Journal of Namibian Studies, 33 S3(2023): 3359-3384 ISSN: 2197-5523 (online)

Song Dynasty Brick Pagoda Imitation Timberwork And The Major Woodwork Practice Of The Treatise On Architectural Methods (Yingzao Fashi)

Yiming Cao*, Jiayuan Jiang

Institute of Architectural History and Theory, Southeast University, Nanjing, 210096, China
220190017@seu.edu.cn

Abstract

This paper takes a look at Song dynasty brick pagoda imitation timberwork, focusing on the complex part of the major woodwork, the brackets, and later discussing other major woodwork elements. The study begins with the similarities and differences between brickwork and woodwork as a premise, followed by a discussion of the differences arising from the stressing properties and construction logic. Finally, a key example, the Xiangji Temple pagoda in Liquan County, will be compared and contrasted in terms of cai and fen modules. This analysis suggests that the imitation of woodwork in brick pagodas is in fact a balancing act between concealing material properties and yielding to them, with the modal and partially proportional relationships of woodwork being inherited. At the same time, the structural properties of the material are brought into play by changing the way in which it is constructed, for example, by reducing the number of horizontal arms, by linking the perpendicularly arms, and by replacing the arm with a rafter. The brickwork imitation timberwork is neither a system independent of the Treatise, nor is it a system that remains unchanged, but rather a process of reconciling the two types of material and synthesising them.

1. Differences in brackets

1.1 The Prerequisites for Differences

The fundamental difference between brickwork and woodwork in the Treatise(Yingzao fashi) is due to the different materials used in their construction, specifically the different stressing properties of the materials and the different logic of their constructions.

1.1.1 Similarities and differences in the forces applied on components

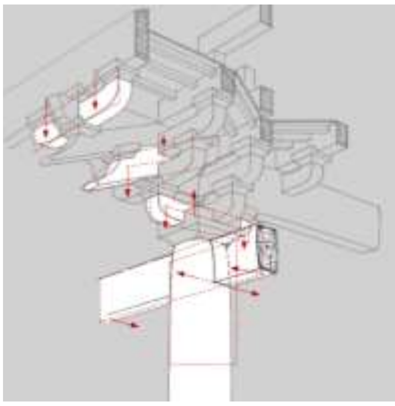

Figure 1 Force analysis of timber frame

In the case of timber structures, under vertical loads, the bracket joint is mainly loaded through decoratively-craved nose of a bracket set(shuatou), transversal bracket arm(huagong), arm and beam(gongfang), end block(sandou) and cap-block(ludou), and the timber is compressed horizontaly. Under horizontal loads, the bracket joints mainly transfer the load in the form of the bending resistance of each arm and the timber is bent. The post-linetal joint transmits the horizontal load to the appendage mainly through the cross-grain pressure between the mortise and tenon of the wooden column, which causes the appendage to be twisted and the cross-grain pressure to be applied, and causes the wooden column to be pulled at the mortise and tenon of the wooden column, and the horizontally-positioned architrave(pupai fang) to be pressurised. At the foot of the column, the horizontal load is mainly transmitted to the beam by the cross-stripe pressure between the mortise and the architrave, which causes the arch to be bent and twisted, and causes the wooden column to be pulled at the mortise, and the arch and the medical device to be pressurised (Fig. 1).

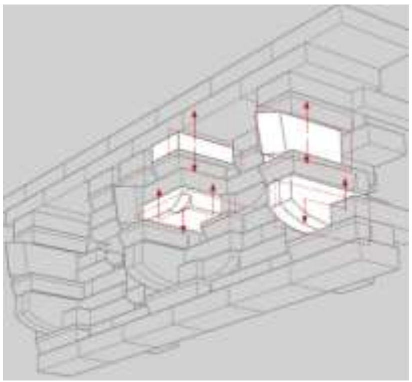

Figure 2 Force analysis of brick masonry

For the masonry imitation wood structure, due to the transformation of the structural system so that the post-lintel system does not exist, that is, the joints and the way of intersection are no longer working, replaced by the vertical direction of the stacked blocks. In the masonry structure, most of the blocks are subject to vertical pressure, and only the transversal blocks (such as the ones that imitates the transversal bracket arms) have a half-brick-length overhang subject to bending (Fig. 2).

As a result, the forces are the same in that both are subject to pressure from vertical loads, while the difference lies in that the timber elements are subjected to a combination of pressure, shear and tension due to the complexity of the structural system and force transmission paths, while the masonry elements are mainly subjected to pressure, with only a small part of the masonry subjected to bending.

1.1.2 Similarities and differences in the construction logic

The construction of timber structure design regulation is based on the cai and fen as the basic modular units, with the pattern of 'floor plans-side diagram- front diagram'(dipan-ceyang-zhengyang), as well as mortise and tenon joints between members; masonry structures are modelled on standard bricks, with 'stacking' as the main method of construction, and gravity as the main method of construction, or with matting and plastering (Fig. 3)

