A Study of the Forms and Technology of Traditional Granary Buildings in the Middle and Lower Reaches of the Fu River

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Abstract
In this study, the authors performed field surveys and investigated the formal and technological characteristics of granary buildings in the middle and lower reaches of the Fu River. Their study could help architects understand the regional features of traditional vernacular buildings. Employing field survey and mapping, the authors found that the building styles of traditional granaries are not different from those of traditional residential houses. This type of architecture challenges the restrictions of the ritual system and highlighted structural flexibility and functional priority through the use of beam structure. In the final section of the study, the thermal and wind environments of granary buildings are analyzed using ECOTECT software. The results of the analysis demonstrate that granary buildings can maintain low temperatures and prevent moisture using eco-building techniques, such as ventilative stone ridges, moisture-resistant walls and heat insulation storage rooms. These achievements demonstrate that traditional vernacular buildings, such as granaries, undergo fundamental evolution in architectural form and technology rather than maintaining the original state of a specific historical period.

Keywords: middle and lower reaches of the Fu River; granary; building form; technology

1. Introduction
The Fu River is one of the main rivers of Poyang Lake and runs through the east region of Jiangxi Province. The middle and lower reaches include Linchuan District, Jinxian County, Dongxiang County and other counties. Due to its flat terrain, food production in this region is high. The Fu River originates in the western foot of the Wuyi Mountains and winds down the reaches for over 300 kilometers. The river not only gave birth to the "Linchuan culture" but also served as an important water road for grain transportation.

The granaries in the middle and lower reaches of the Fu River are primarily distributed along the two sides of the river. According to the Chronicle of Jinxian County in the era of the Tongzhi Emperor, nearly every village owned a granary (Fig.1.). During multiple field surveys, the authors found that traditional granary buildings were scattered through the middle and lower reaches of the Fu River, these buildings were of various granary types, such as Caocang and Shecang and Yicang. The authors also discovered many well-preserved granary buildings in Licuian County, Nancheng County, Chongren County, and Yihuang County (Fig.1.).
Over the past few decades, a number of studies have assessed traditional granary buildings in Jiangxi Province, and have focused on the related storage systems. Those studies include writings by Wenbo Yan, Youming Shi, Hongwei Xie and Xiaohong Wen, (Review of the grain warehousing system in the Qing Dynasty; and Introduction to the grain warehousing system of Jiangxi in the Qing Dynasty; Introduction to the grain warehousing system of Jiangxi in the Ming Dynasty, respectively). In addition, Zuoli Chen briefly summarized the types of granaries in his paper, On the Granary System of the Ming Dynasty; However, studies of traditional granary buildings in the middle and lower reaches of the Fu River remain lacking. Therefore, with the aim of filling such research gap, this paper summarizes the characteristics of the forms and building techniques of these buildings.

2. Background
2.1 Grain Storage Systems
Grain storage systems have been critical to food security and livelihoods in traditional Chinese society. Establishing grain warehouses has also been a common policy for famine relief since antiquity. As early as the Warring States Period, Kui Li of the Wei State proposed the "Law of Pingdi". This law established the practice of keeping a stable grain storage level which has been followed since ancient times (Huang and Wang, 2005). In the Ming Dynasty, the grain storage system became more established. The granaries were generally used in three ways: first, for military expenditures; second, for salary payments of civic officials and food rations for the urban population; and third, for reserving for the relief of natural disasters (Xie and Wen, 2015). The grain storage system of the Qing Dynasty adopted that of the Ming Dynasty. The storage types varied with different functions, which can be divided into two categories: state granaries and private granaries. State granaries were directly controlled by the government, managed by the Ministry of Finance, and operated by the commissioner of each province, which included Jingcang, Tongzhoucang, Caoyuncang and Changpingcang in each province and county (Ya, 2011). Private granaries were managed by local squires under governmental control and primarily consisted of the Yicang and Shecang types. Yicang, a type of granary that was donated by the Ministry of Finance, generally established in small cities or towns. However, Shecang types were typically established in the countryside without designing a new building, and made use of an ancestral temple for storing grain. According to the authors' research, Shecang was invented by Xi Zhu, the well-known Confucian scholar of the Song Dynasty.

Fig.2. Examples of the Single-use Granary and the Mixed-use Granary

3. Types
Granaries in this area can be divided into two types based on their function: the single-use granary and the mixed-use granaries (Fig.2.).

