The 2020 World Congress on
The 2020 Structures Congress (Structures20)
25-28, August, 2020, GECE, Seoul, Korea

Low-rise Cross Laminated Bamboo and Timber Building Design

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ABSTRACT

Cross laminated bamboo and timber (abbreviated as CLBT or CLTB) is an unconventional engineering material developed by the authors, with inspiration from the success and spread of cross laminated timber (CLT). It has the potential advantages of high construction efficiency, wide raw material source, good mechanical properties and environmental protection due to the combination of fast grown species of wood and bamboo, particularly in regions with rich resources of bamboo however short of high quality structural timbers. In this study, low-rise CLBT building design is investigated taking the two-story bamboo house in Beijing Black Bamboo Park as a prototype. The slabs and walls of the building are composed of straight CLBT panels and connectors. According to the tests of the building, CLBT slabs and panels show good behaviors in mechanical properties, thermal properties and durability. Additionally, CLBT is a feasible construction material for prefabricated houses, where BIM system can be integrated to design the assembly scheme and simulate the construction process.

1. INTRODUCTION

Bamboo has a long history as a building material in China, where the resources are abundant and widely distributed. Mechanical tests conducted on bamboo have shown that it has good mechanical properties as an engineering material and is an environmentally friendly engineering material. As the modern timber structure has been highly developed in industrialized countries in recent years, particularly, cross-laminated timber (CLT) has been in limelight. It is a kind of solid panel made by a few layers of kiln-dried plank, which are stacked in alternating directions, held together with structural adhesives. In this way, these layers of plank form a straight and rectangular panel. [1] By interlacing the timber's horizontal and vertical stripes, CLT panel is extremely stable and strong, so that load transfer can be handled on all sides, [1] thus it can be used as a substitute for concrete in construction.

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Based on CLT, a research group led by Xiao has designed a new glubam [2] (glued laminated bamboo) and timber composite material, Cross Laminated Bamboo and Timber (CLBT or CLTB[3]), which is made by placing adjacent glubam and timber layers in an orthogonally alternating direction and then pressing them together, as shown in Figure 1(a) and (b), for the surface layers with thick-strip glubam and thin-strip glubam, respectively. The results of mechanical tests have shown that CLBT is a feasible construction material. Besides, this new composite material not only maintains the advantages of the material properties of each component, but also have the comprehensive properties that cannot be achieved by a single component in the way of combining the properties of each component. Therefore, compared with CLT, CLBT combines the advantages of glubam to achieve further improvement in performance. It is a new building material that is more environmentally friendly and relatively cheaper to manufacture.

(a) (b)

Figure 1 CLBT examples: (a) with thick-strip glubam surface layers; (b) with thin-strip glubam surface layers.

The bamboo house of Beijing Black Bamboo Park (Figure 2) is the second house designed and built as lightweight bamboo structure building system developed by the second author's research group.[4,5] The construction project was sponsored by the International Bamboo and Rattan Organization (Inbar), funded by the Bluemoon Foundation. The bamboo structure adopts the assembled form, and the main components were produced in Changsha. In July 2009, construction of the main system, interior and exterior decoration was completed on the spot by seven workers in only three weeks. The total construction area is 120 square meters. The bamboo house is designed for level two fire resistance, severe seismic fortification intensity, secondary roof waterproofing and 50-year design life. This building is used as the prototype for the design of the CLBT building.

Figure 2 The bamboo house of Beijing Black Bamboo Park (Zhou, 2019)

2. COMPARISION BETWEEN CLBT AND TRADITIONAL CONSTRUCTION MATERIALS

Cross laminated bamboo and limber (CLBT) is a kind of composite material which is made by bamboo and wood, with a specific adhesive which glues them together. The main processes of manufacturing CLBT includes wood selection, surface planning, finger joint, glue spray, assemble, cold pressing, trimming and curing. CLBT structure houses are different from traditional reinforced concrete houses in the aspects of construction method, environmental protection behavior, stress condition, maintenance and other aspects. Also, CLBT structure is an upgrade to the traditional wood structure. It overcomes many shortcomings of wooden structure houses.

As CLT, the construction period of CLBT structure houses is expected to be shorter than that of reinforced concrete houses. All structural components and connectors of CLBT structures can be standardized. Therefore, its construction and assemble speed is significantly faster than concrete and masonry structures. CLBT structure and wooden structure houses can generally be completed in about 2 months, while reinforced concrete structure houses of the same scale need about 10 months.