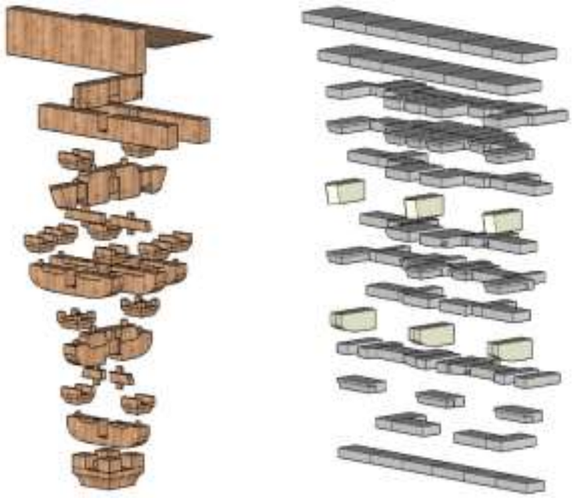

Fig. 3 Left: axonometric decomposition of the timber bracket
Right: axonometric decomposition of the brick bracket

The use of the 'cai and fen' as a module in timber construction, where the module is an abstract concept (Fig. 4) and the individual elements simply conform to the corresponding proportions and can be changed in size according to material, structural needs or aesthetic requirements, also allowed for the pre-fabricated production of components as a prerequisite for the construction of timber structures in the Treatise. This design is a response to the simplicity of timber, and the means of prefabricated, on-site assembly of the elements emerged module and became an integral building system.

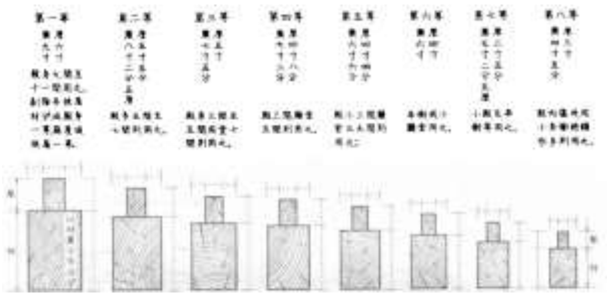

Fig. 4 cai and fen as the basic modular units in the Treatise on Architectural Methods

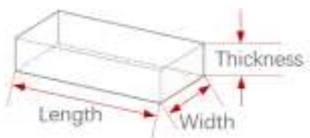

Fig. 5 Modulus of brickwork - standard brick

In masonry, the standard brick, as a module, becomes a solid concept (Fig. 5), and the solidity of the concept makes it difficult for the members to vary in shape and size, turning to the standard brick as a unit for combination and arrangement. In the case of imitating timberwork, these different permutations are used to seek a 'likeness' to the timber elements and conform to dimensional standards. In the process of 'arranging and combining' the brickwork, the notion of subsidiary unit(zhi), resulting from mortise and tenon joints, disappears and the module, which was originally intended to regulate the size of the elements, becomes a function of the number of units - and thus the proportions - in brickwork. The role of the moulding in brickwork is now that of regulating the number of units - and thus the proportions. For example, the ratio of the upper part(shangliu) to the lower entasis(xiasha) is 2:3 (6 points for the upper part and 9 points for the lower entasis), whereas in the brick arms, which consists of three or two layers of bricks, the ratio of the upper part(shangliu) to the lower entasis(xiasha) is probably only 1:1, 1:2 or 2:1, according to the number of bricks.

1.2 Differences arising from force properties

Differences with timber structures due to the different forces of brick are common in Song dynasty brick towers, such as posts and lintels, which are no longer the main body of the load-bearing frame but have become a kind of carving in relief, and are therefore not subject to the proportional scales of the Treatise. However, it is rather frivolous to list all these differences and some commonalities have not yet been identified. This chapter discusses only two of the illuminating aspects of the bracket.

1.2.1 Reduction of projecting distance in bracket

As brick is not as capable of projecting out as wood, most brick arms have a significantly shorter transversal distance compared to the major woodwork brackets in the Treatise. This feature is not only reflected in Song dynasty brick pagodas, but is also a common phenomenon in brick pagodas and tombs from all dynasties before and after the Song dynasty (Fig. 6).

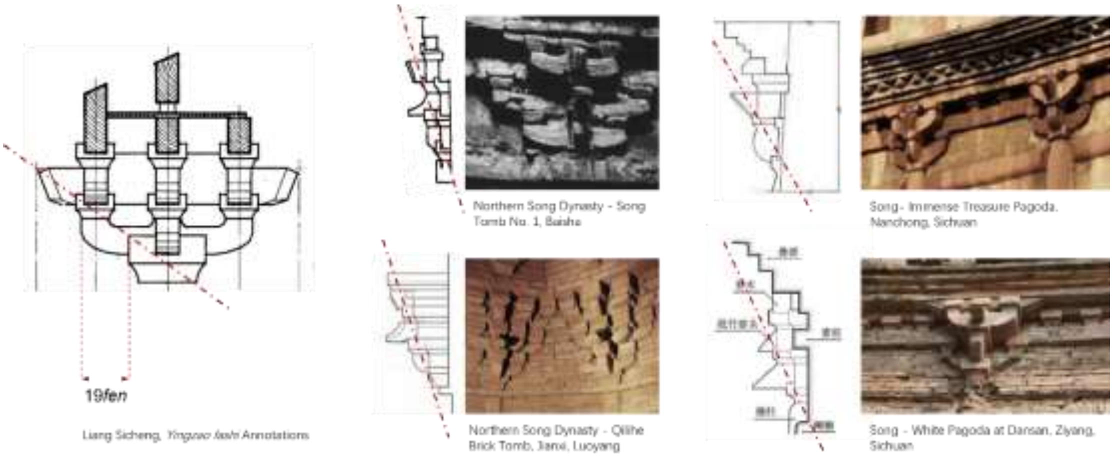

Fig. 6 The brackets of the Treatise and those of the Song Dynasty brick tombs and pagodas

In contrast, timber was commonly used in place of brick in the important projections of brick pagodas in the Liao dynasty (fig. 7), and wooden elements were used in the brackets and projecting sections of brick and timber mixed pagodas popular in southern China in the Song dynasty (fig. 8), both of which were supposed to compensate for the deficiency of brick projections and increase the diatance. This demonstrates that the ancient craftsmen were aware of the inferiority of brick to wood.

