The Modern Interpretation of Bayu Traditional Wooden Architecture - The Optimized Strategies of Structural Detail for the Bayu Wooden Architecture in Modern Creative Design

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Abstract

Bayu wooden building has a long historical standing with distinctive regional characteristics, and is an important part of Bayu culture. Wooden structures have many advantages as sustainable buildings however, the development of modern Chinese wooden buildings has been very slow. This is due to the low compatibility of wood with other materials and structures, limiting its use in modern architecture. This paper firstly introduces the development of the use of wood in traditional Bayu architecture and its limitations in modern engineering; then it investigates the beam structures in modern wood-like construction, which employ steel construction design methods and computer simulation modeling techniques. It proposes the methods for optimizing technology and morphological innovation in building modern wooden buildings. We use Xiang’e Primary School as a case study to investigate contrast and integration of modern, wood construction technology and the regional culture characteristics. Learning from the techniques used to deal with intricate details, we make recommendations for designing a lap joining type and detail treatments for the wooden building components in the Bayu area. As a result, this research has provided a valuable guidance for designing traditional Bayu wooden structures with modern architecture; and has proposed a method to overcome the technical difficulties in design and construction. Finally, it has pointed out the future direction of the traditional wooden building development incorporating modern interpretation.

Keywords: Bayu tradition, wooden building, structural details.

1. THE DEVELOPMENT OF MODERN BAYU WOOD CONSTRUCTION TECHNIQUES

1.1 The geographical features and the evolution of Bayu wooden building form

Bayu is a complicated terrain area which has a humid subtropical climate, with high humidity and very foggy. The forest resources were initially quite rich, but the productivity was very low at that time. So the original Bayu ancestor created the Jinggan style wood construction to fit the mountain environment. The traditional design form would have been conducive to air circulation from the bottom of the house and this would decrease the humidity impact for building maintenance and living conditions as well as deterring insect and beast habitations. When productivity in the area improved,
together with integration with the Central Plains culture, the Jinggan style house evolved to become the Chuandou style stilted building. This style is more responsive to the mountain and its structure can effectively use the terrain elevation with split-level, hanging layer and other techniques to form a unique architectural style, thus forming a distinctive mountain building system (Figure 1) (Shen, 2012).

Figure 1. The development of Ganlan architecture in Bayu area

Figure 2. The Bayu traditional architectural community

1.2 The advantages of Bayu traditional wooden beams frame

Bayu traditional wooden building normally takes a Liangzhu beams structure (Figure 2), and each purlin of the building beams is equivalent to the framework in a modern frame structure. The column and frame can bear the whole roof weight, with the wall only
playing a partitioning and protective role. This results in the ability to freely divide the internal space to match the different functional requirements. This is so called, “Wall down but structure not collapse” as the anti-seismic function of Liangzhu wooden structure building. The expressiveness of wood-beamed framework is to show the purely natural, clear and concise mechanical transmission: roof - purlins - beams - foundation - the earth, and there is no affectation: only real aesthetic performance. The core connection is the Tendon lap which has a certain strength, toughness and deformation. The connection between the Tendon and Maoyan components as the Tendon wood structure, from the hinge point, can withstand pressure well in a certain direction. In addition, the shape of the lap tendon is very simple and elegant to show the beauty of oriental culture (Li et al., 1999).

1.3 The limitations to wide usage in design and construction

The reasons why Bayu traditional wooden structure is very hard to be taken into the designing of modern projects are as follows. First, the wooden structure lap is not rigid enough to support large load components, which has restricted the wooden structure from bulk architectural applications. For example, the connection of the Tendon lap is very weak compared with a concrete structure, so it is difficult to load the large wooden structure. Similarly, because the Tendon lap must be cut off by some volume at the node in order to gain the space for the connection between two wooden components (Figure 3), the mechanical properties of nodes decreases. This effect is even worse when applied to all the various components from multiple directions to intersect one tendon node. So the traditional Tendon lap obviously cannot afford to bear the load of modern complex construction. So, to optimize the structure nodes would be a breakthrough for the future of wooden building development.

