces) and the copper hall in Wutai Mountain (1605–1607), as well as the copper pagodas (constructed around 1610) in both two mountains, are all cast in brass, thereby exemplifying the popularity of brass after the 16th century.

Table 2 XRF analysis of the KCH.

No.	Sn%	Pb%	Hg%	Au%	Zn%	Cu%	Fe%	Building Component	Alloy Type
TD05-1	1.1	8.9	NA	NA	0.2	88.2	1.1	plinth A1	Cu-Pb
TD05-10	7.9	18.8	NA	NA	0.5	71.6	0.6	plinth C4	Cu-Pb-Sn
TD05-11	0.7	29.6	NA	NA	1.8	64.4	2.8	plinth D1	Cu-Pb
TD05-15	0.6	40.1	NA	NA	1.5	56.5	0.9	beam C3	Cu-Pb
TD05-19	6.1	15.1	NA	NA	NA	76.7	1.7	column A4	Cu-Pb-Sn
TD05-20	0.8	11.1	NA	NA	0.9	85.2	1.3	column B1	Cu-Pb
TD05-25	8.2	13.1	NA	NA	0.3	76.2	1.6	column C2	Cu-Pb-Sn
TD05-27	0.2	8.4	NA	NA	1.5	88.8	0.3	column C4	Cu-Pb
TD05-28	3.7	15.5	NA	NA	0.5	79.0	0.6	column D1	Cu-Pb-Sn
TD05-33	2.5	24.8	NA	NA	0.5	70.7	0.9	tie beam A2A3	Cu-Pb-Sn
TD05-35	1.8	20.3	NA	NA	0.3	75.1	1.7	tie beam B4C4	Cu-Pb
TD05-37	0.3	7.4	24.7	NA	0.9	63.8	0.3	column top tie beam B1C1	Cu-Pb
TD05-38	2.4	22.7	NA	NA	0.5	73.3	0.2	column top tie beam B4C4	Cu-Pb-Sn
TD05-39	NA	6.7	14.7	2.8	0.3	74.1	0.2	eave purlin A2A3	* Cu-Pb
TD05-40	0.8	13.4	NA	NA	1.6	83.0	0.7	eave purlin B4C4	Cu-Pb
TD05-41	5.8	5.8	NA	NA	8.8	77.5	1.3	plinth (NE corner pillar)	Cu-Zn-Pb-Sn
TD05-43	0.8	7.3	NA	NA	10.1	79.9	1.0	plinth (SE corner pillar)	Cu-Zn-Pb
TD05-47	0.2	4.8	NA	NA	15.6	78.7	0.5	corner pillar SE	Cu-Zn-Pb
TD05-48	0.1	5.2	NA	NA	21.4	72.9	NA	corner pillar SW	Cu-Zn-Pb
TD05-54	2.1	5.5	NA	NA	13.9	77.3	0.8	frame B2 S	Cu-Zn-Pb-Sn
TD05-55	0.2	1.6	NA	NA	23.6	73.3	1.0	frame B3 N	Cu-Zn
TD05-57	0.8	20.3	NA	NA	5.0	72.7	0.6	frame C1 E	Cu-Zn-Pb
TD05-70	0.2	7.0	NA	NA	17.3	75.1	NA	threshold B1B2	Cu-Zn-Pb
TD05-76	5.9	10.1	NA	NA	11.5	70.5	0.9	threshold D1D2	Cu-Zn-Pb-Sn
TD05-79	0.1	1.7	18.5	1.8	12.6	55.5	6.5	top frame B2B3 (lower)	* Cu-Zn-Fe
TD05-80	1.3	16.2	9.0	2.5	4.7	64.5	0.6	top frame B2B3 (side)	* Cu-Zn-Pb
TD05-81	0.1	5.3	29.4	NA	10.7	42.4	7.7	top frame B2B3 (upper)	* Cu-Zn-Pb
TD05-85	1.9	6.4	NA	NA	14.9	76.2	0.3	lattice door D2D3	Cu-Zn-Pb
TD05-87	0.2	9.0	NA	NA	12.2	78.2	0.1	lattice door D2D3	Cu-Zn-Pb
TD05-88	NA	4.2	12.3	NA	12.6	69.2	0.6	lower tie beam A3B3	* Cu-Zn-Pb
TD05-92	NA	8.1	NA	0.7	8.5	82.2	0.2	outer eave purlin B4C4	Cu-Zn-Pb
TD05-93	0.3	5.9	NA	NA	8.0	84.4	0.8	capital block	Cu-Zn-Pb
TD05-94	0.2	1.5	7.6	NA	13.6	75.7	0.9	parallel bracket 1st level	* Cu-Zn
TD05-95	1.1	3.7	NA	NA	8.6	85.2	0.8	long bracket 1st level	Cu-Zn-Pb
TD05-96	2.3	6.7	3.8	0.9	8.7	75.6	1.0	short bracket	* Cu-Zn-Pb-Sn
TD05-97	0.7	4.5	NA	NA	13.3	78.5	2.1	projecting bracket 1st level	Cu-Zn-Pb
TD05-98	0.3	4.1	NA	NA	12.8	81.7	0.6	projecting bracket 2nd level	Cu-Zn-Pb
TD05-99	1.4	4.5	NA	NA	12.5	79.1	1.6	cross block	Cu-Zn-Pb
TD05-100	0.3	3.2	NA	NA	9.2	86.4	0.6	end block 1	Cu-Zn-Pb
TD05-102	0.4	10.3	20.3	NA	3.4	62.0	0.9	locust head	* Cu-Zn-Pb
TD05-103	2.1	11.9	10.5	NA	12.6	60.9	0.5	T-bracket B3 1st level	* Cu-Zn-Pb-Sn
TD05-104	0.2	4.0	15.6	NA	7.8	70.5	0.7	T-bracket B3 2nd level	* Cu-Zn-Pb
TD05-107	0.2	5.9	15.2	NA	18.5	57.4	0.6	plain beam inside A3B3	* Cu-Zn-Pb
TD05-108	NA	5.0	NA	NA	18.1	76.4	NA	corner beam (SW)	Cu-Zn-Pb
TD05-109	0.4	23.5	NA	NA	9.9	64.1	1.3	plain beam inside B4C4	Cu-Zn-Pb
TD05-110	2.8	7.0	NA	NA	12.4	77.5	NA	plain beam outside B4C4	Cu-Zn-Pb-Sn
TD05-111	0.3	7.8	13.1	NA	11.6	66.3	NA	plain beam under TD05-40	* Cu-Zn-Pb
TD05-113	0.1	4.6	NA	NA	11.3	82.3	0.8	rafter 1	Cu-Zn-Pb
TD05-114	0.1	5.3	NA	NA	8.9	84.3	0.7	rafter 2	Cu-Zn-Pb
TD05-116	NA	0.1	NA	NA	NA	98.3	0.9	roof tile 1	Cu
TD05-117	NA	NA	NA	NA	0.3	98.7	0.8	roof tile 2	Cu
TD05-118	NA	0.1	NA	NA	0.2	98.0	1.2	roof tile 3	Cu
TD05-120	NA	NA	NA	NA	2.8	93.4	2.0	water-drop tile	Cu
TD05-123	0.3	NA	NA	NA	NA	0.8	97.8	corner stone	Fe

