A Comparative Study of Traditional Jointing Techniques

of Vernacular Timber Framings in New England, America and Jiangnan, China

and Some Applications in Conservation Practice

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Abstract:

The start point of this comparative study was to understand how vernacular timber houses in New England and Jiangnan in history responded to building tasks with their characteristic framing and jointing techniques. Function of wood joints was taken as the basis for comparison, as it was the fundamental consideration in the design of joints, and quite similar in vernacular buildings from different building cultures. Therefore two buildings – the Horton House and the Yin Yu Tang house – were chosen as the paradigms of traditional vernacular buildings in New England and Jiangnan. Detailed comparisons were made between their framing methods and wood joints, and more importantly, how the joints accomplished their building tasks. After that, the two actual buildings were located in the larger building contexts of the regions they belonged to, to examine the shared characters as well as diversity within each building culture. The basic consideration was still the problem-solving mechanism, and some concepts underlying were discussed.

The comparison study concluded that: the box frame utilizing three-dimensional jointing, the self-supporting triangular roof structure and jointing emphasizing on structural function were the core characters of English timber framing; while structure composed of simple duplication of building components, ingenious joint designs which had more consideration for aesthetics and reinforced the structure only indirectly were essential to timber construction in Jiangnan.

This conclusion was then applied to develop a critical thinking about methodologies of wood building conservation, with specific emphasis on practices in China. The conclusions were in two categories: 1. applying some western approaches in Chinese timber framing conservation, such as developing systematic scientific research; 2. revitalizing traditional practices of construction and repairing in China, such as studying past techniques via precise conservation process, identifying and utilizing techniques which are culturally valuable, and training professional craftsmen to recover the glorious beauty as well as physical soundness.

Key words: comparative study, timber framing, wood joints, function, building culture, conservation, traditional techniques, scientific approach
0. Introduction

0.1 Subject of research

Wood is a building material and at the same time designates a way of building. Its similar tensile and compressive strengths (the ratio is about 2:1 along the grain) make post-and-lintel construction a feasible way to create a structure, and also allow for cantilevering. Some other properties – dry and warm insulation, and regular shape of timber from conifers also count for the widespread log houses in northern regions. But in different parts of the world, timber framing takes diversified forms, all of which have their own rationalities as a creation of their environment, history and building culture.

One consequent product of timber framing is joint, which is also a critical factor manifesting many considerations of the former: arranging the loads, achieving a certain form or scale, displaying pleasant decorative effect, etc. A notable thing about joint is that, although their designs are affected by various factors, the most fundamental concern has to be their structural functions in the frame. This provides a basis for comparison of framing and joints in different building cultures.

Therefore, this paper would make a comparative study on the functions of wood joints in two representative building cultures – New England and south China. Vernacular buildings are taken as the research subject, as their forms are more directly affected by pragmatic uses (environment and life style) and rationality of framing; besides, their simplicity could help researchers identify the fundamental concerns of a building, based on which the complexity of more luxurious buildings could be analyzed. On the other hand, vernacular buildings are by no means provincial. State-of-the-art building techniques could find their forms and methods clearly revealed in ordinary constructions; the reason might be spreading of techniques, or a shared concept of design (Fig. 0.1).

This comparative study is initiated by the author’s interest in diversified timber framing techniques and the historical and cultural meanings revealed by them. Besides facilitating better understanding of the different traditions in timber construction, this study can also reveal something about the more intangible values like design concept, both of which are important considerations in the conservation of buildings. Therefore, the second half of this paper will work on developing some conservation methodologies based on the comparative study.
0.2 Methodology

For the comparative study, this paper applies two kinds of approaches: one is making comparison based on the functions of framing and joints, and the secondary method is construction history study.

In his book *Wood and Wood Joints* (1997), Klaus Zwerger\(^3\) regarded wood joints as solutions for certain building tasks rather than defining them into categories, to establish a basis for connecting his researches on European wood buildings and Japanese ones. This method proved effective in many discussions of his book: such as how Europeans and Japanese composed the three dimensional grid body of their buildings, or how they developed large span roofs following their typical framing concepts. On the other hand, the comprehensive study of Zwerger used more general typologies instead of focusing on exact examples.

In this paper, the author will adopt this methodology of making comparison based on functions, but only to make a simpler study on the more basic functions of timber framing. This study might not explain some splendid facts of wood architecture, but can provide solid knowledge about the common, ordinary construction of the vernacular, and assist conservation of them.

Study of joint functions alone only presents a “cross sectional data”, while the perspective of construction history could reveal the discourse that led to a certain expression of the function, therefore triggering more thinking centering around this subject. For example, without some knowledge of construction history, one can hardly connect the triangular roof framing of a New England house to the idea that led to splendid truss constructions, and could not build up a scheme within which the truss structure and the many layers of beams in East Asian wood buildings could generate an inspiring discourse. Nevertheless, this paper is not about construction history research, so this perspective is only applied to achieve better understanding of the subject to be researched and compared.

Methodologies about wood joints and framing conservation would be developed based on the comparison research. The core discourse is about China’s attitudes towards conservation theories and techniques from other countries, with regard to its unique building culture and traditional conservation approaches.
0.3 Literature review

Comparison between Chinese architecture and western architecture started since architecture as a discipline was recognized by Japan in early 20th century, and frequently appeared in architectural culture study in China in the past century. When western scholars first judged East Asian architecture with western standards, wood architecture in China and Japan was regarded as backward, unhistorical, merely craftwork without any sense of art; and many of the earliest comparative studies were made by East Asian architectural scholars to respond to these judgments. Ito Chuta in his *Chinese Architecture History* (1931) discussed the different aesthetics of the two building systems, and LIANG Sicheng in his *Chinese Architecture History* laid more emphasis on design concept and building culture. Many essays in the following years have talked about this issue, mostly focusing on the aspects of design concept and building culture, and some best studies were made by scholars from Taiwan and Hong Kong. However, western architecture discussed in these comparative studies is usually the high style masonry buildings; therefore comparison on culture and design is certainly more feasible, as the construction is completely different.

Later in the 20th century, western scholars’ interest in East Asian architecture increased, and their researches have gained high reputation in China. Representative scholars are Else Glahn, James Cahill and Nancy S. Steinhardt. But these scholars are mainly Sinologist and rarely worked on comparative study. Japanese wood buildings, joineries and conservation have also been learned by many western researchers and designers, but comparative study is very few, and the work by Klaus Zwerger mentioned above is the only well-known academic writings on this issue so far.

What truly forms the solid background knowledge of this paper is the field investigation and architectural history researches about vernacular Chinese buildings and New England wood buildings. Research on Chinese vernacular architecture started in 1930s when the first generation of architects returned from oversea study and tried to establish the discipline of architectural history, for which surveying vernacular dwellings composed a significant part. Researches became more systematic since the 1950s. But early works had more emphasis on the building’s form and the environmental forces. In 1990s, vernacular buildings became a subject for research and education in many architectural schools. Since then, products have been greatly extended in depth and width; one thing especially meaningful to this paper is that construction study is introduced to many of these researches.

The modern scholarship about wood buildings in America started from late 19th century, to some extent motivated by the Romanticism Movement. Researches from historical and architectural approaches reached high level into the 20th century, based on voluminous documentation works. Academic works on 17th century
buildings of New England has been published throughout the past century, including: *Domestic Architecture of the American Colonies and the Early Republic* by Fiske Kimball in 1922, *Early American Houses* by Norman Isham in 1928, *Early Domestic Architecture of Connecticut* by Frederick Kelly in 1933, *Early American Architecture* by Hugh Morrison in 1952, and *the Framed Houses of Massachusetts Bay* by Abbott Lowell Cummings in 1979. These works present detailed descriptions about framing, which is illustrated even clearer when combined with the increasing study on traditional woodworking techniques.

As stated above, this paper would utilize extant architectural history researches when studying the functional aspects of wood buildings. Comparative studies in the past will also act as references when comparisons are made in this paper.
Examples are the decorative braces on the facade of European half-timber buildings, and layers of brackets in east Asian wood buildings.

Klaus Zweger is a professor of construction history in Technische Universität München who had rich woodworking experiences since earlier in his life. He researches widely on historic European timber constructions and also gains reputation in China and Japan for his abundant research on wood buildings in these two countries.

Works making such judgments included: *Chinäsische Kunstgeschichte* by Oskar Münsterburg in 1865, *History of Indian and Eastern Architecture* by James Fergusson in 1876, and *Sir Banister Fletcher’s a History of Architecture (1st ed.*) by Dan Cruickshank in 1905.


Liang pointed out that Chinese architecture paid more attention to the plan of the whole complex, and did not pursue the longevity of materials. These are now common senses to Chinese architecture students, but sometimes regarded as cliché by western scholars.

Representative works are *Design Theory of Chinese Classical Architecture* by Li Yunhe (1930-1989, Hong Kong architect) in 1982, and many essays about architecture by HAN Baode (1934-2014, Taiwan architect).

Else Glahn’s study of Chinese building technique inspired Jorn Utzon; James Cahill was known for his study in Chinese landscape paintings and landscape gardens; and Nancy S. Steinhardt is an expert in Chinese architecture.

The author did know some students of Sinologue who made comparative study about architecture. Alexandra Harrer, Ph. D of University of Pennsylvania and now a visiting scholar in Tsinghua University, wrote some articles on the comparison of Chinese and western building techniques. But in general, comparative study could not support a large scheme for academic research, therefore seldom become a subject for the latter.

Important researchers include: SHAN Qide, CHEN Zhihua, LOU Qingxi, LI Qiuxiang and LUO Deying, from Tsinghua University; GONG Kai, DUAN Jin and HU Shi, from Southeast University; LU Yuanding, from South China University of Technology and RUAN Yisan, from Tongji University.
Figure 0.1: Similarity between construction techniques used in high style buildings and common construction (upper left: St. Martin’s Church, Colchester, England; upper right: gatehouse of the Blackmore Priory, Blackmore, England; down left: Hall in the house of an affluent official surnamed Xu, Shexian County, Huangshan City, China; down right: the gate house of an abandoned vernacular dwelling, Shankeng Village, Wenzhou City, China)
1. A comparison between wood joints used in the Horton House and the Yin Yu Tang House

1.1 Introduction

The goal being to compare wood joints used in representative timber frames in south China and New England, this chapter adopts the methodology of comparing the ways these joints solve certain questions put forward by construction. The Benjamin Horton House (c. 1649, also known as the Old House at Cutchogue) and the Yin Yu Tang house (c. 18\textsuperscript{th} century) represent two typical examples from these two building cultures, in that both the form and the construction techniques are very common among buildings of the same region. This chapter focuses on these two cases. The larger context of building cultures will be presented later.

The Horton House was erected by John Budd in early 1649 at Southhold, some ten miles northeast of its present location in Cutchogue, Suffolk County, Long Island. In 1659 Budd gave it to his daughter as a wedding gift. The house was then moved to its present location and re-erected at a cost of 20 pounds "Boston Money". After that, the house has been resided in by the Hortons, the Wickhams, the Landons, and finally donated to the Independent Congregational Church and Society of Cutchogue by William Harrison Case. The house has a plan area of 36’ by 20’, and a typical English wood building composition: two stories plus one attic, the huge chimney and staircase in the center, and parlors, kitchens and bedrooms are arranged on the two sides of them. The house was restored twice in 1940 and in 2005, and is now still in good condition.\textsuperscript{1}

Yin Yu Tang was constructed in the Huizhou region (a northern region of south China) in the late 18\textsuperscript{th} century, commissioned by an affluent merchant surnamed Huang. Merchants from Huizhou became wealthy since the 16\textsuperscript{th} century when industrial and commercial activities prospered along the lower Yangtze River, and many houses of similar kinds were constructed during some 400 years, which today still compose the landscape of traditional Huizhou settlements. Yin Yu Tang has a building area of 4,500 square feet, consisting of three halls and sixteen bedrooms, plus other service spaces. They are arranged in two stories on the two opposite sides of a courtyard, which was then a typical arrangement for houses in that region. The Huang family lived in Yin Yu Tang for two centuries until 1978. In 1996, when the Huang family members planned to sell the abandoned house, Nancy Berliner, Curator of Chinese Art at Peabody Essex Museum (Salem, MA) proposed to buy it. Then the house was carefully dismantled, its every little components transported to America, and reassembled in the museum by conservators and craftsmen from both America and China.\textsuperscript{2}

To clarify, timber framing techniques in China entered a quite stable state since the 7\textsuperscript{th} century, and only evolved slowly afterwards. During the late phase of Imperial China when Yin Yu Tang was built, framing techniques were highly standardized. Therefore, although Yin Yu Tang was built a century later than the Horton House, it is eligible as a representative of traditional framing techniques in the comparative study.
1.2 Framing as the context of joints

It is necessary to look at the framing first, the context where tasks for wood joints are embodied. The Horton house is notable as one of the most distinguished surviving examples of English domestic architecture of the 17th century in America. It is based on a box frame composed of posts, beams and girts; summer beams extend between opposite girts to support floor joists; then rafters connected by collar ties and slim purlins are added atop the box to form the roof structure (Fig. 1.1).

Yin Yu Tang represents a typical framing method of vernacular houses in Huizhou – Chuan-dou frame. The basic unit is a bent, composed of posts and ties connecting them; then several bents are connected by ties again in the longitudinal direction to form a frame. Purlins are directly connected to the posts, which also reinforces the frame in the longitudinal connection (Fig. 1.2). A standard Chuan-dou bent has all its posts reaching the ground, but many times, such as in the case of Yin Yu Tang, some posts are curtailed to the short posts standing on ties; then these load-bearing ties are likely to be treated as beams (tie beams). To make the discussion simpler, this paper only studies the main building to the south of the courtyard, which is about the same size as the Horton House.

A notable difference between the two frames is the relationship between the roof and the body. In Yin Yu Tang, the upper triangle part is integral to a bent, meaning that a bent integrates the main body and the roof frame. For the Horton House, the frame is basically divided into two independent volumes – a carcass and a roof frame. The two framing methods result in different load bearing paths. In the frame of Yin Yu Tang, roof load is directly transmitted to each post via purlins, resembling a simple post-and-lintel structure; while in the Horton House, roof load is exerted on the top plates as thrust from the rafters.

Another difference is the lack of diagonal bracing in Chinese houses. Explanations include: desired resilience against earthquakes; triangle being regarded as ominous by the Fengshui theory; natural evolution from ancient building prototypes; etc. A direct consequence is that the tasks of joints (not the joints themselves) are simplified, as they need to deal with forces in fewer directions. This makes a Chinese timber frame appear more succinct compared to its lively western counterpart.
1.3 Comparison of joints

Now that the two frame types have been clarified as to their building methods, a detailed comparison of joints in the two frame types might be made based on their functions in framing. Framing joinery must resist forces in at least one of the following directions: tension, compression and shear; it should also assist in achieving a desired shape of the structure. Naturally, functions are assigned to the joints via the functional components they belong to (e.g. purlins, rafters, ties); therefore discussion about one would certainly involve the other.

For vernacular buildings, some basic requirements about space and amenity might also be included in the function of joints. They are not discussed in this section, as the two samples chosen for comparison almost represent the most basic form; but they’ll be involved in the next chapter when the larger building context comes into play.

1.3.1 Function of joints in the timber frame of Horton House

(1) Building the box of the carcass

The box frame of Horton House is composed of eight posts (forming three bays) connected by sills at the bottom and girts at the top (here longitudinal upper girts can be renamed plates) (Fig. 1.3). Plates connect the transverse H-shaped bents, and upper end girts and chimney girts connect the front and rear walls. This three-directional joining task is accomplished by a single joint – the English tying joint (Fig. 1.4): the top of a post is cut into two levels, each with a tenon to enter the mortise on the plate and the girt, and the girt is also connected to the plate by a dovetail joint. This circle of interconnected tenons and dovetails is sturdy, but only when executed with excellent craftsmanship to ensure tight joints.

For sills the situation is much simpler. Sills are halved and lapped on the four corners and posts are implanted into them, fixed by gravity. The joint used here is mainly stub mortise-and-tenon so that the sills can prevent some moisture from the ground.

(2) Bearing the floor load

The lower girts together with summer beams and joists mortised into them are the main horizontal supports carrying the loads of the second floor. Retaining more cross-section area for their load-bearing portions is a main consideration when making joints. Summer beams are connected to the girts by tusk tenons (Fig. 1.5), and joists are directly mortised into summer beams and girts (Fig. 1.6). The chimney girts and end girts are
connected to the posts by shouldered mortise-and-tenon joints, reinforced by pegs (Fig. 1.7); while the front and rear girts have smaller section, and are connected to the posts with simple mortise-and-tenon joints (also see Fig. 1.7). This variant of girt were often called “bearers”, although they had less capability in load bearing and binding, but gained popularity as they were easier to process and might lap join with the studs.¹¹

(3) Structural rigidity

Diagonal braces are added to the second floor of the structure to increase its rigidity. They are joined to the posts and girts with stub mortise-and-tenon joints (Fig. 1.8). When they meet the studs, the latter would be cut in two and nailed to the braces. Although some braces are called “tension brace” in terminology, they are mainly effective against compression – note that they are often not pegged to the main frame, meaning that a symmetric arrangement is necessary for the braces to cooperate in their tasks.