Fig. 7 Liao-Ten Thousand Parts of the Huayan Sutra Pagoda, Huhehaote, Neimeng

Fig. 8 Northern Song - Ruiguang Temple Pagoda, Suzhou, Jiangsu

1.2.2 Simplification and Reduction of the parallel bracket arm at the outward projecting end

The parallel arm in Song brick pagodas is characterised by two features: one is the absence of the guazi gong (i.e. the 'stolen heart' style), which is more common in examples (fig. 9), and the second is the simplification of the parallel arm to a horizontal brick without suspension (fig. 10). These two differ considerably in images, but it is believed that their purpose is to reduce the suspension of the horizontal arm.

Fig. 9 Northern Song Dynasty - Huanxian Pagoda, Shaanxi

Fig. 10 Northern Song Dynasty - West Pagoda of The Twin Pagodas of Miaodao Temple, Linyi County, Shanxi

In terms of bearing, the vertical transversal arm has the upper and lower brick layers of equal width, similar to the principle of corbel(diese); whereas the horizontal suspension arm has only the block(dou) bearing below it, with long suspensions on both sides, which is less reasonable in terms of bearing.

In terms of function, the vertically transversal arm serves the purpose of the eave of pagodas, while the horizontally suspension arm has little practical function beyond the visual.

As a result, most brick pagodas have chosen for practical purposes to omit the horizontal arm, which serves no practical purpose, or to reduce the arm to a continuous strip of horizontal brick, reducing its suspension to a corbel-like bearing.

Such a practice has been followed in later generations of masonry imitations of timber architecture and may serve as a testament to the above reasons.

For example, in the stone pagodas of the Ming and Qing dynasties, the number of tiao(layers of projecting arms) is often large but all of them are stolen-heart style (Fig. 11). The Nanjing Museum (Fig. 12) and the Shaanxi History Museum (Fig. 13) designed by Zhang Jinqiu, both of which were designed with the idea of 'regaining the structural role of the arch' and wanted the concrete arch to be structural rather than decorative, can be seen to be the 'stolen-heart' approach of both can be seen. This proves that in the case of brick, stone and concrete brackets, the horizontal arm is not a necessary structural element.

Fig. 11 Qing - Tangyue Paifang, Huizhou, Anhui

Fig. 12 The Republic of China - Nanjing Museum, Nanjing, Jiangsu

Fig. 13 Shaanxi History Museum, Xi'an, Shaanxi

The second type of horizontal arm is simplified and linked into strips, as in the case of the science building at Tamkang University in Taiwan (Fig. 14), where the concrete arch is abstracted and simplified into horizontal strips that act as corbels.

Figure 14 Tamkang University Science Building, Taiwan

1.3 Differences arising from construction logics

The differences arising from construction logics of the materials are reflected in the shape of the brickwork, the size of the elements and the way in which they are combined: for example, in the shape, the original proportions of the timber frame give way to the proportions of the façade and the depth of the eaves restricted by the masonry; in the size of the elements, the brickwork tries to restore the integrity of the original timber elements, but also changes the size or proportions of the elements due to the materialisation of the modules; in the way in which they are combined, as the mortise and tenon joints in the timber frame do not exist, the brickwork needs to be transformed in accordance with its own structural characteristics. These three aspects are discussed in this chapter.

1.3.1 Different angles of projection resulting from different construction methods

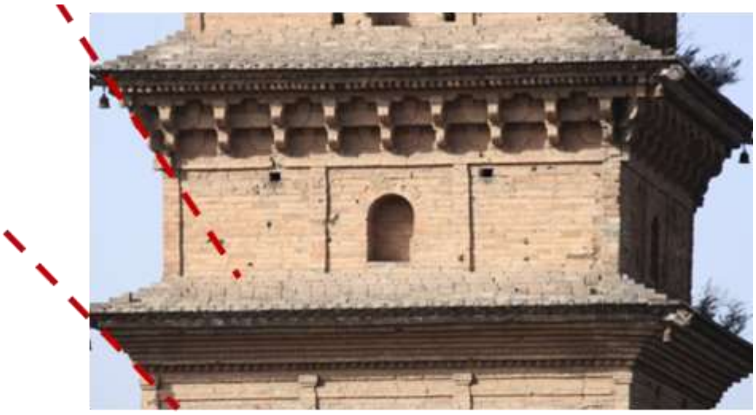

Fig. 15 Northern Song Dynasty - Jingjin Temple Pagoda, Chengcheng County, Shanxi

Fig. 16 Northern Song Dynasty - East Pagoda of the Twin Pagodas of Miaodao Temple, Linyi County, Shanxi

There are two main types of eaves in masonry pagodas: masonry corbel and imitation wood brackets. In the case of 1. different layers of the same pagoda, where the eaves are made using both corbels and brackets(e.g. the Chengcheng County Jingjin Temple Pagoda and the East Pagoda of the Miaodao Temple Twin Pagodas in Linyi County, figs. 15 and 16), it is possible to distinguish that the angle of the bracket eaves is steeper than that of the corbels, i.e. the corbels allow for a deeper eaves projection at the same height; 2. when both corbels and brackets are used on the same layer (e.g. the Yongxing Temple Pagoda in Linyi County and the Cixiang Temple Pagoda in Pingyao County, figs. 17 The actual eaves are carried out by the corbel. The question can thus be raised: is the eaves of the corbel better than that of the bracket? The following calculations are used to verify the eave angles of the different construction methods.