From the point of view of environmental protection, the impact of CLBT structure on the environment is minimal compared with cements, concretes and other traditional construction materials. During the production of reinforced concrete, there is high level energy consumption and greenhouse gas emission. Bamboo and wood are the main renewable building materials. Compared with reinforced concrete structure, they have relatively less impact on the environment because their growth consumes carbon dioxide, which is the main greenhouse gas. In addition, bamboo growth cycle is short (4-6 years) while the growth cycle for wood is relatively long (20 or more years). Therefore, CLBT buildings are more environmentally friendly than reinforced concrete buildings and more economical than wooden buildings.

Additionally, CLBT structure houses have better seismic performance than buildings with conventional concrete or masonry, which are frequently devastated in past

earthquakes. The wooden and bamboo structures behave better, because they are relatively light, and therefore absorb less force during seismic event. The CLBT developed by the authors are also targeted to combine the fast-mature bamboo with the fast-growing wood species, such as poplar which are well available in China.

3. DESIGN OF LOW-RISE CLBT BUILDINGS

3.1 Condition assessment of the prototype bamboo house in Beijing Black Bamboo Park

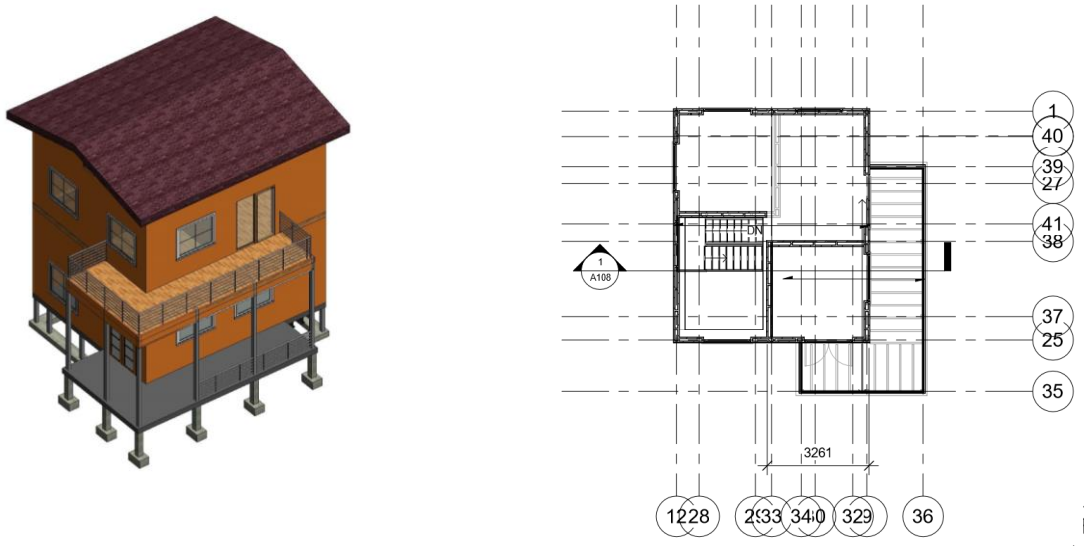
In 2019, on the occasion of the 10th anniversary of the construction of the bamboo house in Beijing Black Bamboo Park, undergraduate and graduate students from Zhejiang University, University of Southern California, Hunan University, Nanjing Tech University, and Guangdong University of Technology conducted an the evaluation of the building. The following performance tests and evaluations were carried out for the bamboo house.

a) Geometric information test: the structural geometry information of bamboo house was measured and the architectural structure layout diagram and spatial distribution diagram were obtained.
b) Dynamic characteristics tests: i. the internal structure of the house was tested by the wood ultrasonic tester, and the degree of spoilage of the bamboo house was evaluated according to the transmission speed of the ultrasonic wave and the received energy; ii.) measuring acceleration and analyzing vibration mode of the forced vibration. The dynamic characteristics of the structure were obtained by modal analysis
c) Test on glubam wall panel insulation performance.

The house is generally in good condition, which is a proof of engineered bamboo being a good engineering material.

3.2 Revit Model of low-rise CLBT buildings

Based on the bamboo house in Beijing Black Bamboo Park, a model of low-rise CLBT building, where glubam panels are replaced with CLBT panels, is built with Autodesk Revit as shown in Figure 3. This model indicates a common design for CLBT house with following characteristics. The wall of the house is constructed in a style that two layers of CLBT boards are connected by a perpendicular CLBT board between them, where an H shape structure is formed and they are nailed together. The external layer of the CLBT wall is equipped with ferrocement and building paper. The internal layer of the CLBT wall is equipped with rock wool and plasterboard. The columns of the CLBT house are hollow block columns with CLBT board covering. The main structure of the roof is wood truss. These design of components of CLBT buildings can be generalized and costumed according to different requirements. For a CLBT building on a larger scale, they still work well. But for high-rise CLBT buildings, reinforced structure, for example, steel-bamboo truss structure, might be applied to increase its loading capacity.