Figure 3. Mortise-tenon joint of roof corner

The second reason is that the depletion of timber resources in China has limited the original wooden material supply, and although China has vigorously increased the construction of plantations, it may take decades to meet the market demand (Zhu, 2009).

2. THE OPTIMIZED DESIGN OF WOODEN LAP JOINING AND STRUCTURE DETAIL

2.1 Comprehensive optimization of hybrid wooden structure

Glued wood was widely used previously however, the material properties of glued wood are not good enough to meet the tension requirements. Therefore, glued wood has is insufficient for span, structure and modeling performance. To compensate for the
weakness of glued wooden structures, it is necessary to take a hybrid form of wooden structures, especially for large-span buildings.

Reinforced concrete buildings are often used as a base and walls, and then wood is used as the main upper structure and the main form of expression to determine the overall structure and spatial shape of the building. This system is aimed to avoid the wooden structure contacting directly with the ground and increases the overall stability of the building. The steel detail components are often subjected to bear the tension or act as the secondary structure interspersed among the wooden structure and the fundamental structure to ensure stability. The applied joint design meets the complex mechanical requirements (Figure 4) (Wu, 2008; Ni and Yang, 2011). The Izumo Stadium, Japan (Figure 5 and Figure 6) completed in 1992, is a typical example of a project constructed with a laminated wood composite structure for a large internal space (Guo, 2008). The comprehensive optimization of a hybrid wooden structure in this project has shown the strengths of wood, steel, film and concrete structures. The large span created is insurmountable for a purely wooden structure (Gao et al., 2013).

Figure 4. The joint of Mixed Wooden Structure System

Figure 5. The Izumo Stadium 1

Figure 6. The Izumo Stadium 2

2.2 The introduction of steel structures and computer simulation technology

The technical development for modern, wooden building structures is very slow. When meeting the structural problems for using wooden structures to construct large spaces or contemporary, large span buildings, the architects and engineers must learn from the designing of steel structures, where there is great experience (Zhao and Li, 2013). There
are many similarities between steel structures and the common timber wood structure which are normally used for modern wooden construction. Firstly, the construction of both timber components and steel structures would be prefabricated in a factory and assembled at site (Wu and Weng, 2011). Secondly, the steel and other metal components are often used for the node details of wooden buildings to connect with other structures. Thirdly, the timber building structures have copied some advantages from the form of steel structures, especially for large-span buildings. As a result, the traditional wood frame construction limitations have been overcome (Yi and Yu, 2013). As a representative modern structure, steel has produced a variety of structural forms, and the utilization of steel for architectural design is relatively mature. Therefore, the introduction of the steel structure design methods for wooden buildings would provide another new effective way to develop modern wooden structures.

The reason why some design instruments of steel structure can be apply to timber structure is due to the similarity of the mechanical properties and usable methods for both type of structure. In the modern steel structural design, steel is used as a rod to arrange large structures (Ni et al., 2012). Actually, the overall structural principles of mechanics are consistent if timber rods are used instead of steel rods to construct the structure. The steel structure design method is easily applied to wood design fields (GB 50005-2003, 2011). So, in computer simulation the wood and metal connection would be able to be incorporated in the design. For example, Beijing Vanke Vancouver Forest project clubhouse, with a glued wood structure, used computer simulation to design a structure that combined timber and steel structures. The shape of a tree extended to the surrounding design built with wood instead of a steel grid (Figure 7).

Before applying the steel structural design methods and theoretical calculations to design the wooden structure, there is another problem needs to be solved: the wooden material in the direction of the force must be homogeneous and predictable (GB 50016-2006, 2006). The modern technology of wooden material has reached this requirement. As the glued laminated wood has been widely used in China, wooden structures have achieved another application in the construction sector, where only steel was viable in the past. From the previous research, not only the design features, but also the connecting rod details can be constructed from wood (Figure 8). Furthermore, the development of the steel production industry, as well as the improvement of prefabricated methods, would have a profound impact on the design of wooden architectures.

![Image](image_url)

**Figure 7.** Interior of Vancouver Forest project clubhouse by Vanke, Beijing
In addition, modern computer technology plays a huge role in promoting the structural design. Through advanced computer-aided design programs, it is easier than ever to implement the use of steel connecting components in wooden construction (Xiong et al., 2006; Parisi and Piazza, 2002).