(4) Constructing the roof frame

The roof frame of the Horton House is not completely independent. Opposite rafters are joined with bridle joints at the ridge, and their feet are set against the plates with birdmouth joints (Fig. 1.9). Collar ties connect the rafters with pegged lap joints (Fig. 1.10), so that this system of barely fastened joints gains stability under the thrust of rafters (imposed through shear at the ridge, tension along the collar ties and compression at the birdmouth joints). On the two gables the construction is different, where the lower ends of principal rafters are mortised into the end girts (which could be renamed tie beam in this case) – forming a typical English tying joint (Fig. 1.11). The triangle truss at the gable is filled with studs for better stability and enclosure (also see Fig. 10). The English tying joint separates roof members from the body of the house, and makes a very sturdy bent to consolidate the whole structure; but it’s curious that the two upper chimney girts are not joined with rafters, whereas they already accomplished the most difficult part of a tying joint. At last, to keep the frame in shape, a continuous purlin is attached to the rafters on each side of the roof by running through slots cut on them, and being pegged at the joint (Fig. 1.12).
1.3.2 Function of joints in the timber frame of Yin Yu Tang

(1) Putting together a bent

In Yin Yu Tang, the first stage task is putting together a bent. Like all Chuan-dou frames, a bent is constructed by connecting posts with ties. Basically the posts bear the load, and transverse ties bind the posts together.

With stub mortise-and-tenon, posts are erected on pad stones, and short posts set on tie beams (how they connect the roofing will be talked about later). For transverse binding, resistances against compression and tension are both important. The ties are segmented between posts and tenoned into them, but aligned to create a neat appearance; this means that two ties joined to one post from opposite sides can only be connected to it with half tenons, instead of the more stable through tenons. To improve tensile strength, the post is penetrated, and the two half tenons have a stepped shape to increase contact surface area with the mortises and with each other. This is an ingenious joint design, but still the direct binding force comes from pegs pinned through the posts and tenons (Fig. 1.13).

(2) Connecting all bents together

Then longitudinal ties are added to connect bents into a house frame (Fig. 1.14). There are three lines of them between the two floors, connecting the three lines of posts (these ties have another important function to bear floor load, and thus might better regarded as floor beams), and six lines under the roofing (the gallery not included). The joints used are still the pegged stub mortise-and-tenon, like those used in transverse ties.

One notable construction is the four hunchback beams used under the ridge in the two main halls on the second floor (also see Fig. 1.14). Their position in the structure indicate that they are only binding members subject to little vertical load, but the position is so notable to visitors that components here must accomplish some ornamental function. In Yin Yu Tang these beams are made of yellow pine and each weighs around 400 pounds, indicating their significance. Through mortise-and-tenon joints connect them to the posts, indicating at least greater binding strength than common ties.

(3) Bearing the floor load

Both transverse and longitudinal ties between the two stories – here they should be named floor beams – have to bear considerable loads from the upper floor. In this case, they increase in height, to more effectively resist shear (Fig. 1.15); but for some beams this is not done with wider wood panels, but composite beams made of several horizontal pieces laid on top of one another. These timbers have curved edges to fit together (like tongue-and-groove joints), and are driven through by tapering pieces to form a single mass (Fig. 1.16);
then the composite beams are connected to the posts by the joint described in Section 2.1 (also see Fig. 1.13). As the floor beams form a grid, they frequently need to enter a post on its four sides; therefore significant volume of wood must be removed from the ends of each beam, and the post as well, to make room for other beams (also see Fig. 1.15).

(4) Structural rigidity

During the re-erection of Yin Yu Tang, extensive load tests performed on it proved that the structure was stable and strong. According to the conservators, the many small pieces, though having limited structural ability when considered independently, generate impressive strength when combined into a frame. This judgment is mainly made in reference to the technique of stepped stub mortise-and-tenon joints and composite beams discussed above.

The composite beam was developed not due to shortage of wood, but because the assembly made of boards from several small trees is less likely to warp. It is worth noting that, in order to transfer loads and other forces evenly, each member of the lamination needed to be very closely fit to the next, which required a high degree of skill and a great deal of time. Many other ties used in the house, although not composite, also have considerable height to improve diagonal rigidity, and these tall beams together serve the same role as diagonal braces in some sense.

(5) Adding the roof frame

Yin Yu Tang does not have an independent roof frame, but we can at least discuss the joints between the roof and its support (Fig. 1.17). A purlin is attached to the purlin holder by dowels, thereby indirectly connected to the posts. This joint design tries to maintain the full cross-section of the purlins when joining them to the understructure. Fixing the purlin holder by interlocking with tie/ridge column clamp is a clever design, as it makes use of the components of a Chuan-dou bent and remains coherent with it.
1.3.3 Comparison of joints used in the Horton House and Yin Yu Tang

By scrutinizing the tasks performed by framing members and wood joints in the previous paragraphs, we can now invert this process by listing tasks mentioned above, and building up the comparison of wood joints by discussing their functions. The difficulty is that European timber frames and Chuan-dou structures do not follow exactly the same logic in construction, so only the more abstract functions can be used as the basis for comparison.

Task I: transverse binding – assembling an individual bent

In the Horton House the basic bent consists of a lower girt joined to two posts with shouldered mortise-and-tenon joint. Such joint could resist compression and tension if properly designed, meaning that the location and size of pegs are extremely important as they provide the main binding strength. These simple H-shaped bents then get further reinforced by the transverse sills and upper girts, with the connection of simple mortise and tenon, but sills and upper girts are more like the components of a holistic box frame rather than bents, as a result of the three dimensional framing concept.

In Yin Yu Tang this task is mainly accomplished by transverse ties connecting posts with the pegged, stepped stub mortise-and-tenon, whose binding force relies on pegs. Pad stones fixed firmly to the foundation also account for the stability of the posts; the joint used here is the simple stub mortise-and-tenon. The necked tenon used near the roofing has effective binding force, but application is constrained to the top of the posts.

Task II: longitudinal binding – connecting all the bents

Again, both tension joints and compression joints are needed. In the Horton house, this is done by: 1. plates and sills housing tenons on both ends of the posts; 2. bearers with pegged mortise-and-tenon joints on both ends connecting the posts – here again the pegs need to be well designed. Transverse upper girt assists the job by providing auxiliary connection between the post and the plate, with the help of the tying joints. In sum, the system is similar to transverse binding, and the composition of a box frame is indeed quite homogeneous within each bay.

In Yin Yu Tang, it’s the same joints for transverse binding that are used here. The joint has to be adapted when four ties meet at the same height of a post, but the prototype is not changed; a slight difference is that the purlins provide some extra binding force.

Task III: shear – bearing the load of the floor
In Horton House, floor load is supported on a system of lower girts, summer beams and joists. To resist shear, joints tend to maintain as much material as possible in cross section area. The shouldered tenons on the transverse girts and the soffit tenons on the summer beams both serve this purpose. Also, the existence of bearers indicates discrimination in the load bearing tasks.

The floor beams of Yin Yu Tang are connected to posts in the same way as ties, as they are the same thing. The new technique here is that floor beams are laminated to increase overall load bearing capacity, especially against shear. These composite beams form a grid as a sturdy structural layer, but also require substantial material being cut out from the joining parts; nevertheless, competent woodworking techniques ensured stability of the overall system.

Task IV: diagonal rigidity

For Yin Yu Tang, laminated ties described above also serve to prevent diagonal distortion, as this technique ensures excellent resistance against shear and warping. In Horton House the approach is much more straightforward, by adding diagonal bracings across the walls of a whole floor. The joint is simply half tenon-and-mortise, which is more effective under compression than tension; nevertheless they are effective enough when utilizing the stability of a triangle structure, and cooperating within the symmetric arrangement.

Task V: spatial framing – achieving desired roof span and roof form

Spatial framing requires interrelated functioning of joints instead of individual performance, making it hard to compare joints purely based on their functions. Fortunately the situation here is not yet complex, thereby the tasks are still very basic – mainly two dimensional connection.

For the roof frame of the Horton House, the basic task is to build a standing triangle, which is a quite independent structure – probably mainly influenced by the need to shed precipitation. The joints only need to fix the laterals and the base (rafters and maybe tie beams) into place. In the Horton House, the upper vertex of each triangle frame is made by a pegged bridle joint, and the lower ones are birdsmouth joints set on the plates or half tenons into tie beams (in the end bents). The collar ties connect the rafters with pegged lap joints to keep the triangle in shape against roof load, though their weak tensile strength still let much thrust go to the rafter feet. Finally, individual triangles are connected by purlins to form a spatial structure; the single notched joint used here is unstable, thus the roofing board nailed to the rafters should have contributed considerable binding strength.

Dictated by the form of Chuan-dou structure, the roof profile of Yin Yu Tang is not independent, but determined by the understructure; therefore the joints only need to fix the purlins to the posts to create a
roof frame. This is done by intersecting purlin holders with tie/ridge post clamp and fixing them into the slotted posts together, then attaching purlins to them. But this joint is quite weak against perpendicular forces, thus even slight deviation of loads may displace the purlins and lead to aggressive distortion.

Task VI: transmitting roof load to the understructure

In the roof structure of the Horton House, thrusts within each triangle are transmitted in oblique paths, but do not require specified joints – joints effective in orthogonal directions would suffice (the thrust might be reorganized into forces of orthogonal directions for easier analysis). Here the thrusts are received by the birdsmouth joint against the plate, or the half tenons into the tie beam in the two end bents. In the latter case the tie beams take over the thrusts, and are firmly fixed to the box structure through the English tying joint, which is to a great degree designed for this situation. Thrusts going to the plates become an issue within the box frame, whose responsible joints have been discussed in the previous section.

In the frame of Yin Yu Tang, load only transmit along horizontal and vertical structural members, resulting in shear in the former and compression in the latter. Due to the integrity of the bent, the joints connecting the roof to the understructure are those defining the roof profile as described above. Therefore another important function of the joint is revealed, that is, to retain more cross section area of the purlins, and also to stabilize them (though only in the longitudinal direction) with the help of purlin holders.
1.4 Comparison of the joinery techniques of the Horton House and Yin Yu Tang

After studying the jointing techniques of the Horton House and Yin Yu Tang, the author realized that although their joints differ greatly in design conception, the practical skills required to produce them are amazingly similar. So this section will concentrate on the more distinguishing characteristics of each jointing technique when introducing them separately, and compensated by a detailed summary of similarities in a comparison section to follow.

1.4.1 Joinery techniques of the Horton House

Unusually fine construction details put together around two hundred wood components of the Horton House, with twice that number of joints, indicating the work of a master builder (the three-part casement windows on the second floor are also praised as the finest of their kind in America). For New England carpenters, perfect joineries were always reserved for the seasoned, wood-wise craftsman who took real pride in his skills.

Scribing the joints is a prerequisite; before the 19th century, joints were scribed by superimposing timbers on one another and marking the intersections (Fig. 1.18). In this method, lines acted as the reference of tenon shoulders and mortises, and variations were perfectly copied to cut the joints to a close fit. For example, to make the joints needed in a bent of the Horton House, the sill, the posts and the girt should be cut to required lengths, arranged properly on the ground, and then lines defining wood joints were inscribed where they cross each other. This procedure was repeated for the other walls, bents and floors, and the resultant numerous inscriptions had to be numbered (“marriage marks”) to guarantee correct matches.18 Accompanying the unevenness of timbers was the rule of always gauging from the face side, for both function and aesthetics, e.g., girts and posts should flush on the exterior, joists should flush by their top plane.19 Tools needed to make these joints (shaping tools) were universal in the carpentry industry (Fig. 19, the finer tools belonged to joiners). One specialized tool was the gauge, which had adjustable knives or spurs used for scribing the joints (Fig. 1.20).

As timbers were worked green, joint design was obliged to take into consideration the shrinkage as they seasoned. A tenon would be inscribed 1/8” shorter or so to prevent being pushed out of the shortening mortise; locations of pegs were carefully calculated to utilize the strength generated by the shrinkage of the post; wedges would be adeptly applied to compensate for the shrinkage gaps (Fig. 1.21).20
1.4.2 Joinery techniques used on Yin Yu Tang

The timber frame of Yin Yu Tang was constructed by local carpenters led by a master carpenter; and joints were processed with techniques commonly used in that region, meaning that most building tasks could be readily directed by established rules. This convenience is firstly revealed by some long sticks made of wood or bamboo (called “Zhang-gan”, the measuring stick) with all the principal building dimensions, e.g. bay widths, post heights, etc., inscribed on them, which decide the dimensions of all building members. Then reference lines are drawn on the surfaces of each member with accordance to the measuring stick, forming a three dimensional grid fundamental to the construction. Only after these two steps, joints could be drawn on the timbers according to reference lines, with different signs indicating different processing methods (Fig. 1.22). Designing the measuring stick and laying out the ink lines are the most critical procedures in construction, and are always in the charge of the master carpenter; while other carpenters contribute their labor to actually carve out the joints. The master carpenter would almost certainly have made a graduated wood stick and presented a sketch to the commissioner of Yin Yu Tang, but unfortunately these things are not preserved today.

What we do know are the woodworking tools used to process the joints, and ink marks left on the extant timber frame. Only a few tools are required to produce wood joints of a vernacular house like Yin Yu Tang (Fig. 1.23), and they are of very basic types carpenters all around the world should be familiar with, except for the ink pot (“Mo-dou”), which is used to snap those tremendously important ink lines. Sawing, drilling and chiseling compose the majority of a joint maker’s job. Detailed rules include that: the two end surfaces of a mortise would curve a little to fit tightly with the tenon; the opening where the tenon exits should be wider than the entrance by the width of the ink line, to avoid ripping, etc.

From the previous sections, we learned that the joints used in Yin Yu Tang, though ingeniously designed, do not require complex tools or great strength. What does matter is the technique to ensure firm assembly and precision of the workmanship. A most challenging joint in the construction of Yin Yu Tang is where the most mortises are needed, i.e. the grid of beams where four laminated beams enter the post. To precisely accept so many penetrating tenons, the mortises here must have very even spacing, so the carpenter would divide the post into four even quadrants in this region. These four dividing lines then act as references for joint making – they are the central axis of mortises and tangential line of peg holes (which should be bored first before the lines are removed by mortises).

Another interesting fact is how tenon shoulders are made to accommodate a round post. This is a question teachers enjoy asking the students during their first field documentation, as it represents a difference
between the thinking methods of traditional carpenters and modern draftsmen. The builders of Yin Yu Tang accomplished this task by drawing ink lines with a specialized tool called “post clamp” (Fig. 1.24), as carpenters in that region still do today. The two legs of a post clamp are fixed to the central axes of two opposite mortises, while the third member perpendicular to them acted as an artificial horizon above the mortise and the column. Marks are made on bamboo sticks placed between this horizon and the post surface at salient points, and then transposed to the horizontal member designed to enter the post. The theory behind this graphing method is also applied in orthographic drawings, but the manipulation of traditional techniques appears more pragmatic for being directly related to construction.
1.4.3 Comparison of the jointing techniques

When it comes to the actual labor of cutting out the joints, Yin Yu Tang and the Horton House share many things in common. To make a clear illustration, a repertoire of joints used in Yin Yu Tang and the Horton house are listed in a form (Table 1.1), with similar ones grouped near each other.

For one thing, woodworking tools for making wood joints are very similar in the two houses. Carpenters of the two projects use tools in a common manner, which has been chosen as the best way to assist their work, rather than showing off their individuality. Carpenter saws are used for general work of cutting, sweep saw for cutting curves, augers for drilling peg holes or starting a mortise, chisels (assisted by mallet) for cuttings not crossing or penetrating the timber surface, framing chisels for clearing the cut surface, and corner chisels for clearing the corner. But different design squares and rulers might make a difference to the detailed dimensions of joints, as carpenters tend to lay out their joints in a way that the squares and rulers could be conveniently used.25

Since the rules of using woodworking tools are predictable, the major factor affecting their usage in joint making is the actual shape of a joint. The basic types of joints in these two projects do not frequently differ in physical shapes; although they each have some characteristic designs, e.g. the English tying joint in the Horton House and the intersecting ties in Yin Yu Tang, these are not difficult tasks merely from the perspective of processing.

Then taking into consideration of the design concept, an apparent fact is that joint making in Yin Yu Tang is much more standardized and pre-fabricated; this is enabled by the uniform and stable sizes of timbers,26 and the ink line system. Although joints were scribed on the timbers for processing, it’s as though they were drawn on a piece of paper, just like the building dimensions being marked on a graduated wood stick. The only abnormal part is the beveled tenon shoulders with which a beam meets with a round post, and this issue is solved by a specialized tool, the post clamp.