Fig. 17 Northern Song Dynasty - Yongxing Temple Pagoda, Linyi, Shanxi

Fig. 18 Northern Song Dynasty - Cixiang Temple Pagoda, Pingyao, Shanxi

The projection consists of two parts, bracketing unit(puzuo) and the rafter(chuanwang), which are calculated separately:

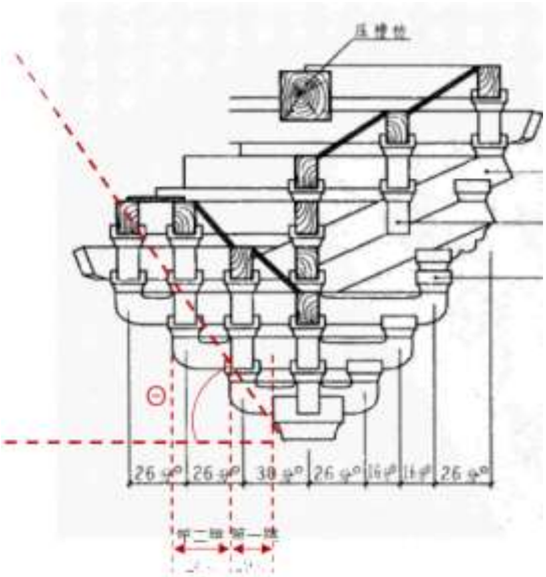

Fig. 19 fen in projection of the timber bracket

Bracketing unit(puzuo) section:

1） In accordance with the Treatise for the construction of timber frameworks, the projection of jumps=19(the first jump)+26(the second jump)+26(the third jump)=71fen(figs. 19), the height of jumps=12(cap-block) +4*21(3arms and shuatou)+30(eaves, or liaoyanfang)=126 fen, the angle of the projection of timber bracket will be TanΘ=126/71；

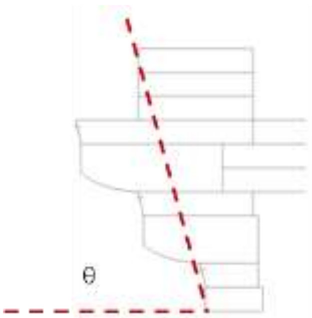

Fig. 20 The angle of the projection of the brick bracket

2） In the brick bracket, the projection of jumps =2*half the brick length=the brick length， the height of jumps =2(cap-block)+2*3(2arms)+3(eaves, or liaoyanfang)=11brick thickness， the angle of the projection of brick bracket will be Tanθ=11thickness/length(figs. 20)；

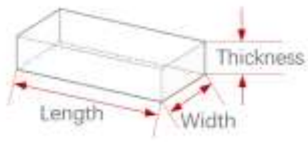

Figure 21 Standard brick length, width and thickness

It is generally accepted that masonry brackets are less capable of projection than timber ones, i.e. θ > Θ, 11*brick thickness/length > 126/71, i.e. when brick length < 6.2*thickness, masonry brackets projects less than timber. The standard bricks are generally within this ratio.

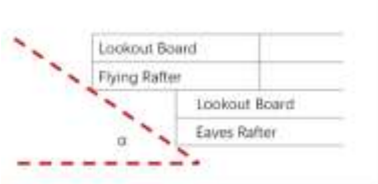

Fig. 22 The angle of the projection of the brick rafters

Rafter(chaunwang) section:
By eaves rafters out of half brick length, the projection of rafter= half-length + 6/10*half-length = 4/5*length, height of rafter=rafter diameter + lookout board(wangban) + flying rafter + lookout board = 4*thickness, then the angle of rafter section will be: Tanα = 4thickness / 1 length (Figure 22);

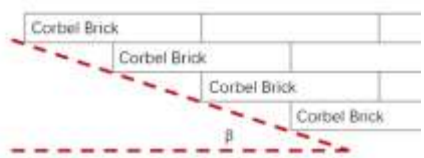

Fig. 23 The angle of the eaves of the brickwork corbel

The angle of eaves is more flexible in the corbelling practice and the corbelling in brick pagodas is generally curved, so for this comparison of projecting capacity, the maximum projecting capacity - i.e. by half a brick length - is calculated as follows:
Each step height = one brick thickness, each jump ≤ half brick length, according to the maximum value of half brick length, corbelled eaves out of the minimum angle Tanβ = 2*thickness / length (Fig. 23).

The result is that the projection angle of bracket θ > the maximum angle of rafter α > the maximum angle of corbel β. The capacity of the projection is strongest in the corbel, followed by the rafter, and last in the bracket.

It is assumed that this imitation of timber was intended to conceal the true properties of the masonry and to create the illusion of timber construction, but following the timber method of construction did not bring out the original structural properties of masonry as a material, so a compromise was made: the modal construction of timber was continued by standard brick and clever masonry, but the eaves were completed by the construction method best suited to masonry: corbel(diese) - or rafter look similar to corbel(diese) - to complete the eaves.