3.1 The Single-Use Granary
The single-use type of granary refers to an independent building that was used only as a granary without other functions. The layout of the patio was horizontal, and the storage rooms were arranged symmetrically.

1) "Xingjuxuan" of the Chen Family of Shifang in Linchuan District
"Xingjuxuan" is of the Yicang type. It has three halls and two patios, 10 m in width and 31 m in depth. The patios are long and narrow. In the lower hall, six storage rooms were laid out symmetrically, and the bottom of the storage rooms is elevated 53 cm above the ground. The granary is adjacent to the Yuqing ancestral temple. It is a column-and-tie construction and the patio is laid out horizontally (Fig.3.).

2) "Yunyuju" of Zhanshang Village in Dongguan Township, Linchuan District

Jiangxi Province is located close to the Tropic of Cancer and has warm and humid weather. Numerous rivers in this province provide ideal conditions for agricultural irrigation. Thus, Jiangxi produces large amounts of tea, tobacco, cotton and especially grain. This province was famous for its wealthy land since the Tang Dynasty and became the most important grain provider in the Song Dynasty. In the Ming and Qing Dynasties, local grain production was greatly improved with the technological development of irrigation. According to the Chronicle of Lichuan County, in the Ming and Qing Dynasties, granary buildings were built in counties with abundant grain (Ji, 1993).

The Fu River is the chief tributary in the Poyang Lake river system. Due to the flat topography, the river has a number of branches, and the middle and downstream regions of the Fu River are suitable places for delivering food. An accompanying road network was built to increase the efficiency of food deliveries. These two advantages contributed to a well-functioning food supply chain. Therefore, it is not surprising that granary buildings are widely used in this area.
"Yunyuju" is a granary that belonged to an individual. It was an attached structure to the "Xiushanjingmao" residence to its north. It has three halls and patios. There are eight storage rooms at the west end, eight by the east section, and a total of 16 storage rooms. In contrast with previously noted types, the storage rooms in this case are free standing from the back wall on the north and south sides. More interesting is a wooden wall between the south side of the south rooms and the building envelope. The structure has a column-and-tie construction, and the patio was laid out horizontally (Fig.4.).

(3) "Yuhu" Granary of the Li Family in Yuhu, Linchuan District

The "Yuhu" granary is located on the north side of the "Zizhengdi" residence, which is the largest granary found in this area. "Yuhu" granary is a private granary. There are 15 existing storage rooms that can store 200,000 kilograms of grain. Three sides of the storage rooms are arranged surrounding a large square patio. The granary has a column-and-tie construction. All rooms on the second floor are connected by a corridor that runs around three sides of the patio. Due to its large food storage capacity, large food deliveries arrived via the brook on the north side of the granary to eventually supply the entire province. According to the Chronicle of Linchuan County, townships such as Dongguan, Tengqiao, and Qingni in the Linchuan District were important food production bases. It was reasonable that Yuhu, one of the most important crop production bases, had such a large-scale granary (Fig.5.).

(4) The 4th Tu Caocang of the 36th Du in Xuwan Township, Jinxí County

In ancient China, a canal system was also developed for the food supply. Caocang (Canel granary) can be found along the canal. This granary played an important role as a transfer station. Numerous granaries are found in Xuwan, which was the largest distribution center in the Fu River area.

The 4th Tu Caocang of the 36th Du is located in Xuwan Township. A typical granary has two halls and one patio. The name of the granary, "The 4th Tu Caocang of the 36th Du," was engraved on a white stone plaque above the granary gate, in which "Du" and "Tu" were the names of administrative units of rural areas in antiquity. The Caocang was 12 m wide and 16 m long, forming a patio in the center; wing rooms were on the two sides of the upper hall, and the two sides of the lower hall were symmetrically laid out as a granary (Fig.6.). The overall building was narrow in the front and wide in the back, and the granary on the west side was wedge-shaped and is currently being
used as a converted storage room. The eastern room has been converted into a bedroom.