On the other hand, builders of the Horton House were engaged in processing timbers of non-uniform sizes.27 There are other factors adding to the individuality of this frame: woods were worked green and thus subject to dimensional change, the frame contains many diagonal components like rafters and braces. As a result, firm assembly of every single joint is carefully studied and attended – even material shrinkage was utilized to increase the strength of joints; another notable thing is a well-developed system dealing with angles, represented by the sawhorse, jigs, and the skillfulness of deciding angles with a square.28
1 National Register of Historic Places inventory – nomination form, No. 10-300 (Rev. 10-74). The house was designated a National Historic Landmark in 1962.
3 National Register of Historic Places inventory – nomination form, No. 10-300 (Rev. 10-74).
4 Girts between the top floor and the roof are sometimes called plates or header beams.
5 Transverse ties are called “chuan” and longitudinal ones are “dou”. But terminology varies in different regions, in Huizhou transverse ties are called *liefang*, and longitudinal ones called *zhifang*. Nancy Berliner, *Yin Yu Tang*, p. 133.
6 The best position for main building in Chinese courtyard houses is usually north or west to the courtyard. But Yin Yu Tang has a different orientation due to the topography, following *Fengshui* theory.
7 *Fengshui* (wind and water) is an ancient theory about the location, arrangement and forms of buildings. One branch of this theory is more environment oriented, emphasizing on topography, lighting, draining, etc.; while the other branch has more studies on the auspicious and ominous power of the environment and the buildings.
8 Class lectures by John D. Childs, *Wood: its properties, use and conservation*.
9 Transverse upper girts could be renamed “tie beams” if they connect principal rafters, but this is not the case of the Horton House.
10 The more effective component protecting the building from rising damp is the stone foundation. Similar is the case in China, where rammed earth and pad stones are used.
12 There is a huge amount of terminologies for joints used in a Chinese timber frame. The same kind of joint, say, stub mortise-and-tenon might have different names when they are used in different places. To make the writing simpler, I won’t use these meticulous terminologies in this paper.
14 Ibid.
17 Then, rafters are nailed to purlins; above the rafters roofing would be added.
21 There are several measuring sticks being responsible for the overall dimension of the building and individual components. In traditional carpentry training, making measuring sticks is the highest task of apprenticeship, after which the apprentice is not far from graduating.
22 The ink pot contains a reel of string and a cotton wad soaked in ink. The string end exits the pot through a hole and can be fixed to the timber; then by pulling the ink pot to the direction needed and catapulting the string, straight ink lines could be snapped on the surface of wood.
26 Using timber of standardized sizes was a rule in official Chinese carpentry manuals. Though vernacular construction did not follow strict standardization, they adopt this methodology and tried to produce uniformed timbers when sawing. Drying wood for three months before using is the common practice in south China, besides, fir shrinks and cracks only a little when being dried.
27 But this is not the case in the 19th century when the square rule was applied. This rule presumes a system in which a regular-shaped timber is envisioned within the real, irregular timber, and joints are cut to the surface of the imagined inner timber. Carpenters sank and leveled the seat around the joints made on a timber of varying dimensions, so that the joints could be of standard dimensions and don’t need specific matching to fit; the new rule resulted in many changes in joint making of the 19th century. Roy Underhill, *The Woodwright’s Guide*, p. 56.
Fig. 1.1 Assembly of the Horton House

Fig. 1.2 Assembly of southern portion of Yin Yu Tang

Fig. 1.3 The box frame of the Horton House

Fig. 1.4 The model of an English tying joint (without rafters)

Fig. 1.5 The model of a tusk tenon (also called soffit tenon)

Fig. 1.6 The connection between joists and the summer beam
Fig. 1.7 Jointing between the girts and the post  

Fig. 1.8 Jointing of diagonal braces

Fig. 1.9 The birdmouth joints between the rafters and the plate

Fig. 1.10 Rafters connected by collar ties  

Fig. 1.11 Connection between a purlin and a rafter

Fig. 1.12 The tying joints used on the end bents of the Horton House
Fig. 1.13 The stepped, pegged half mortise-and-tenon joint used on ties and beams of Yin Yu Tang

Fig. 1.14 Bents connected by longitudinal ties Fig. 1.15 Floor beams made from laminated timbers Fig. 1.16 Laminated beams

Fig. 1.17 The connection between the purlin and the post (purlin is not shown here): a cross-shaped slot is cut into the top of each post to receive the necked tenon on a tie (or a “ridge column clamp” when it’s a ridge post) in the transverse direction; then a long piece of wood called “Ji” (the purlin holder) in the longitudinal direction also goes across the posts and intersects with the tie/the ridge column clamp. A purlin is attached to the purlin holder by dowels or nails.

Fig. 1.18 Cutting the mortise for joists using the scribe rule Fig. 1.19 Tools commonly used by New England carpenters
Fig. 1.20 Mortising gauge (left) and tenon gauge (right)

Fig. 1.21 Various ways to deal with wood shrinkage

Fig. 1.22 Ink lines as the references of making joints

Fig. 1.23 Carpentry tools used to process the joints in Yin Yu Tang

Fig. 1.24 The post clamp and the bamboo stick
2. The building culture context of jointing techniques used in the Horton House and Yin Yu Tang

2.1 Introduction

For a comparative study, it is necessary after comparing two things to explain the reasons for their differences. For construction history research, however, a certain building form is the result of numerous factors: materials and tools, environment, culture, aesthetics, tradition and even influences from other regions. Including such extensive contexts is beyond the scope of this thesis. Nevertheless, since this paper intends to develop a methodology about wood building conservation through comparative study, this second chapter plans to trace and locate the two individual cases of the previous chapter in a larger context of building culture.

Although the comparison based on two representative buildings has revealed plentiful interesting facts about the buildings of two distinct constructions, the two houses are only individual cases which probably missed the many creative, interesting or contingent solutions that might happen to a house in the huge context of their building culture. Moreover, comparison of individual cases appears more meaningful to the author as a valuable instruction to form a roadmap of comparing more general situations of the two building cultures.

Another reason for looking at the larger context is that, characters of the two houses are not something absolute or changeless. Instead, they are a result of a long history of evolution, and various preferences in building once prevailing in that region. Although numerous factors might have contributed to a consequence, among them only a few are decisive forces. When connecting individual buildings to the expansive context around them, we should be able to detect some forces, at least their traces, which have exerted influences on numerous buildings.

For more practical reasons, when learning from preservation practices from another building culture, it is not the strategy developed for a single building that is learned, nor is the strategy applied to a single house. Therefore getting a more general understanding of the building culture is necessary before moving on to the discussion about wood joints and framing conservation.
2.2 Timber framing types of vernacular buildings in New England and Jiangnan

2.2.1 Timber frame types of New England houses

2.2.1.1 Background

Although the Horton House is located in Long Island City, the earliest European settler to Suffolk County came from the county of Suffolk in England, which was also the reason for its naming. Due to the specific geography, immigrants from the New England states could conveniently come to this region by water route. The hamlet of Cutchogue was located in the northwest region of Suffolk County, and was thereby even more kept away from the influences of the Dutch Hudson River Valley. As a matter of fact, English settlers began arriving as early as in 1640, and the Horton House which was built shortly after is now the oldest English-style house in the village and one of the best surviving examples in the United States. Therefore the context of building culture to be presented behind it is about New England timber framings.

The first settlers in New England largely came from the south-eastern counties of England, which were extremely populous then. This region also benefitted from the prospering national economy during the reign of Queen Elizabeth, and had started a “Housing Revolution” aiming at comfortable and convenient housing for common citizens and villagers. Timber-framed houses were predominant for the artisan and agricultural classes there; they constituted the majority of immigrants, among which a notable group was the young journeymen who just finished their apprenticeships, and other junior or middle-aged craftsmen who found their trade more and more competitive in the old country.

These immigrants brought with them timber construction techniques and tools. Despite a few simplifications necessitated by economic conditions, residences of New England during the 17th and 18th century revealed striking resemblance to those of the old country. The main difference was that immigrants had to surface their houses with clapboards over the traditional infills of wattle-and-daub or noggins, due to the harsh climate. Today nearly eighty frame houses survive in the former New England states, including stylistic forms such as the lobby-entrance house, the Saltbox and the Garrison house. Abundant English medieval features – angular shape, overhang with pendant decorations, wide lofty chimney and asymmetric composition, connected colonial houses with their precursors in the aspect of exterior appearance; nevertheless, the following discussion will focus on less apparent features - namely jointing techniques.
2.2.1.2 Framing as the context of wood joints

The simple box frame system described in the previous chapter represents a typical English timber frame, but other frame types also existed. In the following paragraphs they will be discussed from simple to complex; truss systems specifically will not be discussed as they often use metal fasteners instead of wood joints, and the diversity of types would require laborious sample collection.

A simple form of column-and-beam construction is composed of a row of bents with separate header beams connecting each neighboring pair (Fig. 2.1). Although the three defining elements – columns, transverse tie beams and longitudinal header beams – all are present, their joinings are two dimensional compared to a box frame, and the discontinuous header beams also undermine structural stability. Fortunately, most colonial timber houses in New England had already moved beyond this primitive framing, thanks to the widely used tying joint.

From the perspective of “prefabrication and assembly”, independent bents could be advanced as each bent including the roofing truss could be produced separately and assembled on site. Indeed, this was a construction method for barns that emerged in New England after the 1830s (Fig. 2.2). The greatest motivation underlying this method was standardization of components and joints, but framing design might have also played a role – huge barns were almost exclusively aisled frame. This frame had one or more rows of interior posts forming a nave, and lean-tos adding to the nave on both sides. Continuous plates were certainly feasible, but assembly would have been too labor-consuming for the 19th century.

Another simple frame was that used in early story-and-a-half houses. Like a box frame, it was composed of bents connected by continuous plates; but only the two end walls had tie beams, and all the rafters between them directly rest on the plates or spring over them (Fig. 2.3). In some cases principal rafters were arranged in line with the posts, but does not change the load bearing condition due to the absence of tie beams.

Independent roof structure is indeed something intentionally sought after, which developed hand in hand with the box frame. The ideal solution is to let the notched tie beam hold the rafters and resist the lateral thrusts of roof. In this light, the roof structure of the Horton House is not independent enough since many common rafters exert thrusts to the plates directly.

A framing type slightly more complex than a simple box frame was the lean-to frame (e.g. the saltbox), which was to a great extent fashioned by subordinate service space. When adding a lean-to to a timber house, it was widely recognized by immigrants to connect another row of posts firmly to the original rear posts with binding components, but the rafters were simply lapped and pegged to the existing rafters/plate/tie beams.
(Fig. 2.4; the rafter feet were still joined to the lean-to’s rear wall frame with tying joint). Integral lean-to frame was an American innovation (Fig. 2.5), which cantilevered the tie beams of the main structure to prevent rafters from meeting the rear plate, so that they did not need to be interrupted, and complex tying joints could be omitted on this wall. Sometimes summer beams were arranged transversely and project over the plate to support rafters. This frame closely resembled a simple box frame despite a small but intelligent adjustment to each individual bent.

Another important variant was the house with an overhang on the front facade (e.g. the garrison house). This was said to have been invented as a strategy for more space in densely built European towns; other advantages can also be identified for this construction, such as draining further from the base of the house. In most cases, the front wall of the first floor was topped by continuous plate, and the front posts of the second floor were supported by transverse girts cantilevering over this plate (Fig. 2.6), directly or with the help of the overhanging girt. Although the rest of the house was constructed in the same old manner, bents were no longer the basic unit of the frame. Jetty houses in New England maintained principle load bearing posts on the front wall of both floors, like a vestige of a bent; but in a small Tudor timber houses in East Anglia, in old England, posts were frequently not distinguished from studs. The front wall of the second story might be composed of merely studs and infills between the overhanging girt and plate, supported on a line of joists projecting over the first floor’s continuous plate (Fig. 2.7). The fact that the front wall formed an integral section, and that the bent was no longer a primary unit, brought notable changes to the jointing and assembly of a timber frame.

Facade gables, necessitated by additions perpendicular to the original structure, called for other variations in framing methods. The principle rafters of the facade gable might be supported by either the plate of the carcass or an individual tie beam, while common rafters were in many cases simply butted against the roofing of the main house (Fig. 2.8). In New England there were also a few cases of facade gable with valley rafters, a component mortised into the main structure and receiving valley jacks, indicating more reliable jointing. In old England both situations were common, and valley rafters, more typical for important or public buildings, apparently suggested a refined manner of construction (Fig. 2.9).
2.2.2 Timber frame types in vernacular Jiangnan houses

2.2.2.1 Background

Yin Yu Tang is a typical vernacular house of Huizhou region, which was regarded as a part of “Jiangnan” district (the region immediately to the south of the lower Yangtze River) in history. When northern regions suffered from warfare, Jiangnan served as the refuge for a large fugitive population including the social elites, and continued to prosper; this nursery cultivated building techniques at a high level.\textsuperscript{11} Like in western countries, master-apprentice relationships and guilds have long existed in the carpentry trade in China, except that craftsmen belonged to a more disadvantaged class;\textsuperscript{12} during the early Qing dynasty when Yin Yu Tang was built, commerce and craft industry were highly developed in Jiangnan, and people could easily look for good carpenters in their workshops.

Regional variations existed in Jiangnan timber frames – Suzhou, Huizhou and Wuzhou (which respectively refer to south Jiangsu Province, south Anhui Province and north Zhejiang Province) were the three major branches. Also, some coherent characteristics were maintained across this region due to similar natural environments and frequent communication.

2.2.2.2 Framing as the context of wood joints

Three types of framing were used in Jiangnan district, all of which were put up by connecting bents with ties, as exemplified by Yin Yu Tang. This is a feature of significance, since in north China both official and vernacular buildings were built by erecting a grid of posts first, then adding connecting ties and roof frame.

The Chuan-dou frame used in Yin Yu Tang is regarded as the aboriginal frame type of Jiangnan District (Fig. 2.10). Tai-liang frame was imported from north China;\textsuperscript{13} its individual bent is built by supporting (“tai”) one beam (“liang”) on another beam below it, and purlins are held by the beams (Fig. 2.11). Cha-liang structure is a combination of the other two: its basic structure resembles Tai-liang in form, but the processing techniques, i.e. inserting ties into posts, have more similarities with Chuan-dou (Fig. 2.12).

Chuan-dou structure directly distributes load to the posts, and therefore avoids the repetitive load bearing work that is present in the other two structure types. It also does not require huge beams. The advantage of a spanning beam is to avoid the presence of posts in the space below. It is therefore preferred in structures intended to enclose large interior spaces.\textsuperscript{14} Tai-liang has wider distribution in Suzhou, while Cha-liang is more
typical in Huizhou and Wuzhou; but for the space requirements of most vernacular residences, Chuan-dou would suffice, and it is used in end bents across Jiangnan due to better stability and enclosure.

The primary scale of a bent includes five purlins/four rafters; this was also the largest scale of house a common citizen could have, as regulated by law. Builders’ creation in a timber frame was firstly linked to expanding an individual bent to enlarge the interior space – a privilege for nobilities. This was basically accomplished by adding tie beams and posts on the two sides of a basic bent. When two stories were needed, floor beams and joists were added between posts to make a grid, as exemplified by Yin Yu Tang. In the following table some representative bent forms in Jiangnan are illustrated with brief descriptions, from past documentation work of the author.