1.3.2 Variations in the proportional relationship in the form of bracket elements

In brick brackets, the scope for variation is limited by the standard brick as a solid module, and a balance is often found between imitating the timber frame in accordance with the Treatise and following the proportions of the standard brick. The following is a list of common brickwork practices, using the cap-block(ludou) and arm(gong) as examples respectively.

1.3.2.1 Cap-block(ludou)

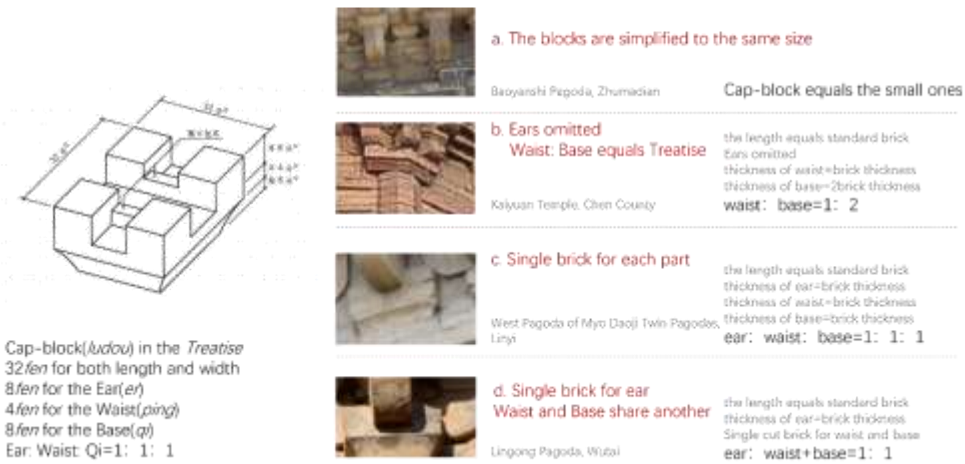

Fig. 24 The cap-block in the Treatise and the Song Dynasty brick cap-block

The dimensions of the cap-block in the Treatise are 32° wide, bearing-block 8° in ears(er), 4° in waist(ping), and 8° in base(qi), with a ratio of 2:1:2. There are four main types of cap-block in brick brackets (Fig. 24):

a. The blocks are simplified to the same size. For example, in the pagoda of the Baoyan Temple in Zhumadian, the capital block is as large as the small ones, both made by chopping bricks in the same way.

b. The block ears being omitted and the proportions of waist and base being the same as in the Treatise. This practice is consistent with the logic of brickwork construction (without mortise and tenon), but also takes into account the proportional relationship in the Treatise, as in the case of the Kaiyuan Temple in Chen County, where one layer of bricks is used as waist and two layers of bricks are padded underneath as the base. That is, the ratio of the three parts is 0:1:2.

c. The ear, waist and base are all of one layer of brick. This approach focuses on imitating the integrity of the Treatise elements and seeks to represent each part, but using two layers of bricks each for ear and base would result in an oversized block and an imbalance in the proportions of the façade, so the proportions of the base are sacrificed and the three parts are represented by single layer of bricks each, also making the ratio of the three parts 1:1:1.

d. A single brick is used for the ear and another single used for the waist and base jointly. This is one of the more common examples and is presumed to be due to the fact that the total height of the cap-block is 20 fen, equal with the thickness of cai. In combination with the practice of using two vertical bricks parallel for the transversal arm(huagong), it is clear that the thickness of the two bricks = 20 fen, so it is reasonable to use two bricks for the cap-block. The ear bricks being too laborious to cut for inserting the arm in the middle, therefore used a separate layer of brick and the lower part padded with another. Then the ratio comes to ear: (waist+base) = 1:1.

1.3.2.2 Arm(gong)

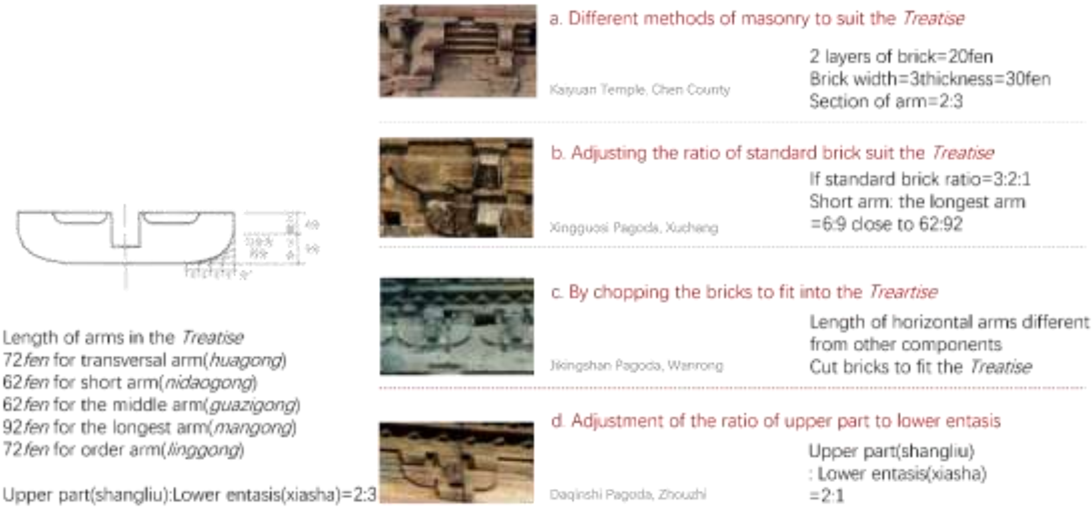

Fig. 25 The arm in the Treatise and the Song Dynasty brick arms

The dimensions of the arms in the Treatise are 72 fen for the transversal arm(huagong), 62 fen for the short arm(nidaogong), 62 fen for the middle arm(guazigong), 92 fen for the longest arm(mangong), 72 fen for the order arm(linggong), 6 fen for the upper part(shangliu) and 9 fen for the lower entasis(xiasha). The arms in the brick brackets, in the absence of measurements, can be deduced from the photograph to have been made in the following ways (Fig. 25) :