3.2 The Mixed-Use Granary

For this type of granary, grain storage facilities were inserted into ancestral temples or residential houses; thus, the building was transformed according to local conditions. There is no fixed plane form but there is high flexibility and adaptability. According to the Chronicle of Jinxian County in the era of the Emperor Tongzhi, "In the ninth year of the Emperor Shunzhi of this Dynasty, Governor Cai supervised food supplies. Because the granary was too close to a private residential house, he suggested moving the granary to a new location. Dapin Shi, the county magistrate, then sold the real estate of the granary and purchased the deserted site of the Xiong Family in Wutu of Liaozhou to build two halls, eight rooms in the east and west wings, as well as 16 rooms for grain storage. The old warehouse of Caocang in Xuwan collapsed, and the house site became open and was called Huacangqian by the locals. In the seventh year of the Emperor Yongzheng, Tianshu Dong, the county magistrate, pledged donations from the local gentry and ultimately bought the house site of the You Family and transformed it into a granary as well as an office, in two buildings. In the second year of the Emperor Daoguang, Yun Li, the county magistrate, raised money to repair and renovate the gate of the office complex while constructing two rooms, one each in the east and west wings, to be used as a granary, as well as an office building (Cheng, 2013). These records indicate that the mixed-use granary was rapidly generalized with the official's endorsement.

(1) "Fengying" in Fujiacun Village of Dongguan Township, Linchuan District

"Fengying" is a granary that belonged to an individual. The "Fengying" Granary is located in the north of the "Fenggaoyunze" residence. The main entrance of the residence is on the south, while the entrance of the storage area is on the north. "Fengying" was engraved on the stone plaque above the granary gate. Upon entering, one can see the patio in the middle surrounded by storage rooms on two sides (Fig.7.).

(2) The Granary of Zhou's Ancestral Temple in Zhoujiacun Village of Shuangtang Township, Jinxian County

Initially built in the Ming Dynasty, Zhou's ancestral temple is of the Yicang type and belonged to the family. It had three halls and two patios. A granary on the two wings of the lower hall and foyer consisted of 12 rooms and was symmetrically arranged, representing a typical case of converting an ancestral hall into a granary (Fig.8.). Floor beams were placed on the ground level, and mobile gates were built on the facade of the granary. According to the locals, the grain was elevated to the top of the granary by a pulley and was poured down. All storage rooms are in the ancestral temple.

(3) The Granary of Xidongcao Village in Langju Township, Jinxian County

This small private granary is located on the north side of Xidongcao Village next to the Fu River. The growth pattern of the village follows the pathway of the Fu River. According to local residents, two other granaries were transformed from ancestral temples; however, today they are damaged. In the existing setup, which is part of the residence, three granaries were arranged in a triangle on the way to the ferry. There are four storage rooms inside the granary. The granary has a column-and-tie construction, is two stories high, and the bottom floor is elevated. All storage rooms are
inserted in the residence and laid out on one side of the patio (Fig.9.).

4. The Forms of Granary Buildings

4.1 The Plan

The single-use granary can generally be divided into two types: one that has two halls and one patio and another that has three halls and two patios. The single-use granary always uses a rectangular plane. The granary is arranged along the gable, and a narrow patio is arranged in the middle. The storage rooms are symmetrically laid out along the patio. Small-scale granaries typically comprise 3-5 rooms in each row, whereas large-scale granaries can have 8-10 rooms per row. The storage rooms have various combinations according to different building layouts and are flexibly joined into the building but are not connected to the external walls and are separated from the external walls at a distance of approximately 0.7m.

In general, the patios of the granary can be divided into two types: the vertical, which was used for a single-use granary; and the horizontal, which was a mixed-use granary. For the latter, the local people reused some rooms as storage space in the original building.

This is why the mixed-use granary adopted a vertical patio.

4.2 The Structure

The granaries always adopted the mixed structure of brick and wood. The building envelope was normally a brick wall, and the internal beam-frame adopted the column-and-tie construction. Between the upper and lower floors, there was a space for ventilation measuring approximately 450mm to 600mm high, the wall (30mm thick) was built with bamboo mixed with mud. This type of wall is simple to build but can maintain low humidity, which is good for food storage. The storage room is always one floor lower than the building roof so that grain can be poured from above into the storage room (Fig.10.).

The mixed-use granary was relatively smaller than the independent granary. The storage rooms were normally 2 to 3 square meters, similar to "Fengying" and the granary of Zhou’s ancestral temple (Table 1.). The width and depth of the room was sufficiently small for a column-and-tie construction. This structure was used to store grain in a manner similar to the private granaries.

The floor of the storage rooms was placed above the wooden beam (100mm in diameter) and was supported by stones. In this case, the floor of the storage rooms never touched the ground, which is effective for preventing moisture. The stone ridges (100 mm thick and 500 mm high) supported a wood frame above the ground floor.