Table 2.1: Bent types used in timber framings in Jiangnan region (resource: documentation of the author and colleagues)

<table>
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<tr>
<th>Bent</th>
<th>Description</th>
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<td>Suzhou region</td>
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| 1. | From: Yun Xing Tang house, Qingguo Alley, Changzhou City, 16th century  
This is a typical Tai-liang structure with additional tie beams enlarging the interior space;  
The inner end of each additional tie beam is inserted into a post, while the outer end sits on a post and supports the purlin, this component is called a “step tie” (“bu-chuan”) by local carpenters. (The front porch is a later alteration) |
| 2. | From: Zhen He Tang house, #105 Qingguo Alley, Changzhou City, 16th century  
This is an end bent from a house similar to the previous one, with dense posts for stability;  
This is a Chuan-dou structure put together by ties, which have hunchback-shaped facings to imitate huge beams. |
| 3. | From: Song Jian Tang, Qingguo Alley, Changzhou City, 18th century  
The core structure is Tai-liang, but reveals later evolutions, i.e. the short posts reach purlins;  
The smaller component dimensions is a result of depletion of large trees;  
Has step ties and short posts to enlarge interior space. |
| 4. | From: Li He Tang house, #133, 141 Lane, Qingguo Alley, Changzhou City, 18th century  
This is also an end bent, resembling the previous end bent in shape;  
This bent is almost completely put together by step ties, and not distinctive as any of the three basic framing types. |
<table>
<thead>
<tr>
<th>No.</th>
<th>Image</th>
<th>Description</th>
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| 5.  | ![Image](57 Qiongguo Alley, Changzhou City, 18th-19th century) | From: # 57 Qiongguo Alley, Changzhou City, 18th-19th century  
This is also an end bent similar to the previous one, except that the central structure uses a small Tai-liang construction;  
Has additional step ties to enlarge space. |
| **Huizhou region** | ![Image](A residence in Pingshan Village, Huangshan City, early 19th century) | From: A residence in Pingshan Village, Huangshan City, early 19th century  
This is almost the most basic form of Chuan-dou;  
The building complex is large, but composed of simple individual units;  
One tie beam cantilevers from the front post to support another purlin to extend the eave. |
| 6.  | ![Image](Yin Yu Tang, 18th century) | From: Yin Yu Tang, 18th century  
This is almost the most basic form of Chuan-dou, with an additional level of tie beams below;  
Another tie beam of decorative hunchback shape is attached to the front to create a gallery. |
| 7.  | ![Image](You Qing Tang, Pingshan Village, Huangshan City, early 19th century) | From: You Qing Tang, Pingshan Village, Huangshan City, early 19th century  
This is an adapted Chuan-dou structure with four short posts, all standing on the lowermost tie beams, whose large span make this frame close to Cha-liang;  
Has two levels of tie beams running through the short posts as connections, but do not bear load. |
| **Wuzhou region** | ![Image](a house in Shankeng village, Wenzhou City, mid-19th century) | From: a house in Shankeng village, Wenzhou City, mid-19th century  
This is almost the most basic form of Chuan-dou, with an additional level of tie beams below;  
Has additional tie beams and posts to the front and the back, creating extra spaces (here one is interior space and the other is bay windows);  
(Large span and curved shape of tie beams is a character of this region) |
| 9.  | ![Image](a house in Shankeng village, Wenzhou City, mid-19th century) | From: a house in Shankeng village, Wenzhou City, mid-19th century  
The roof frame is mainly put together by step ties, common tie beams also exist;  
Has an additional level of tie beams below;  
Has two sets of additional tie beams and posts attached to the front and the back, enlarging interior space and creating a porch.  
This bent has characters resembling both Chuan-dou and Tai-liang, making it hard to be categorized. |
To sum up, vernacular houses in Jiangnan freely manipulated the positioning of their ties, beams, tie beams, step ties, short posts, etc., to build up a bent satisfying the need for larger, diversified space. But what is listed above is only the simpler and pragmatic methods applied in common houses. Some timber frames, especially those in the luxuriant Suzhou, had exquisite designs. Besides aesthetics, this was also a further step towards larger space. After all, builders could not keep on adding ties or increasing the span of beams – such modifications might be considered hideous, not efficient for load bearing, or constrained by availability of materials. The critical solution was to divide the roof frame into two layers (Fig. 2.13). The lower portion was composed of juxtaposed framing units of pleasant finish and scale; the upper portion completed the structure, and could be processed more roughly, as the lower portion also supported a ceiling to hide it.\(^{16}\)

Particular aesthetic emphasis in Chinese building was placed on the roof. Official architecture had complex framing methods to achieve exquisite roof shapes (Fig. 2.14); but vernacular builders in Jiangnan were more persuaded by convenient techniques, making the composite roof resemble the lean-to in America (Fig. 2.15). As shown above, posts and various ties/beams could be conveniently added around a frame. Eaves could also be added after purlins and rafters had been fixed to these posts/ties/beams. Buildings with diverse roof shapes were also based on bents, with posts and diagonal components added to the corners to create hipped or broken pitch roofs. For a couple of reasons, vernacular houses did not have perpendicular additions,\(^{17}\) and a house cluster was made by arranging cuboid building units around the courtyards; this also reduced the number of complex wood joints required for an average house.

Overhang was a common structure in Huizhou and Wuzhou, mainly used for creating a gallery on the second floor. The technique also used cantilevered beams, like its western counterpart, but no floor joists. All the beams cantilevered over or through the front posts to support posts on the second floor directly, so there was no need to break the bent into two stories, but the heavy load on the cantilevered part often called for bracing (Fig. 2.16). The underlying principle was that: the bent was the irreducible basic unit, and cantilevering should be subordinate to it. In southwest China (a Chuan-dou frame region), overhang is in
many places a building feature; here cantilevered floor beams significantly reduce their section area to go through posts uninterruptedly, which also maintains the integrity of bents (Fig. 2.17).

It is interesting that western timber framing went through a transition from purlin roof to rafter roof, which happened along the urban expansion during the Middle Ages. The purlin roof, which was dominant before the transition, had posts support purlins carrying the inclined rafters. This is suspected to originate in a primitive construction which placed purlins in the forks of two posts and hung small trunks on them as rafters (Fig. 2.18). Slight adaptations occurred over time, such as removing the forks and the ridge posts. But these seem to be mere interim steps toward the complete replacement of purlins by a rafter roof. Along with the construction of cathedral roof trusses, rafter roof was soon improved by the superb techniques of truss construction. But it should be mentioned that, before introducing from Italy the truss technique which used king post to suspend the tie beam in the 15th century, English builders could only apply queen struts to enhance the lengthening rafters (a technique developed in the 13th century), as the lengthening tie beam was also faced with the sagging problem, thus could not bear any vertical posts (Fig. 2.19).

A transition in a different direction happened in China, also during its medieval period. According to architectural images around the 5th century in north China, large buildings were only achieved by attaching wood structures to huge rammed earth bulks, and bent construction had not been cultivated in the mainstream, state-of-the-art building techniques. Images of early wood buildings then indicated notable similarity with western timber constructions – continuous plates, one-piece front/rear wall, and roof frame built with principle rafters (Fig. 2.20). The popularity of this frame type should not be underestimated as this was the most common building image discovered in the northern capital and important grotto temples from that period. In the next century Tai-liang structures prevailed and the bent became the basic building element. The underlying motivation was the pursuit of larger interior spaces – the method being to expand individual bents, as has been shown above (Fig. 2.21). The Properties of wood species selected might also have played a role in such a choice: ancient Chinese mostly built with softwood (pine in the north and fir in the south), which is not as capable of resisting thrust as hardwood if made into the tie beam in a triangular roof. Nevertheless, before the invention of two-layer roof frames, many enlargements were still done by adding lean-tos around the main structure.
2.3. Joints used in vernacular buildings in New England and China

2.3.1 Joints required by various types of framing

In this part, new joints required by the variations of framing are introduced, except for roof framing. The reason is that: the basics of roof construction has quite independent methodology and barely changes with the form of the timber frame. The joint connecting the roof and the carcass is more interesting as it has lots of variants across different regions and periods, but this issue belongs to the diversity of building techniques. Therefore these will be left to the next section on the variation of commonly used wood joints.

2.3.1.1 Joints required by framing variants in New England

(1) Lean-to and integral lean-to frame

To connect a lean-to to the main frame, the critical step is to attach a row of posts firmly to the original rear wall; this is accomplished with some tie beams joining the posts and plate of the lean-to on one end with tying joints, and connecting the main structure on the other, with tension joints such as dovetail (Fig. 2.22). The rafters undergo very little changes in their joinery – merely lapping and pegging. Such is the case when a lean-to becomes integral to the frame, where the only additional renovation is to lay the tie beams of the main structure atop the posts with simple mortise-and-tenons, and support the integral rafters on these tie beams, also with simple mortise-and-tenons; when summer beams are cantilevered, a simple lap joint would suffice.

(2) Overhang

An overhang would require some different jointing methods. Cantilevering girts over the ground floor posts is usually attended as a three dimensional jointing task, thus with an alteration of traditional tying joint; in this sense, the first floor alone is regarded as a box frame. Transverse girts, posts and first story plate are joined in a way resembling tying joint, except that girts cantilever over the plate with a halved lap joint, which generates some tension resistance and make the previous dovetail lap unnecessary (Fig. 2.23). Adding second-floor posts is simpler – they are either hung on the projecting girts or connected to the longitudinal overhang girt, with simple mortise-and-tenons in both cases. In old England, as was mentioned above, bents were less existent, resulting in second-floor posts and studs almost exclusively supported on the overhang girt (Fig. 2.24, but corner posts might get extra reinforcement).
A notable fact is that some New England jetty frames were still based on bents, probably due to the influence of the traditional box frame. The Ward house in Salem and White-Ellery house in Gloucester, both in Massachusetts, use discontinuous bearers with stub tenons to connect their crossframes on the first floor. On the other hand, this might be a less established technique as the bearers connect the posts in the Ward house, while the projecting transverse girts in the latter. Another exception is the Ross Tavern in Ipswich, which applies reverse assembly (the plate is supported above the girts) to allow for a continuous first-floor plate jointed to cantilevered girts with half lap (Fig. 2.25). This assembly is less stable than the traditional tying joint, but better than those with discontinuous bearers. To sum up, various jointing efforts have been tried to construct the overhang, but often show inferiority compared to the traditional method, as they only experiment with less challenging stub tenons and lap joints, while abandoning the reliable three-dimensional joining techniques.

(3) Perpendicular addition and facade gable

The typical landscape of a historic English town with crowded, lively gables suggests that it is convenient to add a gable or a wing perpendicular to the original structure. Indeed, in New England, simple mortise-and-tenon would suffice where two roof frames intersect with each other; lap joints also exist in some cases when the addition includes a tie beam to be supported on some projecting transverse components from the main structure (see Fig. 2.8). Evidences showing an addition being tied into the main roof frame, such as valley rafters or tension joints, are rare in America; but even in the case of valley rafters, simple mortise-and-tenon joint and pins could fix them to the main frame. Nonetheless, the abundance of facade gables in English vernacular houses suggests that this simple jointing method is in fact quite sturdy when reinforced by roofing and infills.
2.3.1.2 Joints required by framing variants in Jiangnan

As stated above, a vernacular house in Jiangnan could expand its individual bents, add more bents and build an overhang by simply adding ties, beams and posts; the same old joints could accomplish the task: posts are connected by ties, ties/tie beams are inserted with pegged stub tenons or through tenons. High-style houses with two layers of roof frame have more technical requirements such as designing the roof curves, laying off components and drawing ink lines; these mostly are the responsibility of the master carpenters, but the actual processing of timbers remain essentially the same.

To enrich the roof form, one additional joint type is required to connect purlins and ties from perpendicular sections of a hipped roof. The joint applied here is the halved lap joint, a very ordinary technique except that the joint is processed in a way, called a “waist” in terminology, that could improve tension strength and better hide the voids (at the expense of slightly lowering load bearing capacity, Fig. 2.26).
2.3.2 Comparison of other joint variants used in New England and Jiangnan timber frames

Various framing types in fact demanded very few new joint types other than those used in a typical frame. But coming back to the basic framing forms exemplified by the Horton House and Yin Yu Tang, we find from more examples that certain functions could be accomplished with joints varying from those used in the two paradigms. The following presents these joints based on their functions.

Task I: transverse binding (tying joint)

The joint should resist compression as well as tension. Besides the method described in the previous chapter, a number of ideas have been tried to reform the English tying joint in New England; this will be discussed below as a tying joint attending to both tasks at the same time, and alteration to it was holistic. Besides, a few modifications were made to the joint of the lower girts to increase their binding force, among which a truly effective one is wedged dovetail through mortise-and-tenon (Fig. 2.27). This joint is said to be found in buildings of all nationalities and types and from every period, while other modifications happened much more occasionally (Fig. 2.28).

In Jiangnan, the direct binding force of transverse ties often merely came from the pegs. Thus one preferred method was to use pegs of curved shape, as they fix the tenons in place tighter – note that in New England a similar effect was achieved by slightly staggering the peg holes and letting wood shrinkage do the work. Other improvements made to this joint are the “horn-shape peg” and “umbrella-shape joint” (Fig. 2.29); other designs utilizing similar method appeared in official carpentry manuals in the 11th century. They respectively resemble the extended tenon and the wedged dovetail through mortise-and-tenon in New England. This resemblance indicates some shared experience in the search for reliable tension joints; but in fact these joints reveal more kinship to their original building culture.

Substitutes of the necked binding joint will be discussed in the next section, as these often appear near the roof frame where three directional jointing (transverse binding and longitudinal binding) has to be considered. Also, they are less independent as beams/step ties involve posts and purlins to form a larger composite joint.

Task II: longitudinal binding/connecting

Again, both tension joints and compression joints are needed. As exemplified by the Horton House, traditionally this task was accomplished by plates and sills, assisted by bearers or girts. A few adaptations of the English tying joint were the major creations seen in New England. A slight alteration resembles that of a jetty, where a tie beam is lap jointed with a plate (Fig. 2.30); beginning in the second half of the 18th century,
more differences were brought about in an effort to maintain the tie beam and the plate in close levels, in order to create a neater look. Although fundamental functions of the new joint complex – transverse binding and longitudinal binding – did not change, modification often led to material removal at joining parts and abandonment of the original three-dimensional interlocking solution. As a result, many creations in these joints are aimed at maintaining the connecting strength between the plate and the tie beam (Table 2.2).

Table 2.2: New joint designs replacing traditional English tying joint (sources: “Historic American Timber Joinery”, re-edited by the author)

<table>
<thead>
<tr>
<th>Joint types (“t” indicates tension and “c” indicates compression)</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(left: Quaker Meetinghouse c. 1783, Adams, MA; right: a 1791 house in Cheshire, MA)</td>
<td>Mortise-and-tenon used for longitudinal binding; Lap joint used for transverse binding, might be assisted by lap dovetail; Lap joint might fail when shrinkage happens.</td>
</tr>
<tr>
<td>(left: a pre-1810 house in North Adams, MA; right: a 1785 house in Adams, MA)</td>
<td>Mortise-and-tenon used for longitudinal binding; Lap joint used for transverse binding, assisted by two-way cog; Lap joint might fail when shrinkage happens.</td>
</tr>
<tr>
<td>(left: a 1791 house in Cheshire, MA; right: a 1785 barn in Adams, MA)</td>
<td>Mortise-and-tenon used for longitudinal binding; Joint resembling lap joint (forked tenon, mortise and tenon) used for transverse binding.</td>
</tr>
</tbody>
</table>
In Jiangnan, jointing of longitudinal ties to the posts was significantly below the post top, sparing the complex designs of three dimensional joints, and longitudinal ties were assembled with joints similar to those on transverse ones. But diversification of the joints connecting roofing and understructure also happened. Regional variations of bent types, e.g. replacing ties with beams or step ties, to some extent account for these alterations. Some designs of this joint commonly seen in Jiangnan are listed in the following form.
Table 2.3: joints commonly used to connect posts, purlins and ties/tie beams/step ties (source: documented and modeled by the author)

<table>
<thead>
<tr>
<th>Joint in bent</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Joint 1" /></td>
<td>This joint is used in Tai-liang structure in north China. It is included as a comparison with the Tai-liang structure in Jiangnan. Notice that the beam is supported on the top of a post with a stub mortise-and-tenon joint as connection.</td>
</tr>
<tr>
<td><img src="image2.png" alt="Joint 2" /></td>
<td>This is a most common joint type in Suzhou, and codified in the carpentry manual <em>Yingzao Fayuan</em>. Used in Tai-liang and step-ties, but very different from the northern example: the beam/step tie and post are connected with a forked joint, the beam is supported by as well as housing the post, making a more stable connection.</td>
</tr>
<tr>
<td><img src="image3.png" alt="Joint 3" /></td>
<td>This kind of joint might appear in buildings with “dou” in both north and south China; “dou” increases workable joining and load-bearing area of the post; It may make a Tai-liang joint, but purlins are often interrupted by partition walls, thus supported by dou and post indeed – this is not a stable joint but accepted in regions with Chuan-dou building tradition.</td>
</tr>
<tr>
<td><img src="image4.png" alt="Joint 4" /></td>
<td>This is a joint widely used in Tai-liang in Jiangnan; purlin is supported by the beam; What appears surprising is, although the beam should be cut to intersect with the dou in order to prevent lateral movement, like the beam shown on the right, it often goes straight through the dou like the one shown on the left; This might be a simplified jointing.</td>
</tr>
</tbody>
</table>
This joint is similar to the previous one, and also widely used across Jiangnan due to its simplicity; Beam crosses the post, sometimes intersects with the latter; in this stereotype, purlin holder is divided in two by the beam and housed in mortises on the post.

Almost the same as the previous one, but the spindle-shaped short post is more typical in Suzhou regions; The purlin is supported by both the beam and the post.

This joint is used in Yin Yu Tang, and commonly seen in Huizhou; The placement of components is indeed similar to the three previous examples, but the tying function of the tie beams is much more emphasized.