2.3 The metal node in wooden structure

The traditional timber component of Tenon takes the form of a cross-connection to support itself. Metal components with good physical properties can easily meet the mechanical requirements to connect timbers with a simple shape. In many European countries, metal components have played very important role with the small components, such as nails, bolts, etc, usually only playing the secondary role of reinforcement and protection. The large-scale use of metal nodes with a wooden structure after the industrial revolution was developed with steel structures, and then the methods of designing nodes for steel structure was copied for the wooden structure. Finally metal nodes grew to become the dominant type.

The most difficult part of wooden structure design is the node design. Well designed detail can strengthen the beauty of a structure, build large-scale buildings, and express the cultural context, which is the most important aspect. This is why designers should focus on studying to optimize node details to contribute to the development of wooden building. In modern times, the integration between technology and emotion demonstrated the future trend, and the people’s aesthetic ideas are more diversified.

3. A CASE STUDY OF XIANG’E PRIMARY SCHOOL

This paper has selected Xiang’e Primary School, Dujiangyan City, Sichuan, China as the case study to analyze how the new technology has been taken to design a new modern Bayu wooden architecture. This project is technically supported by Canada for the 512 Wenchuan earthquake reconstruction process. The design scheme has fully examined the regional characteristics of the Bayu traditional building, specifically for the expression of Chuandou patterned modeling with new technologies, via taking the concept from Bayu architectural symbols. The three blocks of this primary school represent the new modern Bayu wooden architecture under the new technologies. The main building including classrooms, accommodation and restaurants, except the kitchen area, were constructed with concrete. The rest of the structure was made of light timber (Figure 9 and Figure 10) (Fan, 2003).
Figure 9. Architectural style of Sichuan and Chongqing region of Xiang’e primary school, Dujiangyan city

Figure 10. Canteen interior space of Xiang’e primary school, Dujiangyan city

3.1 The use of new light timber (Figure 11 and Figure 12)

Figure 11. Dormitory of light wood frame construction of Xiang’e primary school, Dujiangyan city

Figure 12. Construction site of light wood frame construction of Xiang’e primary school, Dujiangyan city.

Figure 13. [Image of architectural detail]
The light wooden structure is a structure in the form of small wooden components connected densely, and the centre-to-centre spacing between wood components is no more than 600 mm. The required bearing capacity, stiffness and integrity of the structure are obtained via the main structural elements (frame members) and secondary structural components (wall panels, floor panels and roof).

It is a box-building system, and the most distinctive feature is the good seismic performance. This is due to the size of the seismic force being directly proportional to the quality of the building itself. Also, the size of the seismic force is directly proportional to the weight of the building itself, and the light wooden components were made by small cross-sectional size timber. This makes it a very light structure compared with other structures. Another reason is that the large quantity of the wooden structural components could absorb the shockwaves via power transmission paths when subjected to seismic force.

For the floor plan, the designer did not take the longitudinal rectangular plane, but designed a square close to plane instead with an enclosed verandah. The former plan can reduce the cross-wall spacing, but the final scheme achieved a better holistic form for its seismic function compared with other designs with verandahs.

Another highlight of this project is that the designer used the theory of sustainability from the starting stage. The various life cycle emissions targets of light timber materials are very low because it is a renewable, biodegradable material with little pollution created during the production process. A related feature the designer included was that the plan integrated with the rainwater recycling system. So, in this way, Xiang’e Primary School has become a representative green education project for its environmental friendly, energy conservation and sustainable features.

The advantages for a light wooden structure to create large interior spaces have been unfolded in this case study. The span of the library is over 16 meters. For the single building wall, it has a keel in spacing of 38*140 mm for the internal wall and a keel in spacing of 406 mm for the facade. The main floor was made by floor grilles and floor panels, with the girders set in the lower elevation of the top of the wall, to strengthen the connection between the grid to fill the block and to both reduce the length of the grid and achieve a larger span.