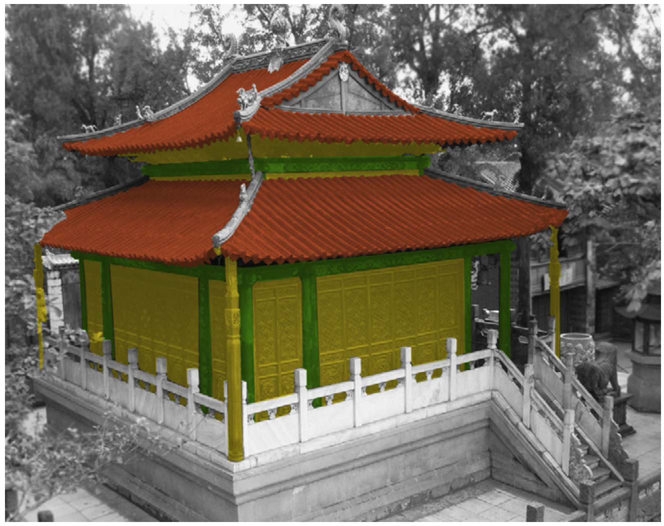

Figure 7 Concluded alloy distribution map of the KCH.

Figure 8 Copper hall in Taishan Mountain.

Given this historical background, brass is assumed to be the first choice when the KCH was built. However, bronze, rather than brass, was used to cast the major structural components. This phenomenon implies a preference for bronze of the craftsmen who selected the major structural building materials. From the perspective of modern materials science, brass does not have worse mechanical performance than bronze and even has a more attractive color. However, the craftsmen of the KCH preferred bronze, in accordance with their own experience and traditional techniques. The plinth, columns, tie beams, column top tie beams, and the purlins above the bracket sets were all considered structural and primary. Meanwhile, the lattice doors, frames, and bracket sets are considered as decorative or secondary. Thus, these components were cast out of brass.