The purpose of this paper is not a comprehensive study of joinery topology. Therefore the two forms above do not include all the possible contingent solutions developed to save time and material in the vernacular building trades. But this group of joints represents some most complex joints used in Jiangnan and New England; a comparison of their designs would thus be instructive.
Table 2.4: Comparison between some three directional joints used in Jiangnan and New England

<table>
<thead>
<tr>
<th>New England</th>
<th>Jiangnan</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="72x710" alt="Diagram" /></td>
<td><img src="187x547" alt="Diagram" /></td>
<td>Connecting post and beam (transverse component): New Eng.: the beam is fixed with a thin tenon, whose orientation helps resist movement in the transverse direction; later alterations in New England do not connect beam with post, inevitably undermining strength and stability; Jiangnan: beam crosses the slotted post top, might intersect with it, depending on whether the beam only serves to bear load or also assist transverse binding; Although the positions of mortise and tenon are reversed in the two post and beam assemblies, they both serve well for the intended functions.</td>
</tr>
<tr>
<td><img src="72x240" alt="Diagram" /></td>
<td><img src="186x372" alt="Diagram" /></td>
<td>Connecting post and longitudinal component (purlin/plate): New Eng.: the plate is fixed with a thin tenon, whose orientation resists movement in longitudinal direction well – adequate tensile strength (this picture shows a later example when tie beam does not connect to the post); Jiangnan: purlin is often indirectly connected to post via purlin holders, in some Cha-liang/Chuan-dou structures post directly enters the mortised purlin with a tenon, while in some Tai-liang frame purlin has no connection to post; none of the above is a stable joint, but all are acceptable as purlins serve for load bearing, not binding, and weak joints indeed maintain larger section area.</td>
</tr>
<tr>
<td><img src="186x240" alt="Diagram" /></td>
<td><img src="295x359" alt="Diagram" /></td>
<td>Connection of horizontal components: New Eng.: tie beam and plate, the traditional solution is a lap dovetail in the tying joint (a); but later when the joint tried to flush these two components and thus gave up tying, various mortise-and-tenon complexes were invented to accomplish a flushed surface and guarantee structural stability at the same time (b); Jiangnan: purlin and beam, almost always direct interlocking in Tai-liang structures as this is critical load bearing point (c); might have indirect connection via purlin holders in Chuan-dou/Cha-liang where load goes from purlin to post (d); There is not much comparability for this joint – for a most basic fact, purlin and plate have completely different roles in the load path, even the order of assembly is opposite. But this is also a decisive factor that shapes the joints.</td>
</tr>
</tbody>
</table>
In both Jiangnan and New England, lateral forces received more attention than vertical forces in joint designs, as they required the more demanding tension joints. In the examples from Jiangnan, mainly the beams/ties/step ties were expected to deal with strong lateral forces, while purlins only assisted in this task, the secondary role of the purlins in tying the structure together allowed joinery which achieved thorough interlocking by making deep mortise cuts. In New England, however, both plate and tie beam needed to be firmly fixed, prohibiting the possibility of removing much material for both; this gave rise to the tying joint, a reciprocal combination of smaller joints. There were cases in New England where the beam is fixed to the post with a “necked” joint, but no further move towards more entangled interlocking. Even if putting aside the consideration for functions, Chinese had more enthusiasm for the interlocking of halved lap joint – it was a favorite solution for perpendicular connection of horizontal components (and carefully dressed up to hide the potential voids); here we might add that, hiding one joint within another was also something fascinating ancient Chinese (see Fig. 2.26 & Fig. 2.29). Naturally, this was driven by the need to create a neater appearance, but prerequisites were that the components had varied dimensions, and that the encompassing wood member would not buckle or split; the former was enabled by the system of standardized timber dimensions, and the later was guaranteed by the character of fir.

Similar methodology (thorough interlocking and hiding one joint within another) was applied in Chinese furniture design (Fig. 2.31). But what is more interesting is that, some ingenious joints in Chinese furniture resembled those in a New England timber frame, in that small joints tied with each other to make a solid whole. For aesthetic considerations, furniture used angled edges to hide the end grains where members joined perpendicularly, and avoided exposing joinery voids by hiding most of them within the assembly, but the design concept was connected to western joinery (Fig. 2.32). A possible reason was the material property – complicated joints usually appear in fancy furniture made with hardwood, often rosewood. Timbers of small cross section area were used, as the material was scarce but strong; this lessened thorough jointing, while tying joints were relied on more due to material strength.

Task III: bearing the load of the floor

Floor load in a New England timber frame is supported by a system of lower girts, summer beams and joists. Housed tenons on girts and soffit tenons on summer beams are preferred as they maintain more section area to resist shear. Diminished housing, which is used in the Horton House, appeared to be the best choice and enjoyed popularity; one of its variations could be found in Connecticut (Fig. 2.33). Other types of housed tenons, such as parallel housing and paired tenons, were developed only after the square rule system was adopted (Fig. 2.34).
As the direct load bearing components, summer beams and joists have been carefully processed through history. A summer beam is basically a load bearing and bridging component, thus its jointing with the girts only needs to maintain enough section area to resist shear (Fig. 2.35). But for the many more ambitious houses, summers were endowed with the function of producing binding forces, assisted by more complex joints like tusk tenons (Fig. 2.36).  

Connections between joists and summer beams were traditionally accomplished with tusk tenons, as it was regarded as maintaining the most material for both the summer and the joists. From mid-17th century onward, tusk tenons were quickly replaced by the much simpler butt cog, but not until much later did people realize that this simpler joint indeed maintained more material for the critical load bearing members – the joists, and that its weakening of the vital compression wood of the summer was negligible (Fig. 2.37). Nevertheless, some builders in 17th-18th century turned to tusk tenons or dovetails when considering convenient and firm assembly: one end of each joist is attached to the summer with tusk tenon or dovetail, while the other end simply sits in a cog on the girt.

Task IV: diagonal rigidity

In western timber framing, braces are not very selective about joint types – whether they are mortise-and-tenon, simple lap or dovetail lap, they can easily accomplish their task of resisting compression so long as enough cross section area is maintained. A main consideration is the failure caused by shrinkage, which means that mortise-and-tenons, dovetails, and those with wedges or useful notches are supposed to have better performance (Fig. 2.38). Still, this will not make a critical part in the overall house frame.

Diagonal braces did exist in roof framings in ancient China, but were almost completely driven out when Chinese architecture matured to rigidity by the 15th century. A few diagonal braces in roof framing seen in the less developed Huizhou and Wuzhou regions are regarded as vestiges from earlier dynasties (Fig. 2.39).

The major effort to resist distortion in a rectangular framing was to lean the bents slightly towards the central axis of the house. This was also an old technique seen in Huizhou and Wuzhou, but was abandoned about a century before the construction of Yin Yu Tang. Like the two-layer roof frame, no specific joints were required; but in order to produce precise assembly, more planning and calculation work went to the master carpenter.

Another construction detail appears within individual bents, and could be regarded as the measure improving their diagonal rigidity. That is improving the contact between the short posts and the tie beams with large, curved tenon shoulders embracing the latter (Fig. 2.40). Such joint allows using mortise-and-tenon joint of
smaller size while still guarantee stability of the short posts. Interestingly, the approach resembled interlocking rather than direct bracing.

Task V: Building a roof frame

Roof framing in New England was very diverse and there was hardly a general scheme followed throughout, but they all followed the task of building standing triangles – when principle rafters and upper girts coexisted in a roof, they almost always composed a triangle as the major load bearing structure – it is principle rafters that made an upper girt a tie beam, and a tie beam that made rafters principle rafters. Principle rafters were combined by bridled or halved lap joint at the apex, and attached to tie beams with simple mortise and tenon joints (except for integral lean-to houses where tie beams might be tenoned into rafters).

Another load bearing triangle was composed of common rafters, which usually set feet directly on plates. As the roofing load press the rafters in place, the joints between them and the plates mainly need to resist compression and prevent shifting. This joint had many variations from simple birdmouth to crafty step-lap (Fig. 2.41), some of which clearly revealed the ingenuity of the builders.

After building individual triangles, collar ties were added to resist both tension and compression generated by thrust and sagging, which was especially useful for the less fastened common rafters. Pegged lap joint was the most convenient solution, as seen in the Horton House. Dovetailed lap was also common, and more effective; still, some houses presented more ingenious solutions, such as the tying joint interlocking rafters, collar ties and purlins in the Gedney House (ca. 1665, Salem, MA, Fig. 2.42).

Purlins were added mainly to erect the triangles into a spatial frame. Although they should be responsible for longitudinal stability, this seemed to be of limited importance, as many examples indicate that joints obtaining only fair resistance against tension and compression were chosen (Fig. 2.43).28

In comparison, Jiangnan buildings still had no intention for independent roof framing. This appears even more characteristic when considering that buildings in north China did build roof structures separately. Two-layered roof in high style buildings revealed a potential of independent roof framing, as the upper layer framing was built on the ceiling supported by the lower one; even so, framing members of the upper layer were incorporated to a scheme already established by individual bents (this could be seen more clearly compared to the two-layer construction in Japan, in which the upper layer has no relation with the lower layer, Fig. 2.44), thereby the challenging task of building a roof was transformed unobtrusively into the familiar art of every eligible carpenter.29
Task VI: Aesthetics

Aesthetics, often the contemporary concept about beauty, is manifested in the overall design of a building; but construction also keeps aesthetics in mind in its every detail, which could significantly affect the design of wood framing and joints. Good-looking construction details at first comply with functional designs, thus have a more stable code about good-looking than the changing style of architecture. Although this paper used function as the basis for comparing framing and joint, mentioning aesthetics becomes an indispensable task here, since its intervening with functional designs has been clearly revealed in the previous discussion.

Joints in a New England building placed more considerations on their functions, in a direct and scientific way. For example: the lower girt should bear heavy floor load, then the mortise-and-tenon joint got a shoulder; a simple mortise-and-tenon joint needed to resist tension, then pegs were added and their sizes and locations carefully studied; the house required diagonal rigidity, then diagonal braces were added with simple joints as simple joints would suffice. For the more decorative timber buildings in middle Europe, braces were arranged in ornamental patterns, and pegs, which protruded above the surface to be re-hammered, might get nicely carved heads. In England, where the fundamental consideration of timber construction was building up stable triangular structures, a major beautification of framing was using curved timbers for braces and roof trusses. This plainness had good reasons to continue in America – early immigrants devoted their energies mostly to surviving the harsh environment, thus their foremost consideration about building was structural stability.

Function gets blurred in the traditional aesthetics of China. For example, shouldered mortise-and-tenons or informal braces, despite their structural validity, were not accepted merely because they interrupted the neat surface. Builders would rather labor a great deal to join four floor beams to a post at the same level, to bevel the tenon shoulders, to make laminated beams, to lean each bent slightly to the central axis, or to hold the beam with fatter short posts decorated with carvings. Typical techniques included hiding the voids of joint by thorough interlocking, or hiding end grains by beveling the ends of components; though determined by functional considerations, they were also considered as icons of beauty in Chinese architecture.

Different from the Anglo-America tradition, embellishment of the framing reached a very deep extent in Chinese timber buildings. Besides carvings and decorative shapes very naturally adorning the structure, one extreme example is the brackets, a most decorative component in Chinese timber building and at the same time a critical joint used for extending the eaves (Fig. 2.45). In the affluent Jiangnan district, people were even more willing to perfect their timber framing with delicate construction details. Thus, even though function was fundamental to vernacular timber framing, aesthetics was so inherent in Chinese timber framing design, that negligence of it could even jeopardize the understanding of structure.
2.4 Conclusion

2.4.1 How the Horton House and Yin Yu Tang are connected to a larger building context

This issue could be articulated still from the perspective of framing and wood joints.

The Horton House has the two typical components of an English timber frame: the carcass composed of a box frame of the roof built with a triangle structure. Both components are the consequence of intentional efforts. The Cressing Temple in England clearly tells about the transition from two-dimensional, separate jointing to three dimensional jointing as a development in the 13th century (Fig. 2.46).31 To the author, builders’ persistence to intervene and integrate individual bents with continuous plate almost certainly predicted the evolution towards three dimensional jointing, as the frame was considered as a three dimensional whole. In the vast land of New England, the rule of three dimensional jointing was compromised many times, but a box frame was still regarded essential to the carcass of a house. The triangle roof structure was another invention prevailed since the Medieval Ages. Besides stability, the independent, self-supporting character of triangle construction was also something sought after. Many houses in colonial New England fixed principle rafters to the tie beams to form an independent skeleton for the roof; but somehow the Horton House did not do so.

Yin Yu Tang, like many other houses in Jiangnan, simply connected individual Chuan-dou bents to form a house frame, then added purlins (quite loosely) to build a roof. Although China did have a period when longitudinal connections gained more emphasis and when triangular structure was utilized to support the roof, a thousand years has passed since then, making the motivations and detailed evolutions unclear to us today. Like box frame and truss structure in the west, independence of bent is praised by Chinese architectural historians as it made way for the later standardization, but very likely ancient builders did not have a chance to develop three dimensional jointing techniques. Bent construction in Jiangnan was simple, unstable and repetitive, yet could still make an optimal choice for its convenience and quality control. Preciseness of joinery could effectively lower the possibility of structure distortion, and by manipulating human scaled space, such as two-layer roof and rich carvings on windows, a simple house managed to present a pleasant appearance to the viewer.

In the aspect of wood joints, the situation is simpler than expected. Although many joint designs could be utilized to resist tension, compression and shear, builders only chose the ones that were most effective, friendly to woodworking, and maintaining more materials. The Horton House and Yin Yu Tang both adopted the most common joint types used in their regions, instead of laboring on the more crafty ones which might have better performances, such as the wedged dovetail through mortise-and-tenon joint or the umbrella joint. Still, it is these common joints that are representative to the building culture they belong to.
2.4.2 Some features of Jiangnan buildings with respect to wood joint and framing conservation

Having made the comparison, one clear feature of Jiangnan timber frames is revealed. That is: construction is organized by expanding individual bents and adding the number of bents, with only a certain variety of jointing techniques. While three-dimensional jointing and trusses in the European building tradition were demanding delicate jointing works, a timber frame in Jiangnan could be neatly put together by regular, orthogonal joints.

So timber frames in Jiangnan are less demanding about craftsmanship for recovering structural stability; moreover, they could be more conveniently dismantled for thorough examination. But disadvantage is also obvious, they are more easily to distort and the deformation is very likely to be aggressive. New England timber houses could reach a stable self-supporting state under moderate distortion, owing to their three dimensional joining, triangular structure and supportive infills. This explains why Chinese had more experience in massive structural adjusting (see the next chapter).

Anglo-American timber framings have less risk of structural problems as their design aims at structural stability in the first place. Although voids caused by material shrinkage were undesired, the main consideration was not aesthetics, but the potential failure of a joint. Western carpenters would not want to hide wood joints, as they feel unsecure about structure if the joint is unseen. In the recent past, conservation of timber framing and joints in America also emphasized on structural function and tended to treat this issue in a direct way. For example, if a tenon deteriorates, it is replaced with epoxy, even mechanic fasteners, as its physical integrity is not as important as its function.

Chinese timber framing would be pleased to compromise the function a little to look better. Frequently, joints improved the structure in a subtle manner instead of going directly for the goal. Whether this reveals weak knowledge of engineering or ingenious approach of design, it calls for better understanding of the curious methods and aesthetic concepts, when implanting conservation techniques from a different building culture. In this light, studying and academizing traditional repairing methods could reveal to conservators a great deal about the nature of their buildings. For example, partial to complete dismantling and reassembly, a time-honored practice in China and Japan, makes more sense in the building cultural context where many joints are hidden, while could not be highly cultivated in the European building tradition; thus this practice could build up a framework for East Asian conservators, which might not be so valuable anywhere else in the world, to organize their understandings of domestic architecture.

This region, called East Anglia, include Suffolk, Essex, Kent, Norfolk, Hertfordshire and Middlesex. Southwestern counties, e.g. Devonshire, Somersetshire, Dorsetshire and Wiltshire, also contributed about one quarter of total immigration. The Framed Houses of Massachusetts Bay, p. 3.


At first clapboards were applied also due to the lack of lime, a key ingredient wattle-and-daub. But later they proved a necessity as thermal movement could destroy any infills in the harsh climate of New England.


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5. At first clapboards were applied also due to the lack of lime, a key ingredient wattle-and-daub. But later they proved a necessity as thermal movement could destroy any infills in the harsh climate of New England.


10. The Framed Houses of Massachusetts Bay, p. 87.

11. The central regions in the north learned building techniques from Jiangnan for several times in the history, especially at the beginning of new dynasties established in the depression after long period of warfare (late 5th century during the Northern Dynasties and late 10th century during Song Dynasty).

12. This fact is taught in Chinese textbooks. But according to the author’s advisor in China, who once apprenticed under a master carpenter in Huizhou, master carpenters were highly respected in the vernacular community.

13. Mature Tai-liang structure as an orthodoxy framing method was likely to be developed by some imperial courts driven to the Jiangnan region around the 5th century. Their buildings were completely destroyed when the northern dynasties united China, but building techniques were learned by the latter and transmitted to Japan. Tai-liang structure in Jiangnan in the later period was also transmitted from north China.

14. Still, Cha-liang is more efficient than Tai-liang, as intermediate load bearing beams could be lessened to just adequate for the needed span of space, other beams acting as mere ties – a convenience learned from Chuan-dou.

15. There are also some fixed scales for Chuan-dou structure: three posts/purlins-one layer of ties, five posts/purlins-two layers of ties, or eleven posts/purlins-five layers of ties.

16. This technique used for increasing the scale of a structure elegantly could already be seen in a temple of the 9th century. In official buildings where brackets abound, separation of framing is also a product of a separate bracket layer.

17. These reasons might be: daily life does not require such space organization, the technique is demanding, the triangle shape of a gable is regarded ominous.


20. It is plausible that bent has been a basic building element in China as early as the 1st century, especially in the warm and humid southern regions with a long history of timber construction. But only several centuries later did Chinese architecture acquire its mature form, and the most reliable, informative building images then came from the north.