### 3.2 Fire protection

After Xiang’e Primary School was been built, it proved that the timber system can be utilized to construct fire resistant and safe buildings and this project has achieved all of the requirements in “Architectural Design Code for Fire Protection”. Firstly, some timber materials itself have got good fire protection properties, such as OSB panels (oriented veneer particleboard): because it is very dense, it is hard to burn. Some rungs in the wooden structure, not only strengthen the integrity of the timber structure, but also play a role in the fire protection and prevent a chimney effect. Secondly, all the walls outside the structure of the nail studs are first wood-based structural panels (such as plywood), then covered with fireproof plasterboard. Plasterboard filled with glass fiber can reduce the heat transfer between cotton studs and the floor grilles, lightweight concrete floor and the paved surface. These structures mentioned above, prove that the architecture is fully guaranteed to reach fire code requirements, namely its fire resistance and anti-burning performance can ensure the safety of the building.

### 3.3 Moisture-proof and moth-proof via design details

Damage from insects often occurs at the site, because the climate in the location of Dujiangyan is very humid. In the design of Xiang’e primary school, the designer took
some preventative measures to minimize the effect of the elements on the wooden structure. The full implementation of these “4D principles” are: deflection, drainage, drying and durable materials, and to apply these principles to the macro and micro designs.

When designing a project for a site with a humid climate, pests such as termites normally gradually invade the timber structure from the foundation upwards and the same is true for water penetration. Therefore, the key task for the moisture-proofing and moth-proofing of a structure is to block the route of ingress. To do this effectively takes three important components: water-proof board, pearl film beams and CCA wood preservative (Figure 13 and Figure 14).

![Figure 13. Construction details.](image)

Figure 13. Construction details.

![Figure 14. The connection between concrete foundation and wooden structure.](image)

Figure 14. The connection between concrete foundation and wooden structure.

3.4 Door and window design

In a wooden frame construction system, some special modifications for the door details have to be implicated. The key point is at the connecting point between door and window with the exterior water-proof wall materials. The basic principle is to ensure run off, but also to pay attention to other details of the design (Figure 15).

![Figure 15. Door and window design.](image)

Figure 15. Door and window design.
3.5 The installation of outdoor horizontal wooden lines

Timbered building often takes horizontal lines for facade application, some of these lines are for decoration, and some are simply building wall panels. However, the gaps in between are a weakness in the water-proofing of a building. It is necessary to create a drain board for the exterior detailing (Figure 16).

![Figure16. The joint of exterior horizontal lines.](image)

3.6 Roof form

For wooden frame construction, the roof normally takes the slope shape which matches the style of the regional architecture. Generally the slope roof would have eaves and cornices, this demonstrates the system for connecting the waterproof materials, cornice boards and flashing lap board.

3.7 Conclusion

During the design and construction process of Xiang’e primary school, the outside wall and facade of this project have had a water-proof layer applied. Wooden components which are contacting the concrete foundation have been embalmed. The plate barriers were installed between the bottom of slab and the top of the foundation, and the gaps, cracks or joints were filled with anti-termite caulks. Sloping roofs with good drainage were constructed with waterproof layers, and insect nets were set at the top of the roof structure. To prevent damage to the roof structure from condensation, vents and roof moisture barriers were set in the roof. For insect prevention purposes, the site clean-up work was carried out carefully before the construction, and created an additional soil barrier.

Maintaining the foundation to avoid the creation of cracks for insects, and spray painting non-toxic pest control agents for the ground floor foundation have the distinctive value of preserving the structure and are important processes for the future Bayu wooden building design.

4. CONCLUSION

The modern wood frame construction technology has the advantages of being applicable, energy saving, economical, flexible, environmental friendly etc. In China, although the wooden structure as the main building form has lasted for thousands of years, modern wooden architectural research and development has been conducted in the past decade. What is worse is that the historically prominent Bayu area has now fallen behind in expertise level. Therefore, future research should focus on exploring how to take traditional techniques and construction technology to the modern, innovative and optimal design; to develop the most appropriate and reasonable design for each
situation; to combine the creation of modern wooden buildings with traditional Bayu regional culture; to seek the integration of modern technology and traditional wood frame technology; and to explore the new development of Bayu wooden buildings in practice, through inheritance, protection, and innovation to create a modern definition of Bayu wooden architecture.

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6. REFERENCES