Study of Roof Tiles in Lingnan Traditional Buildings and Roof Drainage Technologies

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Abstract. Lingnan building is a key part of Chinese classical architectural schools, and the preservation & repair technologies of Lingnan traditional building roofs, which can embody Lingnan characteristics most, are especially important. The roof tiles of Lingnan traditional buildings and roof drainage technologies were taken as the main study objects. Under the background of Lingnan environmental features, effective roof repair technologies were summarized by combining the roof tile forms and texture types, analyzing the relationship between roof tiling form and roof drainage, and supplementing the traditional tile fabrication technologies, etc., expecting to provide a pragmatic reference for the roof repair of Lingnan ancient buildings.

1. Introduction
As a representative of “Guangzhou school” in Chinese traditional architectural schools, Lingnan buildings are well-known in the world together with “Beijing school” and “Shanghai school”, all of which are precious architectural products formed under Chinese traditional culture. This study analyses the relationship between roof tiling form and roof drainage, expecting to provide a pragmatic reference for the roof repair of Lingnan traditional buildings.

2. Adaptation to Local Climatic Conditions
Lingnan Area is featured as hot and long summer, warm and short winter, and humid air, and the buildings here are generated by complying with these climatic features[1]. Every building is a thing alive, and the repair technology and heritage protection of Lingnan buildings are more supposed to cater to the geographical and climatic features of Lingnan Area. Lingnan buildings adapt to geography and climate and reflect the local Lingnan culture, from Lingnan traditional buildings to interconnection, good ventilation, lightness and subtleness pursued by modern Lingnan buildings, and to contemporary buildings that not only inherit the tradition but also seek for innovation[2]. Following the changes throughout the history, Lingnan buildings have finally formed their own styles integrating Chinese with Western cultures.

3. Tile Forms and Fabrication Technologies

3.1. Tile forms
Roof tiles largely include clay tile, terracotta and glazed tile. Clay tile is formed through clay drying and calcination, with a large dead weight, brittle texture and easy fracture. Terracotta is fabricated through high-temperature clay calcination, with crisp sound. Glazed tile is molded under high pressure
and calcinated at high temperature, and it is usually applied with golden, emerald green and dark blue lead glaze, etc\cite{3}.

The tiles commonly used at present can be divided into small tiles (width: 220 mm, being smaller than 240 mm), medium tiles (240 mm) and large tiles (280 mm). Trapezoid tile is also a traditional tile form, which is 280 mm at one end and 290-300 mm at another end in width, and 320 mm in length. By virtue of unique modeling together with the tiling form, this kind of traditional tiles is very conducive to the roof drainage.

It is worth noting that the tile selection is crucial in the repair of ancient buildings. In general, the priority is given to intact old tiles, and the following aspects are worthy of attention during the selection: the size of old tile should be sufficient, to be specific, the width is generally 235 mm or 230 mm, and the thickness ranges from 11 mm to 12 mm. The tangent planes at two sides of each tile should be perpendicular to the ground. Being slightly concaved, the tile body is arched to some extent, and the tile texture should prevent it from crisping.

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{fig1.png}
\caption{The size and shape of the old tile. (Painted by the author)}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{fig2.png}
\caption{Laying methods of traditional trapezoidal tiles. (Painted by the author)}
\end{figure}

3.2. Fabrication process of traditional tiles

3.2.1. Making a cylindrical mold.
A cylindrical mold with fixed size is fabricated with batten, and the mold is small at upper part and large at lower part, aiming to provide a shape foundation for the subsequent trapezoid tile modeling.

3.2.2. Clay scraping.
The prepared clay block is compacted flat, and one piece is scrapped off the block with a scraper, and then it is pasted outside the cylindrical die. When the cylindrical die is rotated, the clay is beaten even on the die using a plank.

3.2.3. Airing and firing.
After the clay is properly aired, the middle mold is taken out, and a quartering mark, which is vertically uniform, is made at inner side of the cylinder with a bamboo knife.

3.2.4. Splitting of tile mold.
The cylindrical die is split along the quartering mark to form four trapezoid tiles.

3.3. Tile material and texture
According to raw material and texture, tiles can be divided into clay tile, terracotta and glazed tile.
3.3.1. **Clay tile.**
Clay tile is made of ordinary clay (silt-free) at sintering temperature of 400-500 °C, belonging to low-temperature tile, and the knocking sound is depressing. Clay tile appears to be yellowish red, because during the natural cooling process after sintering, Fe in soil is oxidized into red ferric oxide. The clay tile is characterized by rough surface, loose structure, light weight, etc.

3.3.2. **Terracotta.**
Terracotta is made of clay or china clay at sintering temperature of about 800-1,150 °C, belonging to high-temperature tile, with crisp and clear knocking sound. Terracotta is divided into two types: unglazed terracotta and glazed terracotta, the terracotta not glazed on the surface is called unglazed terracotta, which is creamy white with smooth and compact surface and hard texture. Glazed terracotta is formed by glazing on the unglazed terracotta, and it is approximate to glazed tile.