21. But north China might have had little contribution to this technical evolution as the Han court moved to the south region (near Jiangnan), and developed their building technique rapidly. Unfortunately, no informative building images have been discovered in this region due to warfare. The Asuka period architecture (the pagoda and Kondō of Hōryū-ji) in Japan was heavily influenced by south China then, thus might be regarded as references.

22. Simple bents connected with discontinuous header beams hardly existed in colonial New England, but here we might just mention that the plates are inserted into posts or tie beams with stub tenons. Although they are pinned, resistance against tension and wind load are significantly reduced compared to continuous plates. Additional reinforcements like roof boarding were applied to make up for the loss of integrity.
The frame of story-and-a-half house is in general similar to the frame of the Horton House. Absence of tie beams might demand tension joints being used on transverse girts to generate more binding forces, but this is not mandatory due to the small scale of the frame.

23 Historic American Timber Joinery, p. 10.
24 The Framed Houses of Massachusetts Bay, pp. 55-56.
25 In 16th century and earlier houses in England, simple mortise and tenon was used to connect joists and summer, which was already not the case by the colonial era of America.
26 The Framed Houses of Massachusetts Bay, p. 66.
27 Usually the collar tie is in tension when the rafter feet are set against the plates, and is in compression when rafters are fixed by the tie beam.
28 For gambrel roofs the purlins have a much more important role. They are heavy timbers supported by posts standing on upper girts, and provide a bearing for the rafters. As gambrel roof is not very common in New England houses and has a different framing system, it will not be discussed in this paper.
29 This solution also conformed to a characteristic of Jiangnan buildings: not complicated in structure, but favored ingenious framing and finishing effect.
30 Early as the 5th century B.C., brackets were regarded as luxurious components in imperial architecture. Love for brackets to a great deal was due to their resemblance with clouds and Kunlun Mountain. When Chinese timber framing gradually established its design language, the function of brackets for extending eaves and buffing seismic forces was full exploited, and they were also appreciated as the sign of beauty and privilege.
31 Seen on the exhibiting panel in the Cressing Temple. The evolution of other joints, such as notched lap joint, mortise-and-tenon joint and scarf joint during that period was also discussed.
Fig. 2.1 Bents connected with interrupted header beams

Fig. 2.2 Barn-rising in Granby, Conn., 1902

Fig. 2.3 Story-and-a-half house and its framing (Peak House, Medfield, Mass., late 17th century)

Fig. 2.4 The end bent showing a lean to, Boardman House (Saugus, Mass., c. 1687)

Fig. 2.5 The integral lean-to frame of White-Ellery House (Gloucester, Mass., c. 1710)
Fig. 2.6 Assembly of a house with an overhang (main structure of the Boardman House)

Fig. 2.7 Continuous overhang girt supported on the first floor joists (a house of Tudor period in Coggeshall, Essex, UK)

Fig. 2.8 Assembly of the facade gamble (left: Boardman House, right: House of the Seven Gables, Salem, Mass, c. 1668)

Fig. 2.9 Assembly of the facade gable in Essex County, England (left: the Old Siege House, Colchester, c. 17th century; right: Granary of the Cressing temple, c. 1575)
Fig. 2.10 Basic type of Chuan-dou frame bent (left) and other variations

Fig. 2.11 Basic Tai-liang structure and more complex variations

Fig. 2.12 Sketches of three different kinds of bent structure (from left to right: Chuan-dou, Cha-liang, Tai-liang). In a Cha-Liang structure, a spanning beam bears most roof load and transfers it to the two outer posts; in its more complex variants, short posts are the main members transferring roof load to the spanning beam, sparing the repetitive load bearing task in Tai-liang.

Fig. 2.13 Different kinds of two-layer roof structure (from: Yingzao Fayuan)
Fig. 2.14 The official method of constructing a certain roof frame

Fig. 2.15 How the previous roof was constructed in Jiangnan

Fig. 2.16 Different kinds of cantilevering in overhang structure (Yin Yu Tang and two houses in Pingshan Village, Huizhou region)

Fig. 2.17 Overhang structure in southwest China (Enshi, Hubei Province)

Fig. 2.18 The primitive form of a purlin roof

Fig. 2.19 Two different kinds of large span rafter roof construction (left: Lincoln Cathedral, Lincoln, England, c. before 1280; right: Tewkesbury Abbey, Gloucestershire, England, 1400-1410)

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Fig. 2.20 Architectural image of rafter roof in 6th century China and architectural historian’s restoration of this kind of frame (left: tomb ware; middle: grotto temples; right: restoration drawing made by FU Xinian)

Fig. 2.21 Early architectural image assumed to be of Tai-liang structure (tomb wares), and architectural historian’s restoration of this kind of frame

Fig. 2.22 The joint connecting a lean-to to the main frame (Fairbank House, Dedham, Mass., c. 1637)

Fig. 2.23 The joint used for cantilevering in the end bent (left) and the chimney bent (right) (the Boardman House)
Fig. 2.24 Overhang construction in England (the Old Siege House)

Fig. 2.25 Different methods of overhang construction (left: Ward House; middle: White-Ellery House; right: Ross Tavern House)

Fig. 2.26 Joint connecting two horizontal purlins in a hipped roof

Fig. 2.27 Wedged dovetail through mortise-and-tenon joint

Fig. 2.28 Through mortise and tenon with dovetail shoulders found in two post-1750 barns in New York (left); a couple of kerf-wedged dovetail mortise-and-tenon found in Massachusetts (middle); and through mortise and extended tenon in Connecticut (right, regarded more typical for Dutch barn timber frame)
Fig. 2.29 “Horn peg” and “umbrella joint”, and another method used centuries earlier

Fig. 2.30 Some slight alterations of an English tying joint

Fig. 2.31 Thorough interlocking joint used in Chinese furniture

Fig. 2.32 Tying joints used in Chinese furniture
Fig. 2.33 Variant of shouldered mortise-and-tenon in Connecticut

Fig. 2.34 Housed mortise-and-tenon using the square rule

Fig. 2.35 Simple lap connection of summer beam and end bearers

Fig. 2.36 More complex tusk joints on summer beams

Fig. 2.37 How joints of summer and joists affect the load bearing

Fig. 2.38 Different joints (all pegged) used to install diagonal braces

Fig. 2.39 Diagonal braces in Jiangnan architecture

Fig. 2.40 Processing of short post which could improve its stability
Fig. 2.41 Various kinds of joints at the contact of rafters and plates

Fig. 2.42 The tying joint between rafters, purlins and collar ties in the Gedney House

Fig. 2.43 Various ways of assembling purlins to rafters

Fig. 2.44 Two-layer roof structure in Japan and Suzhou (left: section of Daihoon-ji hondo in Kyoto, Japan; middle and right: typical sections of two-layer roof buildings in Suzhou)

Fig. 2.45 Brackets in Chinese timber framing

Fig. 2.46 Emergence of three-dimensional jointing illustrated in Cressing Temple
3. Discussion about wood building preservation methodology based on the comparative study

3.1 Introduction

The comparative study aims at developing a more critical perspective to look at current practices of timber building conservation, and also providing some methodologies to guide the practice. At present, conservation of historic wood architecture in China is a combination of traditional craftsmen skills, modern technology and academic research. Advanced research and techniques introduced by returnees from America and Japan were instrumental in establishing a conservation program in the 1930s, based on which traditional repairing techniques and studies on domestic architecture were integrated. Today, Chinese conservators still try to keep up with preservation achievements worldwide to improve their own work, including the many powerful tools from related fields of this multidisciplinary profession, such as architectural archaeology and construction history.

Learning preservation practices of another culture (in this paper America is taken as an example) could provide domestic practitioners with plentiful new solutions, especially when historic preservation in China still needs improvement when compared to some successful practitioners. Furthermore, making a comparative study could make it clear to conservators and researchers about their individuality, explaining the differences in present practices and encouraging their own creations. Such is the case for historic preservation in China: on the one hand, conservators are still unsure about many issues and expect to get inspiration from other countries, e.g. maintaining traditional craftsmanship, properly intervening with modern technology, applying effective academic research; on the other hand, Chinese conservators have become more aware of the uniqueness of their heritage during the discourse with other cultures, and try to make their learning from the latter more selective. In recent years, cultural significance and cultural diversity, which are important notions in international heritage charters, are now gaining directing force in China’s conservation strategies.¹

The following paragraphs would start with demonstrating the conservation work of wood joints and framings in China. Then, based on the previous comparative study, we can comment on these practices and examine how some conservation practices in America could be applied in China, while in some other places China should maintain its unique building culture and cultivate its own approach.²
3.2 Preservation of wood joints and framing in China

Both the theories and practices of wood building conservation are influenced by the characteristic of the material itself. The transiency of wood requires periodic maintenance, including repainting, weeding, draining and sheltering (during harsh weather). The building methods enable and also require partial to thorough dismantling of the structure so that each component could be examined and repaired. Within this scheme, this paper would form a more specific discussion centering on the pathology and conservation technique of wood joints.

3.2.1 Pathology of wood joints in Chinese timber framing

In historic China, fire was the most destructive force for wood buildings, but gradual deterioration has become more typical today when many wood buildings are abandoned. Damage to a timber frame happens in a systematic way, most frequently starting from water penetration, caused by leakage, drainage problems and rising damp, then numerous structural problems appear after the material is undermined. Movement of the foundation from uneven settling or upheaval, might bring structural distortion; this could also be caused by strong exterior forces, but extremely inclement environment is rare in Jiangnan.

Failure of a joint happens within this large scheme of pathology, indicating its incapability with the functions assigned to it. This is usually caused by excessive strains, deterioration of materials and breaking apart of the assembly; but in most cases, tremendous loads become fatal only after the joint has already been weakened by material deterioration and structural distortion. Deterioration is typically caused by water penetration and poor ventilation. Typical victims include: joints connecting the purlins and the substructure under a leaking roof, tenons fixing the posts to their pad stones with rising damp problems, and joints sealed by contacting walls (masonry). This problem might further expand to include the many half-enclosed places not used after the house is abandoned, for example, storage spaces between the two floors in Huizhou buildings where the floor beams are located, and attics in many Suzhou houses which contain the roof structure (Fig. 3.1).

Flexible wood joints are advantageous in surviving strong exterior forces like earthquakes, but also pay the price of weakening the resistance against structural distortion, which could be aggressive and cause damage before they are adjusted. Distortions increase stresses in some joints and cause detachment of some others, and the resultant moving of more components exacerbate the distortion – typical examples are that the beams or purlins fall or roll out of place, misplacing all the members directly loaded upon them. When combined with the loads going to the joint, even slight deterioration or distortion could be destructive; one
result is that problems are more frequent on horizontal load bearing components, whose two ends are subject to great shear stress, including beams, tie beams, floor beams and purlins.

Here we should also understand that, even when a timber frame is protected from the destructive forces mentioned above, time would still undermine its solidity, which is inherent and irreversible: load-bearing beams/floor beams/tie beams have to creep and deflect after functioning for centuries,\(^5\) purlin ends are not very good at bearing compression perpendicular to its fibers, and various flaws within the timber, such as knots and spiral grains, would be magnified as the structure ages.
3.2.2 Traditional conservation methods of wood joints in China

Within the traditional building culture of China, Japan and Korea, architectural conservation was performed and regularized by specific organizations, who were often the same agents conducting the construction, and their ordinances. Engineering departments were responsible for official buildings and craftsman guilds for vernacular ones. Today, left from the old system are some senior master carpenters, the working manuals, codified or oral, and master-apprentice relationship in the trade; the traditional portion of Chinese conservators’ tool kit is largely inherited from the these historic assets.

Traditional conservation techniques were developed according to different components with their own pathology. For example, posts in most cases only needed partial repairs in place, like patching the deteriorated part and binding large cracks with iron hoops. For the triangular upper part of each bent where plentiful joints concentrated, partial dismantling was often required to repair or replace the broken components, or to adjust the frame. Here repairmen would prop up the problematic part, pull out the components to do the repair, or knock the deformed frame back into place. Such work required even more adeptness than constructing the frame, and formed some specific professions within the carpentry trade in many places.

When the building needs more thorough, meticulous therapy which could not be achieved by partial dismantling, the structure would be completely dismantled and reassembled (Fig. 3.2). Like in the case of partial dismantling, components will be examined, repaired and reassembled; but complete dismantling provides a chance for thorough study, of both the building’s technique and pathology. In historic China, dismantling and reassembling was often combined with stylish rehabilitations, while the Japanese maintained a tradition of conservation in status quo, which now represents the orthodox version of this conservation technique.

Table 3.1 provides a more detailed set of steps used in the traditional restoration of timber frame joints in China (the component would be replaced when deterioration is believed to severely undermine structural capability):

<table>
<thead>
<tr>
<th>Subject &amp; problem</th>
<th>Repairing method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterioration of tenons</td>
<td>Beam: tenons of the beam seldom break, but might rot because of moisture. The repair method is to cut out the rotted part and duplicate this part with wooden panels; the new portion would house the beam and be attached with glue and nails. The repaired beam could not be as strong as an intact one, but this method maintains most material of the original beam, and is economic when huge timbers become rare today. If the beam deteriorates too much to support the roof (purlin), or has cracks along the transverse cross section, it...</td>
</tr>
</tbody>
</table>
should be replaced;
Purlin: on its two ends meeting the posts and the beam, damage might be caused by either excessive pressure or moisture. The broken part would be cut out and a dovetail-shape mortise be cut on it. The cut out part is mocked with wood of better quality and joined to the purlin end with a dovetail tenon, then reinforced with glue and nails;
For most components, such as ties and floor beams, tenons are repaired in the same way as that of the purlin.

<table>
<thead>
<tr>
<th>Damage of mortises</th>
<th>Very rare. Could be cracks or deterioration of the material; For cracks, the component would be bound with iron straps, and the voids be filled with some putty; for material loss, the voids might be wedged, or filled by putty to stabilize the joint.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detachment of joint</td>
<td>Often caused by distortion of the frame and displacement of components. This problem is most frequent on purlins, which are connected to the beams with very weak joints; might also happen to half tenon connections. In serious matters the beam might roll out of place and widely affect other members; The repair method is to return all the components to their original position, nail or peg the components together, or fasten the whole joint with iron straps (there are nails and iron straps designed for this purpose); For purlins, another option is to nail the rafters to them with long iron nails, so that the roof forms a solid plane against displacement.</td>
</tr>
<tr>
<td>Distortion of the frame</td>
<td>This could be the ultimate reason for many joint problems, and there is a specific repairing technique dealing with this: locate the problematic part, prop up the loads, loosen the joint, and adjust the supporting member. Supporting poles from several directions (horizontal and vertical, perpendicular and right against) are fixed to both the components to be propped and the components to be adjusted, so that this process is more controllable; Various methods are used in the process: the propping could be done with pulley and lever, or simply by knocking in two opposing wedges under the supporting post; loosening could be done with hammer or crowbar; adjusting has even more options, but is basically done by pulling and pushing the supporting poles (Fig. 3.3).</td>
</tr>
</tbody>
</table>

* Might need to add auxiliary reinforcement to joints or structure. Such as adding supporting posts or small bearers, pinning wood panels, etc.

These traditional conservation techniques reveal some approaches directly derived from the nature of timber buildings; on the other hand, they appear to be completely the business of the repairmen: even though some require amazing skills, they were not regarded as intellectual or academic work.

### 3.2.3 Conservation of wood joints and framing in modern China

A most significant effort of historic preservation in early modern China was made by its first generation of modern architects, in an institute called Yingzao Xueshe (ca. 1930-1946, “Society for the Study of Chinese Architecture”). Its several leading characters received both traditional Chinese and modern western
education; no wonder that their work concentrated on traditional Chinese building culture as well as integrating theories and techniques from western countries.

The preservation work began with collecting and studying carpentry manuals of vernacular builders and official engineering department. Conservation practices started from consulting the conservation project of the Forbidden City in 1931. Conservation of official architecture was a well-developed trade in China, and was then still conducted by old fashioned craftsmen. Therefore the society learned a lot from the craftsmen in both practical repair work and literature study. From this process these early scholars developed a firm trust in the craftsmen’s status in preservation work, which remained unchanged throughout their lives.

As returnees from western countries, some society members also applied modern techniques in preservation projects. In the conservation plan for Wenyuan Chamber and five pavilions on Mount Jing (1932 & 1934, Beijing), Liang Sicheng made detailed structural calculations for building members and compared the performance of different materials, and came out with the suggestion to repaint with anti-corrosive paint and to replace the wooden beams with reinforced concrete ones.

Another important project of the society was their field research across the many regions in China, during which numerous first-hand materials of measured drawings and oral history were collected (Fig. 3.4). By combining them with literature research, the “grammar and syntax” (from western architectural theory, introduced by Liang) of historic and regional Chinese architecture was established, and acted as references for restoration work. On the other hand, although forms of timber framing made up an outstanding part of this research, the emphasis on styles prohibited adequate attention to the intangible building techniques and many unseen wood joints.