Each storage room had a gate (Fig.11.). The door was made with several wood panels of the same size for ease of loading and unloading. However, only two existing cases for panel doors remain in the "Fengying" Granary, while one remains in Zhou's ancestral temple (Table 1.). The width and depth of the room was sufficiently small for a column-and-tie construction. This structure was used to store grain in a manner similar to the private granaries.

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4.3 The Roof

Granaries along the Fu River Basin follow the form known as si shui gui tang (literally "the four waters return to the hall"). This form refers to square-shaped groups of houses enclosing a small patio. Because the roofs of the four surrounding houses are inclined,
they lead rainwater to flow from all directions into the patio. This type of roof is commonly found in regions south of the Yangtze River, such as Jiangxi, Hunan, Hubei and Anhui. There is no ceiling under the roof; therefore, the whole wooden-frame structure is exposed. When constructing this type of roof, rafts are placed over purlins and paved with roof boardings on which small cyan tiles are laid. The tiles are hanging, so that the interstice between two layers of tiles (covering tiles and base tiles) forms an air space. Because the air space decreases the accumulation of heat, the construction of the roof may help to lower the temperature of the interior space.

5. The Technology

Granary buildings are not different from traditional residential houses in style and technology. In addition, the floor was always elevated above the ground, and in some cases, wood panels were placed between the storage space and the building envelope to reduce moisture.

5.1 Underground Ventilation

In the middle and lower reaches of the Fu River area, granaries had a significant characteristic: a ventilation floor below the storage room that helped circulate air and reduce moisture. In addition, cats were free to walk under the floor to prevent damage caused by rats.

5.2 Anti-humidity Walls

In most cases, storage spaces were designed independently, or shared only one wall that formed "the building in a building". For example, the "Yunyuju" Granary has a row of wood columns set back one meter from the outside wall. Wooden panels are installed between each set of columns. The distance between the wall and the storage room was 500mm on the other side of the wood panel. In other cases, even without any panels, the distance between the storage rooms and the external wall of the building was substantially larger. This prevented damage to the grain from the moisture from outside.

5.3 Heat Insulation in Storage

Low-temperature grain storage is a "green" approach. A low-temperature environment can effectively postpone food spoilage. The granaries provide thermal insulation in two ways. First, thermal insulation is achieved through the construction of the walls of the granary. In terms of material, the walls are made of bamboo plaits plastered with mud. Bamboo is a material with low thermal conductivity and therefore reduces the speed of heat transfer. In terms of color, both sides of the walls are plastered in white; white walls can reflect more sunlight radiation, thus reducing indoor radiant heat and lowering the temperature of the storage surfaces. Second, thermal insulation is achieved through the construction of the roof of the granary. There is empty space above the roof. Connected with the outside, this space provides ventilation and allows flowing air to remove the heat absorbed by the roof, effectively preventing the collection of radiant heat.
6. Simulative Analyses of Thermal and Wind Environments

ECOTECT ecological building simulation software, developed by the British company Square One, is CAD software that allows comprehensive technical performance analyses. ECOTECT provides interactive analysis and integrates functions that analyze aspects such as thermal, light, sound, and sunlight environments, economy, environmental impacts and the visibility of buildings. This study selects the Yunyuju Granary, which is comparatively well conserved, and conducts simulative analyses of its thermal and wind environments with ECOTECT.

6.1 Thermal Analysis

Thermal analysis in ECOTECT applies calculations based on dynamic loads. By combining inputted 3D models and local climate data, it can simulate the thermal environment of a building.

(1) Temperature distribution analysis

Temperature distribution analysis refers to the distribution of the interior temperature of the building for each hour in a year. As displayed in Table 2, the range of the temperature of Yunyuju Granary is 6-32°C; 78.1% of the year, its interior temperature remains below 26°C (Table 2.).

(2) Annual average daily insolation distribution

An annual average daily insolation analysis demonstrates the distribution of insolation of a building. An annual average daily insolation analysis of Yunyuju Granary using ECOTECT shows the area with the highest daily insolation in yellow and the lowest daily insolation in blue. The retaining structure of the Yunyuju Granary blocks most radiation and keeps the daily insolation of its interior space relatively low. As the patio of the granary is directly exposed to sunlight, its insolation is higher than other parts of the building (Fig. 12.).

(3) Monthly solar radiation

As seen from the figure for monthly solar radiation, the radiation decreases sharply in autumn and winter and reaches a peak in summer. Thus, the insolation of the granary building is lowest in January and highest in July (Fig.13.).