The preference for bronze can also be observed in the copper hall found in the mountain of Taishan (constructed in 1613–1614: Figure 8). In this building, most of the major structural components are made of bronze, and the other components are made of low Zn brass. According to a previous study (Zhang, 2012), the Taishan copper hall might have been made entirely from bronze. However, financial reasons probably caused the structure to have more than one-third of its components made of brass, which is a cheaper alternative during the time of the hall's construction (He, 1995–1999). As indicated in Figure 9, most of the major structural components (all the four corner-spanning beams and three of the columns) are made from bronze.

Most of the components from both copper halls have been appropriately classified, based on modern architectural knowledge. However, the classification is not always accurate. For example, the bracket sets, the corner pillars, and the plinths of the KCH are considered as secondary and decorative, but these components have structural functions according to modern architectural knowledge. That the

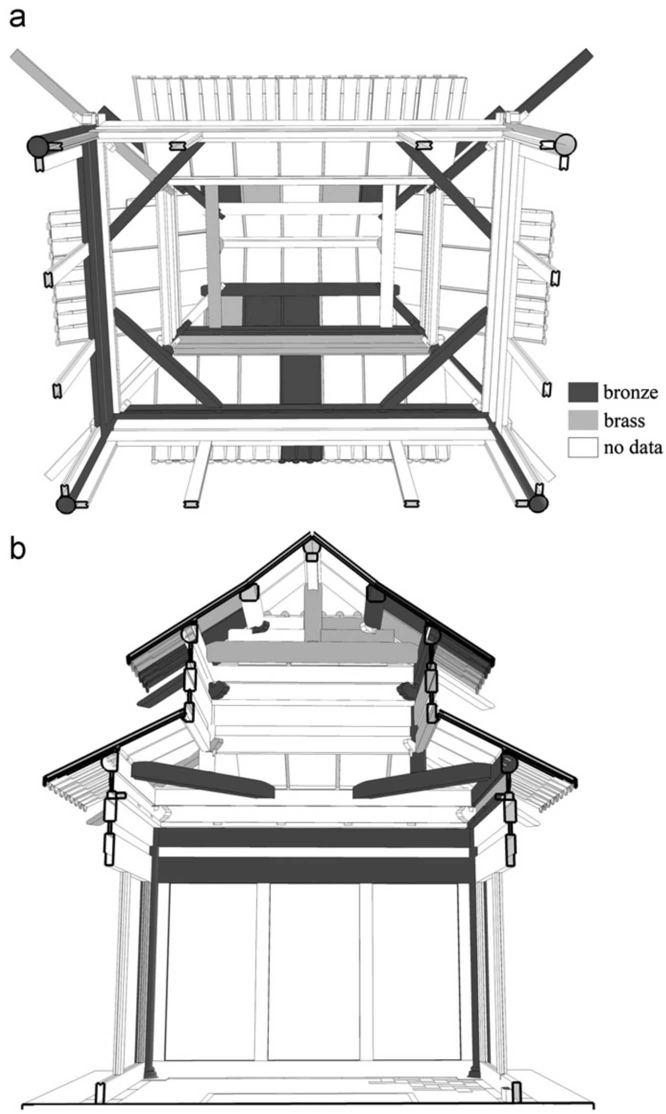

Figure 9 GIS alloy map of XRF results for the copper hall in the Taishan Mountain. Perspective view of (a) the ceiling and (b) the selected section.

craftsmen considered these features to be decorative rather than structural is understandable given the numerous decorations on the bracket sets. Likewise, the additional corner pillars have elaborate ornaments. Nevertheless, the accuracy of the classification of the components is not the main topic of this paper. The key point is the need for the classification of these components. That is, the motivation behind the deliberate decision to cast the building using different kinds of alloys.

4.2. Possible theoretical sources

Two possible theories in metallurgical history could explain the observed phenomenon. First, it can be interpreted as the practice of the ancient metallurgical technique called the "six recipes" (*liu ji*). The "six recipes", as recorded in the ancient text *zhou li kao gong ji*, is a theoretical manual for the casting of the six types of bronze, which was dated no later than the Warrior States period. According to the "six recipes" theory, the recipes for the specific types of bronze are differentiated by the proportion of the copper and tin. Therefore, these six types of bronze works, namely, the bell and tripod, the axe, the spear and halberd, the sword, the arrow head, and the mirror would exhibit suitable performance because of the deliberate and specific proportions of copper and tin.

The detailed explanation of the "six recipes" has been the subject of debate (Chang, 1958; He, 2009; Hua 1999). Likewise, the casting of the KCH in not definitely based on the "six recipes". However, the core philosophy and principle of the "six recipes" aim to perfectly produce products by combining well-proportioned materials.

Another possible explanation is the theory of "temper the hard and flexible mutually assist each other" (*gang rou xiang ji*). As a typical Chinese philosophy, this theory can often be found in historic texts such as the *zhou yi* and *huai nan zi*, which discuss the dialectic relationship between two

Figure 10 Copper hall in the Xiaolian Peak, Mount Wudang.