a. The different methods of masonry are adapted to the Treatise. In the case of the Chen County Kaiyuan Temple, the transversal arm(huagong) is made of double bricks, the short arm(nidaogong) is made of vertical bricks, and the sloping arm is made of three horizontal bricks, resulting in a height-to-thickness ratio of 3:2 in the transversal arm section, which is in accordance with the proportion of the material section in the Treatise.
b. Adjusting the standard brick width to thickness ratio to suit the Treatise. For example, in the Xuchang Xingguo Temple pagoda, the short arm(nidaogong) is composed of horizontal pasted vertical brick, and the longest arm(mangong) three-horizontal brick stack + horizontal pasted vertical brick, so it is known that the brick width-thickness ratio is 3:1. The choice of the standard brick ratio is thus presumably related to the adjustment of the arm length to fit the Treatise.
c. By chopping the bricks to fit into the Treartise. In the case of the Jishan Temple Pagoda in Wanrong, the horizontal arm is measured two bricks

long + two bricks thick, and the width of the arm is one brick width. If the brick ratio being 4:2:1, then the arm is too long and does not conform to the proportions in the Treatise; so it is presumed that bricks were cut to fit the arm length in the Treatise.

In addition to the different methods to adapt to the Treatise, there are also methods that cannot comply with the Treatise due to the construction of masonry, such as:

d. The ratio of upper part(shangliu) to lower entasis(xiasha) is adjusted. The arm is made up of three bricks, the upper two without a cut and the lower one with a rounded cut, which gives a ratio 2:1. Due to a shift in construction logic, the arm is made up of two bricks with upper part: lower entasis = 1:1, and three bricks with 2:1 or 1:2, all different from the Treatise.

1.3.3 Difference between the parallel transversal arms and the individual bracket

The parallel transversal arm, i.e., the arm under the eaves of the pagoda or exterior balcony(pingzuo), being evenly arranged, plausibly not corresponding to the position of the column, and the horizontal arms being either concealed, or connected into a whole component (fig. 26). The individual bracket, i.e., under the eaves of the pagoda or exterior balcony(pingzuo), possesses the integrity of transversal arms, horizontal arms and carved nose(shuatou), which clearly distinguishes the difference among the column-top ones, intercolumnar ones and the corner ones (fig. 27).

Fig. 26 Parallel transversal arms, Northern Song - Fusheng Temple Pagoda, Shangqiu, Henan

Fig. 27 Individual brackets, Northern Song Dynasty - Jingde Pagoda, Hu County, Shaanxi

The individual bracket, in order to present the integrity of the bracket set, needs to respond to each of the elements of the timberwork, and this construction, which is not applicable to brick materials, can only be achieved by changing the dimensions of the elements: for example, the brick horizontal arm tends to be smaller, and the projection of the transversal arm is smaller in order to accommodate more loads. The shortened projection of the arm burdens the upper rafters and the corbels, which are responsible for the projection. The paralleled transversal arm, on the other hand, is the equivalent of a cantilever, and because it does not need to support a separate horizontal arch, it can have a much deeper reach. Some of these concealed carvings and horizontal arms already have the effect of corbel, so the essence of this paralleled arm is a corbelled arm or cantilevered arms.

2. Differences in other major timber components

Of the other major timber components, the brick imitations are both referenced and adapted to the Treatise.

2.1 Columns

The columns in the Treatise are divided into two types: straight columns and shuttle columns, the straight columns being naturally divided, with the head of the column tightly entasis; the shuttle columns are entasis on the upper part. The dimensions are: "columns in palatial structure: 2cai 2qi to 3cai (42-45 fen), columns in hall structure: 2cai 1qi (36 fen), and in ordinary residence: 1cai 1qi to 2cai (21-30 fen), which is large compared to the examples of wooden structures. "In addition, the height of the pillars is "not to exceed the width in-between pillars", with a width to height ratio of about 1/8 to 1/9.

Fig. 28 Northern Song Dynasty - Taiping Temple Pagoda, Qishan, Shaanxi

Fig. 29 Northern Song dynasty - Wuling Temple Pagoda, Yongshou, Xianyang, Shaanxi

In the imitation of wood column, the brick ones is not bearing the load as a frame structure, but acting with the rest of masonry structure to bear the load, which is actually a "wall column". There are two main approaches: horizontal brick stacking and vertical brick parallel laying. In the case of horizontal brick stacking (fig. 28), the columns are approximately equal in height to width of the central-bay(xinjian), as in the case of the Taiping Temple pagoda in Qishan, where the ratio of column width to height is approximately 1/5.2; in the case of vertical brickwork (fig. 29), the columns are approximately equal in height to width of the central-bay(xinjian), as in the case of the Wuling Temple pagoda in Yongshou, where the ratio of column width to height is 1/5.