Even today, conservation work in China is within the scheme established by Yingzao Xueshe (though quite a few approaches were learned from western countries). Doing field documentation and combining it with local building history form a compulsory training in China’s architecture education today. In the recent decades, scholars have made considerable progress beyond the achievements of Yingzao Xueshe, that is, studies about building techniques, construction history and architectural archaeology are integrated when doing more professional history and preservation research. Wood joints are very important references in these fields and have gained much more attention. Still, many of these approaches are introduced from western countries, so when practically applying them, domestic conservators should pay attention to the varied domestic situations.

In the aspect of modern conservation techniques, many of those used today were already in use during the first restoration projects after the Cultural Revolution (ca. 1966 - 1976), thanks to the new republic’s
perseverance for industrialization. In the early 1980s, epoxy, unsaturated polyester resin, reinforced concrete, rebar/steel plate reinforcement, and of course structural calculation, were applied in conservation, and regularized by new ordinances (Table 3.2). These repairing methods appeared mechanical, very much fashioned by the old methods, and have not changed much until today; but today’s practice gets closer to scientific therapy with more accomplished methodology and newer techniques, like dendrochronology, non-destructive investigation and microscopy.\textsuperscript{15} Furthermore, as domestic architecture receives more attention, engineers have made numerous studies on the property of timber framing and wood joints, which now compose a useful database.

Table 3.2: Application of new techniques in the conservation of wood joints and framing\textsuperscript{16}

<table>
<thead>
<tr>
<th>Subject &amp; problem</th>
<th>Repairing method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterioration of tenons</td>
<td>The broken part is cut out, and the missing part duplicated with better wood. This new part would be attached to the original component with epoxy and screws;\textsuperscript{17} Another method is to make a new tenon with glass fiber reinforced plastic, the new tenon has a wooden pith, which is inserted into the original component, and their jointing is reinforced with epoxy; another option is to make the new tenon with solid wood, insert it to the original component, and wrap this part with GFRP.</td>
</tr>
<tr>
<td>Damage of mortises</td>
<td>The mortise is cleaned and recovered to its original shape with epoxy putty; cracks are also filled with epoxy. When a damaged tenon is remade with GFRP, some material of its mortise is also cut out to be replaced by polyester resin, as this material can squeeze the tenon tighter.</td>
</tr>
<tr>
<td>Detachment of joint</td>
<td>Not much renovation. Very occasionally there might be better designs of fasteners.</td>
</tr>
<tr>
<td>Distortion of the frame</td>
<td>Cranes and jacks of proper designs are utilized in structural adjustment, but the use is constrained as historic buildings are usually located in densely-built old neighborhood.</td>
</tr>
</tbody>
</table>

Nevertheless, established professionals often remain conservative towards new techniques. The Palace Museum for example holds quantities of world class conservation techniques, such as the Qianlong Garden project by Getty Conservation Institute, but its structural repairs heavily rely on centuries-old craft experience. Structural analysis is compulsory for important buildings, but for the numerous smaller houses, a redundant approval procedure prohibits any effort of this kind. According to a friend of the author who works there (Peng ZHAO, Department of Historic Architecture, Palace Museum), he introduced the technique of carbon fiber reinforcement in a project without reporting to the cultural department, as he knew this technique was too fresh to be approved.

At present, several academic institutes and enterprises are specifying in conservation, and facilities in engineering and material science are providing a good basis for these specifications. But this is far from establishing systematic conservation science research. The absence of such a system is the greatest adversity in applying modern technology in China. For example, many engineers test with timber framing and joints
without effective communication with conservators, therefore practical conservation works seldom apply their research. Even in the field of antique conservation, which shares many similar approaches with building conservation but is doing much better in China, scientific and technological methods do not compose a well-rounded scheme.\textsuperscript{18} Besides, some senior conservators are happy with the convenience brought by modern conservation techniques, but are impatient with the meticulous attitude of technicians from western countries. This author has seen her colleagues joking about the careful condition survey on every column of a 9\textsuperscript{th} century temple hall (east hall of Foguang temple), or the exact color match of inscribed tablets in the Palace Museum by GCI.

The third aspect of conservation, traditional craft and craftsmen, is also experiencing some changes in China’s rush towards modernization. In less developed villages, many informal repair tasks are still done by local carpenters (Fig. 3.5); formal conservation projects are in the charge of qualified institutes, and require the presence of professional craftsmen as practitioners and consultants of original techniques/designs. In the highly developed, modernized Jiangnan region, most carpenters enter the labor market, which very occasionally might distribute some resources to the abandoned wood buildings. Another important change is the criteria observed by practitioners in this time-honored trade, as they have been compromised a great deal today: the years of apprenticeship are shortened, wood is seasoned for less time, power tools are used whenever possible and their tool marks not completely cleared. Although conservators in general agree that the simple timber frames of vernacular houses do not require superb skills to return to a sound state, many are concerned about the loss of our ancestors’ excellent woodworking techniques.

Another change in building conservation is that China developed new principles in the past decade based on its own building culture.\textsuperscript{19} The principles regarding wood joints and framings are: understanding the uniqueness (technical and cultural) of our architecture; protecting physical heritage as well as the techniques and materiality underlying it; restoration that respects original materials, composition and techniques; maintaining as much original material as possible; interventions being reversible; new techniques being carefully tested and not taking over the original structure; and training professionals in related fields.\textsuperscript{20}
3.3 Applying wood joint/framing conservation experiences of America

3.3.1 A brief introduction to wood building conservation in America

The modern scholarship about wood buildings in America started in the late 19th century, following the blossoming of town history research triggered by the Romantic interest in the colonial past. Into the 20th century, research in historical and architectural approaches reached a high level, based on voluminous documentation works. Seventeenth century buildings of New England received wide interest, and research about them was presented in academic publications: *Domestic Architecture of the American Colonies and the Early Republic* by Fiske Kimball in 1922, which focused on style, and *Early American Houses* by Norman Isham in 1928, with more emphasis on construction.

The truly influential efforts on preservation were made by William Sumner Appleton (1874-1947), founder of the Society for the Preservation of New England Antiquities (1910, now Historic New England). Countless notes, observations, photographs and measured drawings made or collected by him still compose significant references for today’s preservationists. It is also believed that the philosophical policies and methodical recording techniques developed during his preservation work still surpass today’s practices in several respects.

Historical and architectural studies combined with solid documentation work composed the major efforts regarding historic New England buildings in the following decades. As a result factual information continued to accumulate and theoretical understanding of historic buildings also improved, and they still provide credible references for architectural and historical studies required by preservation work today. In fact, these practices mentioned above are similar to those in China.

At approximately the same period, study of colonial woodworking techniques was added to the traditional architectural and historical perspective, responding to the need to research and restore historic wood buildings. In America, rapid evolution of construction methodologies to a great extent caused the loss of knowledge of the historic building trade, as the evolution continuously involved changing styles, materials, and economics. Furthermore, the old ways of building, which had been taught through an oral tradition, were not well documented, as they were regarded as common knowledge to people involved in the trade, let alone that many skilled workers were not good at writing. According to a present carpenter, his 15 years of experience in the general carpentry trades did little to develop the skills of laying out and cutting up solid timber framework. As a matter of fact, when research on woodworking skill was first initiated by intellectual amateurs, its validity was often undermined by the researchers’ unfamiliarity with practical woodworking.
Nevertheless, perseverant explorations have made the picture much clearer today, for which craftsmen’s participation in preservation work and academic research into construction history contribute greatly. 27

The pathology of Anglo-American timber framing is distinguished from its East Asian counterpart, to a great extent due to the different framing method. As has been articulated above, English timber framing was based on the principle of producing stable structure, and it has less risk of structural problems. Uneven settlement of the foundation frequently caused distortion of the frame, but is not regarded as a significant problem when the frame is well reinforced by the three dimensional jointing, pegs, diagonal braces and supportive infills, and many leaning houses in England are still used and loved by people (Fig. 3.6). On the other hand, damage happening to the rigid structure are likely to be irreversible – typical problems of this kind are caused by the thrust of rafters and huge pressure perpendicular to wood grain. Besides, as English timber frames use green hardwood, the irregular structure and unstable performance of this material (compared to softwood) would often cause significant issues as the structure aged. Aside from these inherent pathologies, systematic deterioration is quite similar to that of Chinese buildings: moisture penetration and poor ventilation are the most common reasons for material deterioration; other factors include biological attack, physical damage, weathering, overload, etc. As English timber frames are often half-timbered structures, meaning that timbers have more intimate contact with infills, deterioration might be aggravated by poor ventilation and contamination. The commonly used techniques for repairing are listed in the following form (Table 3.3).

Table 3.3 Conservation techniques of timber framing in America28

<table>
<thead>
<tr>
<th>Subject</th>
<th>Material used</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial repair (patching)</td>
<td>Same or similar wood, wood of better quality; or Steel for load bearing members and Synthetic resins/fiberglass for decorative trims.</td>
<td>Remove original material with minimal destruction; Seal end grain of the original and replacement wood; Attach patches.</td>
</tr>
<tr>
<td>Replacing/reconstructing members</td>
<td>Similar materials; New materials including steel, acrylic and glass.</td>
<td>Woodwork; or Make molds and cast the replacement; Might need auxiliary reinforcement of structure during work.</td>
</tr>
<tr>
<td>Auxiliary reinforcement</td>
<td>Materials of high strength, such as steel; stainless steel is preferred.</td>
<td>Build steel beam framework for overall structure support; or Apply fasteners to weakened timber members.</td>
</tr>
<tr>
<td>Internal reinforcement</td>
<td>Wood, steel, glass fiber, carbon fiber for reinforcement; and Epoxy or hide glue as isolation material.</td>
<td>Cut away damaged original material to sound wood; Isolate original wood; Cut structural support elements to fit and embed them in the original wood in matrix of epoxy resin (WER, Wood Epoxy Reinforcement).</td>
</tr>
</tbody>
</table>

Condition survey and monitoring development of problems are also indispensable procedures.
Some similarities with the practice in China are obvious: materials used are similar, woodworking is utilized, and works fall into similar categories of partial repair, replacing, and auxiliary reinforcement. Complete dismantling and reassembling is viable, but often not used, probably due to the precedent that Appleton considered moving the Browne House to another place, but was dissuaded by Norman Isham. The reason Isham gave was that: “All these little bits of extremely important detail (not only the framing) will be lost unless you work slowly along with the house as it stands and ask your questions of it as you go and have the house to go back to if you don’t understand the answer to some query and want to ask it over”.

At the same time, more intervention of newer techniques and materials are made (compared to China). Examples of this are:; the wood-epoxy reinforcement (WER) system, which might require several steel bars to penetrate very deep into the timber, (which has a risk of epoxy leakage if the timber has cracks). Wood joints are critical structural components, and in America it is often considered that the safest conservation method is to reinforce them with metal fasteners. Reasons for this heavier reliance on metal fasteners in America could be that: 1. Americans used metal fasteners on truss constructions from an early period, making this a natural repairing method for even earlier wood joints; 2. Chinese timber framing allows for easy disassembly of the joints to do in situ repairs, which is not the case for New England timber frames.

The best argument for interventions using modern techniques is that they are based on scientific approaches. Conservators need to thoroughly study the pathology of the house, the condition of each member to be repaired, and the performance of repairing materials and techniques; experiments should be done before actual repair, and documentation and summaries be made after the work. Moreover, the whole thing is supported by an academic system including research, laboratory, publications and communications.

The author visited a few 17th century New England timber frames guided by conservation staff from Historic New England. For the Browne House, two conservators and three carpenters were on site, and talked to the students about the construction system, deterioration and original designs. Many details were revealed about the timber frame, such as typical techniques (scarf joint on the summer, noggins as infills), construction of the roof frame, and current condition of each building member. The exhibiting panels showed Appleton’s work on the building, which was about thorough understanding of the construction details. This reveals the execution stage of wood building conservation in New England – practitioners deal with the very concrete facts of a house, not only about the pragmatic aspects of function and condition, but design, history and interpretation as well. Besides, a woodshop as a base for the carpenters supported the restoration work, which was well equipped with power tools, hand tools (including hundreds of planes and chisels for joinery) and a small lumber yard.
3.3.2 Inherent differences of wood joint/framing conservation in New England and Jiangnan

Summarizing from the previous discussion about jointing techniques and conservation experiences, there are some inherent differences in the conservation of timber framings in New England and Jiangnan. These differences exist at the level of practice, but also influence the theory and methodology of conservation if conservators were to cultivate their work to higher academic levels.

New England timber framing is primarily focused on structural stability. The design guarantees structural rigidity, and also avoids using invisible, thorough interlocking joints. As a result, frames usually require less overall structural adjustment – They do not have to be perfectly upright to retain stability. Because of rapid evolution of building techniques, and the loss of traditional knowledge in the building trades, historic preservation in New England relies more on existing buildings as documents of traditional techniques. Compared to complete dismantling and reassembly, carefully studying every detail of an intact house is more valued. But for wood buildings in Jiangnan, which are put up by connecting individual bents with two dimensional joints, massive structural adjustment, even monitoring of aggressive distortion, proves truly effective for prolong its wholesomeness.

New England houses are freer to utilize newer techniques, such as mechanical fasteners, as these techniques became common from an early age, and loss of colonial carpentry skills has made it very difficult to perform traditional framing and jointing work (such as making the tying joint). China has a well-established tradition of building repair, and its traditional social-economy in the vast suburban regions still cultivates many old-style carpenters. As a result, today’s conservation in China inherits many traditional repairing techniques, and often relies on craftsmen to conduct them. The fact remains that, even though architects and conservators have a good knowledge of wood joints, carpenters know a lot more about the actual fabrication. Therefore in conservation and restoration work, jointing work naturally goes to the craftsmen. Such choice is also feasible in the sense of economics, i.e. labor is more available and also much cheaper than technology in China.

At last, the design concepts of joints and framing in the two building cultures have clear distinctions: tying joint vs. thorough interlocking joint, functional consideration vs. aesthetic pursuits, scribe rule vs. abstract ink line system. These differences indicate more specific approaches when actually dealing with the characteristic jointing techniques of the two cultures. Among these differences, aesthetics requires due attention in conservation. New England buildings, even their finer precursors in England, could have their structural stability recovered by engineers and carpenters. But timber buildings in the affluent Jiangnan district, which integrate the pursuit for elegant finish in every construction detail, require true craftsmen to recover its full glory – to see aesthetics beyond the functional aspect of joints, and to maintain the function without losing
that other intrinsic quality of these joints, their beauty. As has been mentioned above, traditional carpentry skills have been considerably compromised in today’s China, and will face the danger of extinction when old master carpenters pass away. Although carpentry schools will continue training skillful woodworkers that are well received by the labor market, they do not acquire the skills of the excellent carpentry art of the traditional period that are required in building conservation. Therefore it is suggested that the state establish training programs for professional conservation carpenters. Similar practices have been carried on in several regions with rich woodworking traditions, like Japan and North Europe. Ironically, in China, a place with the longest, richest woodworking history and a large carpenter population, such organized and academized practice is hardly at a starting level.
3.3.3 Applying wood joint/framing conservation experiences based on the comparative study

Based on the comparative study in the previous chapters, and conservation practices in China and America discussed above, it is also viable to form some strategies to direct conservation work. The strategy making could be approached from two directions: feasible conservation experiences of New England timber framings, and more individual methods based on the uniqueness of Jiangnan buildings (Table 3.4).

Table 3.4 Useful conservation experiences of New England timber framings and methods fashioned by the uniqueness of Jiangnan timber framings

<table>
<thead>
<tr>
<th>Useful experiences from New England</th>
<th>Paying attention to cultural diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applying multi-discipline researches in conservation, among them tectonic research is a very practical approach, such as construction history;</td>
<td>Learning jointing/framing techniques and details from practical conservation work;</td>
</tr>
<tr>
<td>Getting thorough understanding of construction techniques and details through conservation;</td>
<td>Researching on traditional jointing techniques, especially some uncommon designs, with scientific approaches (analysis and laboratory test);</td>
</tr>
<tr>
<td>Establishing systematic conservation science research to support proper intervention of modern techniques; On site practitioners should have a good knowledge of concrete issues including details and functions of the framing as well as history and interpretation of them; Equipping carpenters with well-organized woodshops.</td>
<td>Making technical innovations based on conservation science research, such as new techniques in holistic structure adjusting and dismantling &amp; reassembly; Utilizing conservation projects to provide chances for training craftsmen and maintaining/recovering traditional construction techniques; Making design innovations based on understanding traditional carpentry techniques, to get traditional craft better prepared for the modern social economy.</td>
</tr>
</tbody>
</table>

As preservation concept develops, the authenticity of traditional craftwork gets so valued that even America, whose colonial woodworking tradition diminished during two centuries, is gradually replacing its high-tech repair method by learning from other building cultures an approach emphasizing craftwork. The National Park Service set up the Historic Preservation Training Center (HPTC) in 1977 at first to meet its growing demand for craft skills. This program now utilizes preservation projects as the vehicle for teaching building crafts, building technology, and preservation philosophy, and has sponsored several carpentry workshops. An even more professional endeavor is made by the National Center for Preservation Technology and Training (NCPTT), which combines training with in-depth preservation research, and provides rich technical information.