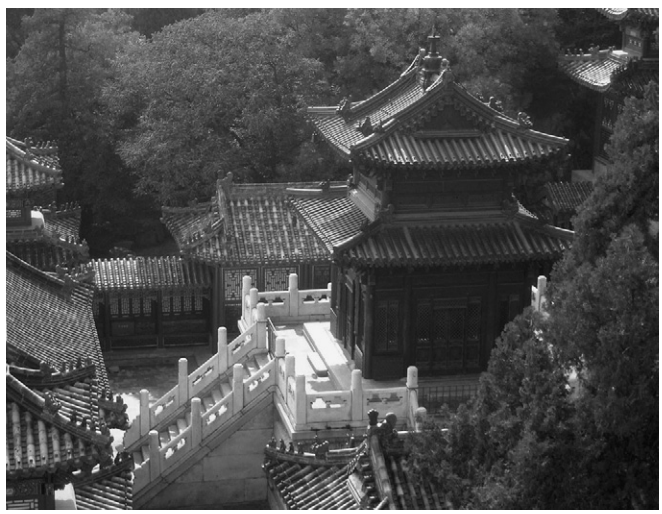

Figure 11 Copper hall in the Summer Palace of Beijing.

states on the philosophical level. Furthermore, this theory has technological applications in China. For example, bone knives with stone blades were excavated from a Neolithic site in Gansu (Archaeological Team of Gansu Provincial Museum, 1974), bronze axes with iron blades were excavated from the middle Shang Dynasty (16th to 11th century BC) in Hebei and Beijing (Hebei Provincial Museum, 1973; CPAM, 1977), and numerous multi-material swords were excavated from the period of the Warrior States (5th to 3th century BC). The multi-material swords are made of a bronze body combined with iron blades, or low-Sn bronze body combined with high-Sn bronze blades (He, 1995–1999). This technology is recorded in the famous 11th century scientific book *Dream Pool Essays* (*Meng Xi Bi Tan*) by Shen Kuo (Shen, 1965-1970).

This theory can persuasively explain the diversity of the copper alloys used in the KCH. According to the craftsman's experience and knowledge, bronze is used for the primary structural functions, brass for secondary and decorative functions, and red copper for decorative functions. Therefore, the merits of each material are utilized by combining all of them.

4.3. Craftsmen and building construction

As a minor form of Chinese traditional architecture, copper halls imitate the style and the structure of timber architecture. However, the ancient and profound technological traditions and theories in metallurgy have been integrated into the copper halls. The different copper alloys are deliberately assigned to different positions, which can only happen under two conditions: First, the craftsmen are aware of the different alloys. Second, the craftsmen have the knowledge of architecture, specifically with respect to structural knowledge. Therefore, the construction of such buildings can only be achieved through the collaboration of the craftsmen from both professions. The coppersmiths should have played a key role during construction. Regrettably, no records exist of the coppersmiths or carpenters involved in the construction of the KCH. However, from the inscriptions on the copper hall in the Xiaolian Peak of the Wudang Mountain (Figure 10), and the copper hall in the Summer Palace of Beijing (Figure 11), the chief craftsmen were clearly those who skills in foundry.

5. Conclusions

Unlike the analysis of objects such as bronze vessels, statues, or coins, the analysis of copper-based architecture should be implemented based on the building components. Otherwise, the material selection strategy of the architecture cannot be identified.

The KCH is a typical example that illustrates the materials used in traditional Chinese copper halls. The XRF analysis indicates that the materials used in the KCH are bronze, brass, and red copper. From the GIS analysis and the discussion, the different alloys are found to be deliberately chosen according to the function of each component in the entire structure. The motive behind this phenomenon is probably derived from the Chinese traditional theories of "six recipes" and "temper the hard and flexible to mutually assist each other," particularly the latter one.

This study is significant in the following aspects. First, the complexity and diversity of the materials of Chinese traditional architecture is investigated. Second, the development of traditional material science and technology in China is explained. Third, the application of traditional Chinese technological theory and philosophy in traditional architectural theory and practice is exemplified. The application of these theories proves that the technology of metal architecture was well developed in traditional Chinese buildings, although it represents a minority compared with the timber architecture in China. Meanwhile, the analysis results serve as a necessary database for the preservation of the surviving copper halls.

Acknowledgements

This work is financially supported by the National Natural Science Foundation of China (Grant no. 50878043) and the Scientific Research Foundation of the Graduate School of Southeast University (YBJJ1019). The authors thank Mr. Li Tao (Michem Technology Ltd.), Mr. Yan Xiao-Nian (Administrative Office of Golden Hall Park in Kunming), and Mr. Zhao Yuan-Xiang (Chengdu Institute of Archeology) for their kind assistance with the field work.

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