Hence, the brick imitations of wood follow 'the eave-columns do not exceed the width of the bay' in the Treatise, but their height to width ratio is significantly smaller than that of wood, and the columns are shorter and thicker. The reason for this is that brick pagodas are mostly eight-sided or six-sided and have a smaller plan than palatial buildings and halls, so the height of the eave-column shortens with the width of the room, and the height to width ratio decreases while the diameter of the column remains the same.

2.2 Architraves and Beams(efang)

The architraves are divided into four types according to the Treatise: longitudinal lintel(lan'e), eave-architrave(yan'e), second architrave(you'e) and floor beam(difu), the dimensions of which are: "longitudinal lintel being 2cai in height, width 2/3 the height (20 fen), both ends entasis, 1/2 the height (15 fen) when there is no intercolumn brackets; eave-architrave being 2cai 1qi to 3cai (36-45 fen) ; second architrave being 2-3 fen shorter than longitudinal lintel(17-18 fen); floor beam being 17-18 fen, width 2/3 the length".

Fig. 30 Northern Song Dynasty - Kaiyuan Temple Pagoda, Bin County, Xianyang, Shaanxi

Fig. 31 Northern Song Dynasty - Wuling Temple Pagoda, Yongshou, Xianyang, Shaanxi

Fig. 32 Northern Song Dynasty - Cixiang Temple Pagoda, Pingyao, Shanxi

In the brick imitation wood structure, similar to the "wall column", architraves do not enact the structural role in the frame structure, more of façade division. There are mainly 3 consequences in the cases: 1) only longitudinal lintels: such as the construct of 3 layers in Kaiyuan Temple Tower (Figure 30), if the height of arm is measured by 2 layers of brick for cai, the longitudinal lintel is equivalent to a height of 1cai; 2) both longitudinal lintels and eave-architrave: such as the Wuling Temple Pagoda (Figure 31), the longitudinal lintels(lan'e) and board architraves(pingbanfang) are measured by 2 layers of brick, if the thickness of 3 layers of brick for cai, the height is less than 1cai; 3) the case of only the board architraves: for example, Pingyao Cixiang Temple Pagoda (Fig. 32), the height being 1layer of brick, and if cai is measured by 2 layers of bricks as in the transversal arm, the height will be 5fen.

In summary, the height of the architraves in the brickwork imitation is much smaller than that of the woodwork, probably because the lintels in the brick imitation woodwork does not need to play a structural role and is only used as a façade division between the brackets and the wall, which size being reduced.

2.3 Corner beams(jiaoliang)

The four types of corner beams in the Treatise are the Great Corner Beam(dajiaoliang), the Sub-Corner Beam(zijiaoliang), the Hidden Corner Beam(yinjiaoliang) and the Continuing Corner Beam(xujiaoliang), the dimensions of which are "four inches for one bay, five inches for three bays and seven inches for five bays; the Great Corner Beam is 28-30 fen long and 18-20 fen high; the Sub-Corner Beam is 18-20 fen long and 15-17 fen high; the Hidden Corner Beam is 14-16 fen long and 16-18 fen high".

Fig. 33 Northern Song Dynasty - Shende Temple Pagoda, Tongchuan,

Shaanxi

In the brick imitation wood examples, Tongchuan Yanchang Temple Pagoda(Fig. 33), with 3 bays for the façade, whose corner beam projection is still made by brick masonry, the maximum for the half-brick length, (take half-brick length for two brick thickness 20 fen, the 8th cai), then the corner beam projection is less than or equal to 6 inches, which is not much different from the Treatise. The length and width of the corner beam is the same as that of the transversal arm, i.e. 15 fen wide and 10 fen thick, which is less than the Treatise. In masonry buildings, the corner beams do not support the roof, but are used with the rafters to complete the eaves, and are only formally distinguishable from the rafters.

2.4 Eaves joists(liaoyanfang)

The eaves joists are 30fen high and 10fen thick in the Treatise, but in brickwork the eaves joists are about the same height as the horizontal arms, i.e. 15 fen, much less than in the Treatise. With the change in construction method, the brickwork does not play the role of "eaves-raising", but rather serves as a transitional element between the transversal arm and the rafter, close to the effect of corbel, and therefore does not need to be of great height.

2.5 Rafters(chuan)

The rafters in the Treatise are divided into two kinds: eaves rafters(yanchuan) and flying rafters(feizi). "The dimensions of the eaves rafters' diameter is 9-10fen in the palatial construction, and those of the halls are 7-8 fen; the projection being 3chi 5cun with the diameter of 3cun, while the projection being 4chi to 4chi 5cun with the diameter of 5cun. The dimensions of the flying rafters' width is 8/10eaves rafters' diameter, thickness being 7/10eaves rafters' diameter; the projection is 6/10that of the eaves rafters."

Figure 34 Northern Song - Xingguo Temple Pagoda, Xuchang, Henan

Figure 35 Northern Song Dynasty - West Pagoda of The Twin Pagodas of Miaodao Temple, Linyi, Yuncheng, Shanxi Province

Most of the rafters in the brick imitation wood construction practices are similar (Fig. 34, Fig. 35), the eaves rafters share the same diameter with the flying ones, which are of single layer of brick (taken 2 layers of brick as 1cai, the rafter diameter being 5 fen), the distance of projection by the eaves rafters is the same as transversal arms, while that of the flying rafters being a little shorter.