3.3.3. **Glazed tile.**
The die of glazed tile is fabricated using off-white sand-free fine puddle, and glazing is done after cooling. After being dried, the colored glaze is put into a kiln with a relatively low temperature for secondary sintering. The glazed tile in Southern China is called encaustic tile, and the color of glazed tile depends on the sintering temperature and blending of different metallic oxides contained in the colored glaze. For instance, ferric oxide glaze will be sintered into yellow glazed tile, copper oxide into green glazed tile, and cobaltous oxide into blue glazed tile, etc. The glazed part is covered by a smooth and compact thin film, which can reflect partial ray of light, and the knocking sound is clear and crisp. The colored glaze on drilling glazed tile can only cover the projecting surface, the plate body is an uncolored face, and such design aims to increase the frictional force of the projecting plate body and ensure that the projecting tile can fit with the cornice junction more solidly. For a long time, the glazed tile will not fade, with fire-proof acid resistance.

4. **Roof Tiling Form and Drainage**

4.1. **Single-cylinder single-tile roof, and double-cylinder double-tile roof**
The combination of black cylinder and tile roof is a Cantonese characteristic, and black color represents “water” in the five basic elements, with the implied meaning of “water restricting fire”[4]. The roof tiling mode can be simplified as the “single-cylinder and single-tile” form, but single layer does mean the splicing of single piece of tile, instead, it refers to a layer of tiles regularly stacked[5]. The tile stacking method follows the traditional methods.

After western buildings were introduced in Guangdong, the local roofs were improved, forming a new “double-cylinder double-tile” structure, namely, adding a layer of single-cylinder single-tile structure based on the original single-cylinder single-tile structure. Although this increases the roof weight, it strengthens the rainproof and thermal insulation effects of the roof. In the meantime, there is a gap between upper and lower tiles of the double-cylinder double-tile structure, which facilitates the air ventilation between upper and lower tiles on the roof, and this can keep the dry status inside the roof tile structure while bringing away the heat.
4.2. Different fabrication methods of roof rafter plate

After western buildings were introduced into Lingnan Area, many unreasonable parts were improved, the double-cylinder double-tile roof was invented, and the fabrication method of rafters were also improved[6]. The placement mode of rafters are changed. Rafters are not laid flat as usual, but instead, they are vertically placed after 90° rotations. As the roof weight is increased after it is changed into double-cylinder double-tile structure, its stress-bearing capacity is enhanced after the vertical placement. In the meantime, the quantity of cross bars can be reduced. The traditional flat rafters and the improved double-cylinder double-tile roof structure and vertical rafters are shown in the following figure.

4.3. Mortar between two tiles is isolated and does not touch the rafters

It rains a lot in Lingnan Area, the risk of rain leakage exists if it is too late to drain the rainwater on roof under heavy rain condition, which brings about a new challenge to the roof rainproof measures.
The spacing of rafters on roof is generally fixed at 240 mm, and the width of old tiles adopted in ancient buildings is 235 mm or 220 mm, with a slightly large tile spacing.

When the rainwater drain fails under heavy rain, the water may reach higher than the tile surface and further touch the cylinder. The mortar between tiles then goes through water absorption due to capillary action, it is easy for water to enter but hard to expel when mortar touches the rafter, so the rafter will be corroded due to the dampness. There are many solutions according to experts and wisdom in the folks.

Method I: The motor between two tiles is isolated and does not touch the rafter. Nearby Keyuan Garden in Dongguan, a thin copper sheet is placed between two tiles on the roof of residential building, which can prevent the water-absorbing mortar from falling onto the rafter plate, and now it can also be replaced by rust-resistant metal skin[7].

Method II: Broken tiles are inserted between two tiles, but the effect is poor.

Method III: A bamboo pole is placed between two tiles, which can also prevent the water-absorbing mortar from contacting the rafter plate.

Method IV: Tung oil waterproof mortar. In the repair of Foshan ancestor temple, craftsmen use self-made leakage-proof mortar, namely tung oil is added into ordinary mortar, and after screeding, a waterproof layer is formed to fill the bottom.

No matter which method is used, all of them aim to isolate the water-absorbing mortar and ensure that it will not touch the rafter.
5. Conclusion

Every building is of life, the repair and protection of Lingnan buildings should adapt to local conditions.

First of all, the roof tiles used in traditional Lingnan buildings largely include clay tile, terracotta and glazed tile. The tiles currently used can be divided into small tiles (width: 220 mm), medium tiles (conventional width: 240 mm), large tiles (280 mm) and traditional trapezoid tiles (the width is 280 mm at one end, and 290-300 mm at the other end, and the length is 320 mm).

Secondly, the roof modes include “single-cylinder single-tile” structure, namely, a layer of tiles regularly stacked, and “double-cylinder double-tile” structure which is formed after western buildings entered Guangdong. The “double-cylinder double-tile” structure is a layer of single-cylinder single-tile structure which is added to the original single-cylinder and single-tile structure.

And then, the tile stacking method follows the traditional methods, and this stacking mode is directly related to the roof drainage.

In the end, by integrating the wisdom of experts and folk tradition, four methods that prevent the roof rafters from being damped and corroded were summarized, which can provide a pragmatic reference for the repair of Lingnan ancient buildings.

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