6.2 Wind Environment Analysis

The wind environment analysis refers to the wind conditions of the natural exterior wind under the effects of the natural topography. Natural ventilation is an effective passive strategy. Guiding incoming wind can speed up the flow of air to improve the thermal condition of a building without consuming energy.

The top of the patio receives solar radiation for a longer duration and therefore has a higher temperature. Wind and heat pressure create a chimney effect in the patio that forms draughts to help circulate the interior air. In summer, good ventilation can speed up heat elimination. The annual average wind speed in the Fuzhou region is 2.3 m/s, and the prevailing wind directions are southeast in summer and northwest in winter (Fig.14.). The granaries in the Fu River Basin are therefore oriented in accordance with the prevailing wind direction (Fig.15.).
7. Conclusion

(1) The balance between the ritual system and function

In terms of the development of Chinese traditional vernacular architecture, the ritual system always plays a more important role than the functional system, especially with regard to residential buildings. However, as a unique case, granary buildings in Jiangxi Province depart from this pattern to a certain degree.

The traditional houses in Jiangxi Province are always laid out symmetrically, and the space is divided into interconnected rooms by patios. In the ritual system, the oldest or the most important person used the north room, the young or less important people used the wing rooms, and the servants used the remaining rooms. The situation is very similar for residential buildings: the storage rooms in a granary were always arranged on the sides of the patio with different grades. However, the orientation of the patio turns from vertical to horizontal. This functional change fundamentally challenged the traditional understanding of the ritual system. Therefore, the design of a granary building is not completely limited by traditional rules. Instead, the change reflects a balance between the function and form. In other words, this balance demonstrates an evolution involving the ritual system and reason.

(2) The appropriation of building technology

The technology of granary buildings was less complicated than that of houses. There were neither complex patterns on column footings nor rich sculptured wooden elements. The entrance was simply designed, with only a few sculptures and murals on the main beam. The material choice was not luxurious. The column in the "Yunyuju" granary, for example, was only 150mm in diameter, while the column of the local house was normally 200mm to 250mm in diameter. Because of these simple choices, granary buildings could be built affordably within a shorter period of time.

However, granary buildings required greater moisture and pest prevention measures than houses. Furthermore, the structure of the traditional house could not provide efficient ventilation for storing grain. Thus, the local people used the flexibility of a wooden structure and high frame, as well as walls and other structures to make it meet use-related requirements. Finally, storage rooms were always designed as small units on the same floor, which were easy to combine and calculate.

(3) Ecological building techniques

Durability, moisture-proofing, heat insulation, ventilation, airtightness, and the prevention of mice and birds are basic requirements for modern granary design. Modern designs usually rely on technical methods such as mechanical ventilation and refrigeration to guarantee food quality, but they have poor energy saving. Ecotect's simulative analyses of the thermal and wind environments of granaries revealed ancient Chinese wisdom in the building techniques of granaries in the middle and lower reaches of the Fu River. These granaries inherited the tectonics of traditional wooden structure and appropriated existing building techniques. Their design created a new building type by integrating storage units into a traditional plan arrangement. At the same time, these buildings adopted excellent design strategies. First, measures such as underground ventilation, anti-humidity walls and heat insulation of storage help to achieve the goals of low temperature, moisture-proofing and pest-prevention. Second, in terms of plan, the orientation of the granary patio is arranged in accordance with the local prevailing wind direction. This arrangement enables buildings to appropriate the passive strategy of natural ventilation all year and to achieve the effect of cooling and exsiccation. Lastly, the construction of the retaining structures benefits heat dissipation and cooling. It is obvious that contemporary granary buildings have adopted appropriate techniques to the greatest extent possible. They contain a rich culture of Chinese traditional technology, and many of their building techniques may have significant reference value for modern design.

Notes

1. The "Linchuan culture" is from the people in eastern Jiangxi Province.
2. The Warring States Period was an era of China lasting 254 years (BC475-BC221).
3. Under the "Law of Pingdi", the government purchased grains from farmers at a state-set price in harvest years to protect farmers from unfair trade. The government also sold grain to civilians at a state-set price in bad years to protect civilians from unfair trade.
4. The Ming Dynasty was the ruling dynasty of China for 276 years (1368-1644).
5. The Qing Dynasty was the ruling dynasty of China for 268 years (1636-1912).
6. The Song Dynasty was the ruling dynasty of China for 319 years (960-1279).
7. The Tang Dynasty was the ruling dynasty of China for 289 years (618-907).

References