In comparison, the diameter of the rafters in the brick imitation timber frame is approximately half that of the Treatise, and the projection is approximately the same as that of the transversal arm, much smaller than that of the Treatise and the timber frame cases. The change in rafter diameter is due to the solidification of the module and the adjustment of the projection is due to the change in construction method, i.e. the maximum projection of the masonry is half of the brick length, much less than that of the timber frame.

2.6 Straight strips(timu)

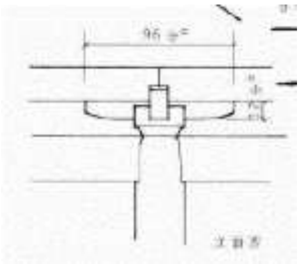

Fig. 36 Straight strips in the Treatise

In the Treatise, the straight strip is 10 fen thick and 12 fen high, and its length varies from 96 fen to 104 and 126 fen, depending on the component below it being a single block(dandou), an order arm(linggong) or a remnant arm (Fig. 36).

Fig. 37 Northern Song Dynasty - Jingde Pagoda, Hu County, Xi'an, Shaanxi

In the case of the brick imitation woodwork, the height of straight strips(timu) being a single layer of brick. Taken 2 layers of bricks as 1cai, so the height of strips being 5fen, less than the 12fen in the Treatise, and the length is about the same as the short arm(nidaogong) (62 fen according to the Treatise), still less than the Treatise. However, in the case of the brick mock-ups, the brackets are so densely packed that the strips in adjacent brackets almost meet, so the reduction in length is not due to the module or construction method, but rather to the avoidance of interlocking members. The reduction in length is probably due to the fact that the strips act to disperse the support provided by the brackets, which themselves do not need to be thicker or longer in order not to create a greater load.

Fig. 38 Northern Song Dynasty - Shende Temple Pagoda, Tongchuan, Shaanxi

There is another type of brickwork imitation in which a rectangular piece is placed between the block(dou) and the eaves joists(liaoyanfang), which is not seen as a complete component in the Treatise, but is similar to the position and role of the straight strips(timu), and is suspected to be an evolved woodwork in brickwork: as the woodwork is used to disperse the support provided by the blocks, therefore its self-weight is required to be as small as possible, it gradually evolved into a rectangular piece of brickwork placed between the block(dou) and the eaves joists(liaoyanfang).

3. Conclusion

The Song Dynasty brick pagoda imitations of wooden components follow the practices of the Treatise of Architectural Methods(Yingzao fashi) while adapting to the dimensions of the Treatise due to differences in both material forces and construction logic. However, the proportions of the Treatise were maintained to some extent by controlling the module of the bricks and the combination of bricks. The construction of the brackets of the brick pagoda imitations of woodwork was neither independent of the Treatise nor a rigid system, but rather a process of reconciling the two types of material and synthesising them.

References

[1]Liang Sicheng. Yingzao fashi zhushi(Annotations to Yingzao fashi), Beijing: Zhongguo jianzhu gongye chubanshe, 1983.

[2]Pan Guxi, He Jianzhong. Yingzao fashi jiedu(Understanding if Yingzao fashi), Nanjing: Dongnan daxue chubanshe, 2005.

[3]Gao Dalun. Zhongguo wenwu dituji(Atlas of Chinese Cultural Relics). Beijing: Wenwu chubanshe, 2009.

[4]Su Bai. Baisha songmu(Baisha Song Dynasty Tomb). Beijing: Wenwu chubanshe, 2002.

[5]Cui Hang. Sichuan songdai zhuanta diaocha yanjiu(Investigation of brick pagodas in Sichuan Song Dynasty). Tsinghua University, 2017.

[6]Zhang Hanjun, Zhang Xiaodong. Liaodai wanbu huayanjing zhuangou dougong-jiantan liaodai fangmu zhuangou dougong gouzhi de shidai tezheng(Liao Dynasty Ten Thousand Huayan Scriptures Pagoda Brick Brackets—Contemporary Features of the Brick Brackets Imitation Woodwork in the Liao Dynasty), Gujian yuanlin jishu, 2000(03):3-15

[7]Zhang Xiaodong. Liaodai zhuanta jianzhu xingzhi chubu yanjiu. Jilin University, 2011.

[8]Harrer. A, Cao Manqing. Fang mugou: Zhongguo yingzao jishu de tezheng-qiantan yingzao jishu dui zhongguo fangmugou xianxiang de zhongyaoxing(Imitation Woodwork: Characteristics of Chinese construction technology-- A brief discussion on the importance of construction technology to China's imitation wood structure phenomenon). Jianzhushi(Architectural History), 2013(02):11-24.

[9]Tianguo. Liquan xian Xiangjisi ta zhuanshi jiyi yanjiu(Research on masonry technology of Xiangji Temple Pagoda in Liquan County). Xi'an University of Architecture and Technology, 2016.

[10]Peng Minghao, Li Ruoshui, Mo Jiajing, Huang Wenlan, Hang Kan, Xu Yitao. Luoyang jianxi qilihe fangmugou zhuanshi mu cehui jianbao(Brief Report of mapping Qilihe Brick Tomb Imitation Woodwork in Jianxi, Luoyang). Kaogu yu wenwu(Archaeology and antiquities), 2015(01):45-52.

[11] Lin Wei-Cheng, "Structural, Visual, or Iconic: The Transmutation of Wooden Brackets in Modern China," Frontiers of History in China 10, no. 2 (2015), pp. 323-365.