Besides American practices, experiences from other countries might be referred to since the framework has been established. For studying and preserving traditional framing and jointing techniques, Japan’s practice is easier to imitate for China due to the two countries’ similar building techniques. Japan’s preservation law stipulates a scheme of both workmanship of professional craftsmen and academic work by scholars and architects. For Japanese, dismantling and reassembly conservation projects are regarded as an essential way
to pass down building techniques throughout history. The effect is many fold: not only are past works thoroughly studied, their performances are revealed by current conditions, so necessary alterations could be made (e.g. using thicker or stronger wood), and senior craftsmen are teaching their apprentices throughout the project, so that their students could take over the work when they retire. Furthermore, architectural schools in Japan have developed many laboratory tests on the performance of traditional building materials and systems, to provide references for practical conservation (Fig. 3.7).

Norway provides another good example about preserving traditional carpentry through conservation projects. In 1991, Norwegian Directorate for Cultural Heritage started the Medieval Project aiming at restoring all registered secular wood constructions prior to 1537, but people soon realized that they had already lost traditional techniques for restoration, so the focus shifted to the skills and knowledge of craftsman, and two important measures were taken. One was academizing the handcraft: this was conducted by training and seminars during the conservation practices, and some academic institutions like Sør-Trøndelag University College provided academic training and degrees. Another approach was to establish master-apprentice education through conservation projects: “authentic processual reconstruction” was regarded a critical part, in which craftsmen researched existing materials and tool marks to recover old techniques, conducted them in conservation work, and trained their apprentices via this learning-through-doing process. Many craftsmen believed that few other projects besides conservation could sponsor traditional craftwork in modern society. One problem met by the Norwegians was that, craftsmen were often not interested in or competent at academic work (e.g. theoretic research and documenting work). Therefore, it is not necessary to force craftsmen to undergo a complete academic education. Rather they should participate through a certain degree of cooperation, and scholars would be responsible for developing interactions between the empirical, transient traditional craft and the more research-based academic work.

In summary, conservation methodologies could be divided into the following categories. One is developing thorough understanding of the construction, especially some curious, unique techniques, which could be done through construction history study, building investigation, conservation science, and academizing woodworking techniques. The second approach is to establish the system of conservation science research based on domestic architecture, which provides the basis for proper intervention of new techniques and materials (but non-destructive techniques can be more freely applied, including professional training and completing infrastructure). At last, preserving woodworking skills as both conservation techniques and intangible cultural heritage forms an important aspect of building conservation, which should be based on training professionals and also assisted by the previous two approaches, as Jean Mignot put to it: “skill without knowledge is of no value”.
1 Cultural significance is a central concept in the revised Burra Charter (1999), which helps estimating the value of heritages, and establishes the scheme of preservation strategies making based on values (more detailed criteria include: historic values, aesthetic values, scientific values and social values). The Nara Document on Authenticity (1994) and Japan’s practice demonstrated the significance of cultural diversity and brought a great difference to heritage conservation internationally. China’s effort to understand its unique building culture has been inspired by Japan to some extent. One representative effort is the recent revision of Protection Regulations for Chinese Cultural Relics Sites, which was first composed with the help of ICOMOS in 2002.

2 I wish I could make a more complete study on wood building conservation in America, but this additional task exceeds the capacity of this paper, which mainly aims at providing a perspective for China’s conservation work by elucidating its subject. Therefore only some representative conservation techniques are briefly presented.


4 Damages caused by insects are also very common, but mainly happen to the lower portion of a house, thus are less typical disease for wood joints in Chinese wood buildings, which concentrate on the roof framing layer.

5 For Tai-liang structure in China, the dimensions of beams were designed to have more redundant strength than needed, which on the other hand means great waste of wood. But thanks to this conservative design, many of the most important structure members are doing their work well even in today. But cracks on the cross section are regarded extremely fatal and indicate immediate replacement of the beam.

6 For example, official buildings were investigated periodically (the cycle ranged from one season to several years, depending on building types and materials) by the engineering department, which then recorded deterioration and calculated necessary expenses in material and labor, organized conservation project and took records. According to the statute books of some dynasties, engineering department documents, and literature works in historic China and Japan.

7 One profession was called “pulling out the beam”; it mainly existed in north China where Tai-liang was the main framing method.

8 The country’s Shinto tradition required its shrines to be rebuilt in its exact original form every 20 years, as exemplified by Ise Grand Shrine. Then a method is applied to non-Shinto structures like Tōshōdai-ji and Hōryū-ji – that is, to dismantle and reassemble the whole structure. Tokyo National Research Institute of Cultural Property, Conservation of Wood. Tokyo, Japan: Organizing Committee of International Symposium on the Conservation and Restoration of Cultural Property, 1978.


10 LIANG Sicheng, LIN Huinyin and LIU Dunzhen were leading characters in the Society. Liang and Lin studied in University of Pennsylvania from 1924 to 1927 (TONG Jun, one of their classmates in UPenn, was also one of the eminent scholars of Chinese architectural history), and Liu Dunzhen studied in the Tokyo Institute of Technology from 1916 to 1921.

11 LIN Zhu, A Brief History of Yingzao Xueshe, pp. 52-54.

12 Liang Sicheng, the Complete Works of Liang Sicheng, Volume II, p. 219.


14 Besides, Yingzao Xueshe held many ideas that conformed to the later international heritage charters, such as authenticity, minimum intervention, adopting modern technology and harmonious yet discernible repairs (the Venice Charter).

15 From the condition survey reports produced by the heritage conservation institute of Tsinghua University, it could be seen that many contemporary investigation techniques have been applied, such as XRF identification, moisture content monitoring, microscopy, owing to the achievements in engineering science. On the other hand, conservation techniques are much less intervened by modern techniques; for example, repairing suggestions for a stone bridge included recovering the integrity of the original structure, partial repairing with sacrificial mortars.

In qualified conservation work today, the contacting surface of the original material and the repair is impregnated with epoxy, like the usual practice in western countries, but for a long time this was not the case.

In China, antique conservation was brought into advanced education since 1989 (in Northwest University), and is now being taught and researched in around ten universities and many more institutes. But according to a friend of the author working in this field (Nan FENG, now a visiting scholar of Art Conservation, New York University), their system is far from perfection, and could hardly support any academic research of PhD level.

They are Protection Regulations for Chinese Cultural Relics Sites in 2002, which was drafted with the help of UNESCO to learn about international standards of heritage conservation; Qufu Manifesto in 2005, by architectural scholars and craftsmen, to establish sensible disciplines when working with traditional craft, and Beijing Document in 2007, to argue with international organizations about our uniqueness in conservation work.

From Qufu Manifesto and Beijing Document.

Representative works included: Under Colonial Roofs by Alvin Lincoln Jones in 1894, and Ipswich in the Massachusetts Bay Colony by Reverend Thomas Franklin Waters in 1905.

The Framed Houses of Massachusetts Bay, pp. 1-2. There were other works in this productive period besides these eminent works, such as the Architecture of Colonial America by Harold Donaldson Eberlein in 1927.

Ibid.

Among them the representative exploits were: the Historic American Buildings Survey started in 1933; numerous writings by Frederick Kelly including: Early Domestic Architecture of Connecticut (1933), Early Connecticut Meeting Houses (1948); Early American Architecture by Hugh Morrison in 1952; the Framed Houses of Massachusetts Bay by Abbott Lowell Cummings in 1979.

Early publications on this subject include: The Modern Carpenter Joiner and Cabinet Maker (1902), and Carpentry by William S. Lowndes (1943)


Publication the author finds very useful are The Woodwright’s Guide by Roy Underhill (2008), Home Building and Woodworking in Colonial America by C. Keith Wilbur (1992), and the periodical Timber Framing published by Timber Frame’s Guild.

Course lectures of Wood: Its Property, Use and Conservation, by John D. Childs.

Quoted from the webpage of the Browne House.


In China, well-equipped woodshop is still rare for conservation agencies. Many carpenters set their workplace somewhere near the conservation site in the open air, and some carpenters drive their power tools around on a vehicle to find some work to do. One friend of the author (Yan LIU, now a PhD of construction history, Technische Universität München) met a farmer who made a circular saw with his tractor, and made a good income from it.

In recent years, many people in China become interested in carpentry. Wood joints are loved as they are regarded as a treasure of the traditional woodworking technique. But present references are either complete imitation of wood joints from Chinese furniture centuries ago, or designs by westerners downloaded from Pinterest (under a title “Chinese creation”). When people need textbooks for woodworking, they read DK Wood Work or Woodworking Basics by Peter Korn. In summary, current interest in woodworking is still a distance away from preserving the traditional, culturally significant carpentry techniques.

From the website of National Park Service and Historic Preservation Training Center.


Website of National Center for Preservation Technology and Training.

Yuyu Huang, the Research of Taiwanese Monumental Documenting on the Preservation and Repair Works, graduate thesis for Master of Architecture, Chung Yuan Christian University in Taiwan, 2004.


This College offered a part-time bachelor program in Conservation and Restoration of Ancient and Historic Buildings in 2008, and a full-time Bachelor in Performing Traditional Craftsmanship started in 2014. In Sweden, similar work is done by Department of Conservation in University of Gothenburg and national center of Craft Laboratory (initiated by University of Gothenburg and Swedish National Heritage Board in 2008).
According to UNESCO's definition, intangible cultural heritage includes “traditions or living expressions inherited from our ancestors and passed on to our descendants, such as oral traditions, performing arts, social practices, rituals, festive events, knowledge and practices concerning nature and the universe or the knowledge and skills to produce traditional crafts”.

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38 Aase H. Eskvik, “the Stave Church as a Medium for the Intangible Cultural Heritage”, graduate thesis for Master of Culture Study, Stockholm University, 2014.

39 According to UNESCO's definition, intangible cultural heritage includes “traditions or living expressions inherited from our ancestors and passed on to our descendants, such as oral traditions, performing arts, social practices, rituals, festive events, knowledge and practices concerning nature and the universe or the knowledge and skills to produce traditional crafts”.
Fig. 3.1 Roof frame in an attic showing water marks (an 18th century house in Shankeng Village, Yongjia County, Wenzhou City)

Fig. 3.2 Woodworkers reassembling the roof frame (a hall in the Palace Museum)  
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Fig. 3.4 Building investigation in China by Yingzao Xueshe (c. 1932-1940)
Fig. 3.5 A restoration site in Yongjia County, China

Fig. 3.7 Twisting timber on a wooden bridge in Umhausen, Austria

Fig. 3.6 Other parts of the house might set lower than the chimney, in older houses in England distortion is more obvious, but the house is still safe for daily use (left: House of the Seven Gables, Salem, Mass.; right: Tudor Bar in Colchester, England)

Fig. 3.8 Lab test on the mechanic property of traditional Japanese straw-and-daub walls in an architecture school in Japan
Conclusion

This paper built a comparative study of wood joints used in vernacular timber houses in New England and Jiangnan, using the criteria of how they responded to building tasks. Then the comparative study was connected with conservation practices in these two regions, based on which methodologies about preserving timber frames and wood joints in Jiangnan were developed, about what to learn from successful experiences of New England and paying attention to the uniqueness of Jiangnan buildings.

The comparative study started with comparing the framing and wood joints used in two actual timber houses – the Horton House and the Yin Yu Tang House from two distinguished building cultures, New England in America and Jiangnan in China. Design of joint is firstly dictated by the timber framing – a box frame with standing triangle roof or individual bents two dimensionally connected by ties. Framing generally assigned to each joints their building tasks: resisting tension, compression or bear heavy load.

More detailed study of wood joints revealed some distinct joint designs in these two houses: three-dimensional tying joint vs. stub mortise-and-tenon with step-shape tenons (the former from the Horton House and the latter from Yin Yu Tang, the same below) for transverse and longitudinal binding; shouldered mortise-and-tenon vs. laminated beams for load bearing; diagonal braces vs. laminated beams for diagonal rigidity; building triangle structure vs. directly relying on the substructure for roof construction. Techniques of framing and joint making are also distinguished from each other despite their similarity in tools and actual processing. New England carpenters worked with green timbers under the scribe rule, which increased individuality of joint and required careful attention to each of them. Jiangnan carpenters worked with uniform timbers and utilized an abstract three-dimensional grid system, which preferred convenient two-dimensional joining, but significantly improved flexibility of design and construction.

Based on the comparison of two individual houses, the larger contexts of their building cultures were introduced to discover the many other solutions for certain building tasks, and to discuss some shared characters within each building culture. This comparison showed that New England timber frames had a strong emphasis on three-dimensional thinking, and regarded the ability to build a box frame and standing roof as a paramount. In Jiangnan, individual bents were fundamental to timber framing and many variations were achieved by expanding the bents – with only a certain variety of jointing skills, which was also an achievement appreciated by Chinese architectural historians. It was also revealed that only a limited number of new joints were added to building more complex houses in both New England and Jiangnan, and that joint design could vary greatly or little so long as they accomplish their function in the framing. To go one step further, joint design in New England was directly influenced by function and structure, but joint design in
Jiangnan buildings usually achieved structural functions in a less direct manner. Typical typologies were thorough interlocking and hiding the inelegant part of a joint (voids for example), which was to a large extent credited to the consideration for aesthetics. Still, influences of building tradition, techniques and aesthetics require further research to make rational judgments in conservation.

Based on the comparative study, conservation methodologies were discussed, about preserving timber frames and wood joints in Jiangnan. Preservation practices of wood buildings in China and America were studied. Both countries have a sound background in architectural history research, but China still needs more pragmatic study for conservation work. China has inherited many traditional repairing techniques and still maintains a few old-style carpenters, but intervention of new material and techniques is only at a starting level, due to the lack of systematic conservation science research. Americans have more intervention of new techniques and establish sequential work of investigation-conservation-monitoring, based on solid conservation science research; at the same time, scholars are trying to recover historic building techniques lost during their rapid building evolution, and new programs have been started to apply the conventional practice of craftsmen repairing in East Asia.

So this paper concluded two categories of conservation methodologies that are judged feasible by the comparative study. New England practices, such as thorough construction detail study through in-situ conservation and lab analysis, could provide experiences in better understanding of the construction. Another approach of great necessity is establishing systematic conservation science research, as many techniques and designs of Chinese wood buildings still need elucidation through a rational scientific approach; moreover, scientific research provides the basis for proper intervention of new techniques and materials. The second argument is for the revitalization of domestic building techniques, which is of great intangible cultural value (hopefully the comparative study of this paper might contribute a little to this understanding). This calls for academic research, but more importantly, as has been proved by the experiences of many countries, should be based on a vital interaction of theory and practice, through practical conservation projects and training of professional craftsmen.
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Fig. 1.3 The box frame of the Horton House (source: modeled by the author, based on HABS drawings)

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Fig. 1.22 Ink lines as the references of making joints (source: Li Zhen, *Forms and Techniques of Traditional Chinese Architecture*, p.158)

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Fig. 2.40 Processing of short post which could improve its stability (source: MA Quanbao, *Comparative Study of Jiangnan Traditional Wooden-frame Craftsmanship*, p. 38; and YAO Chengzu, *Yingzao Fayuan*, Plate 15)

Fig. 2.41 Various kinds of joints at the contact of rafters and plates (source: Jack A. Sobon, *Historic American Timber Joinery: a Graphic Guide*, pp. 35-37)

Fig. 2.42 The tying joint between rafters, purlins and collar ties in the Gedney House (source: photographed by the author)

Fig. 2.43 Various ways of assembling purlins to rafters (source: Jack A. Sobon, *Historic American Timber Joinery: a Graphic Guide*, pp. 40-42; and J. Frederick Kelly, *Early Domestic Houses of Connecticut*, p. 50)

Fig. 2.44 Two-layer roof structure in Japan and Suzhou (source: Klaus Zwerger, *Wood and Wood Joints*, p. 197; and YAO Chengzu, *Yingzao Fayuan*, Plates 4-5)

Fig. 2.45 Brackets in Chinese timber framing which are both functional and decorative, Dengfeng, Henan Province (source: photographed by the author)

Fig. 2.46 Exhibiting panel in the Cressing Temple illustrating emergence of three-dimensional jointing (source: photographed by the author)
Fig. 3.1 Roof frame in an attic showing water marks (source: photographed by the author)

Fig. 3.2 Woodworkers reassembling the roof frame (source: photographed by the author)

Fig. 3.3 Adjusting a column (source: DU Xianzhou, *Repairing Techniques of Chinese Historic Architecture*, Plate 5)

Fig. 3.4 Building investigation in China by Yingzao Xueshe (source: organized by the author, original drawings from LIN Zhu, *A Brief History of Yingzao Xueshe*)

Fig. 3.5 Restoration work site in a village (source: photographed by the author)

Fig. 3.6 Other parts of the house might set lower than the chimney, in older houses in England distortion is more obvious, but the house is still safe for daily use (source: photographed by the author)

Fig. 3.7 Twisting timber on a wooden bridge in Umhausen, Austria (Source: Klaus Zwerger, *Wood and Wood Joints*, p. 16)

Fig. 3.8 Lab test on the mechanic property of traditional Japanese straw-and-daub walls in an architecture school in Japan (source: photographs contributed by REN Congcong)
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