(a) (b)

Figure 3 Revit Model of low-rise CLBT buildings: (a) perspective view; (b) plan.

4. IMPACTS OF CLBT BUILDINGS ON THE SOCIETY, ECONOMY AND THE ENVIRONMENT

4.1 Impacts of CLBT buildings on the society

CLBT is a feasible construction material for prefabricated house because CLBT can be manufactured ahead into beams, columns or boards and ready for assembling. Prefabricated CLBT house has the advantages of higher construction efficiency compared with traditional house because construction components of prefabricated house can be manufactured ahead and delivered to the construction site when needed. Especially in the period of COVID-19, with surging demand for isolation wards, prefabricated CLBT house can be applied and serve as temporary wards with its relatively short construction time, simple construction method and better inhabitability quality. Additionally, high precision components significantly alleviate the problem of wall cracking and house leakage and thus contribute to improving the overall safety level, fire resistance and durability of the house. This kind of lightweight partition system allows the owners to renovate the house based on their needs.

4. 2 Impacts of CLBT buildings on economy

The production of CLBT is an emerging industry. During the development of it, CLBT plants can provide jobs to local people as it is a labor-intensive industry. Both the upstream industries, such as acquisition of raw materials, manufacturing connectors, and downstream industries, such as delivery of CLBT materials, professional construction company of CLBT house, and bamboo furniture production, will benefit from it. Therefore, CLBT industry promotes the economic development by stimulating the development of a series of relative industries. From the aspect of customers, CLBT house is low in cost

but durable in use, which makes CLBT house an economic choice among low-rise buildings.

4. 3 Impacts of CLBT buildings on the environment

The forest resource in China is in shortage and the distribution is uneven. But new forestry resources consist of fast-growing wood species have gradually become available, and China has the most abundant bamboo forest resources in the world. The physical and mechanical properties of bamboo are similar to those of timber, and bamboo has the advantages of light weight, low price, good toughness, wide source of materials and short maturity. Besides, it is a green material compared with concretes and steels. Hopefully, as a form of combination of bamboo and timber, CLBT can reduce China's dependence on timber import, and contribute to protecting the world's forest resources.

CLBT house is of great benefit to energy conservation and environmental protection during its construction and daily use. With its construction mode of factory production and on-site assembly, it can significantly reduce construction noise, discharge of harmful gases and dust, construction garbage and sewage. Generally, it saves material cost by 20% and save water usage by 60%. In the daily house use, the new insulation layer implemented in CLBT house has good insulation ability and therefore can reduce energy consumption to maintain the indoor temperature, as well as energy cost.

5. POTENTIAL DRAWBACKS OF CLBT BUILDINGS

CLBT structure also have some disadvantages. Firstly, at the current stage, there is no industrial base developed for CLBT yet. Therefore, the price of a CLBT structure house is of the same level of a wooden house for about 900 yuan per square meter, which is more expensive than 790 yuan per square meter of a reinforced concrete houses, in Chinese rural regions. Moth-proof should be specially considered when constructing CLBT houses while reinforced concrete buildings are seldom engaged in this issue. However, in general, it is expected that because the high temperature and carbonation of bamboo in the process of production have eliminated the parasitic eggs and removed nutrients, so that the eggs have no growth environment, which improves moth-proof ability as well. Other issues need to be addressed in future also include the fire proof and durability of CLBT.

5. CONCLUDING REMARKS

Cross laminated bamboo and timber (CLBT) is a composite engineering material with good mechanical properties, light weight, beautiful appearance and outstanding environmental protection ability. The design of low-rise CLBT buildings introduced in this article can be promoted and applied in common low-rise CLBT buildings. Promoting and developing CLBT buildings contributes to prosperity of the society, development of economy and protection of environment. CLBT prefabricated house is applicable to situations where temporary houses are needed, such as makeshift hospital and

accommodation for workers at construction site. Developing CLBT industry stimulates the development of a series of relative industries, including the upstream industries and downstream industries, offer a lot of jobs and therefore promotes the economic development. In addition, CLBT house is sustainable because (a) bamboos can partially substitute wood as an engineering material to protect our forest resources; (b) CLBT products save energy on manufacture process compared with cement, steel and other traditional construction material; and (c) CLBT house has little discharge of pollutants during construction. However, this study is just a fundamental study for the design of CLBT buildings. Future studies such as CLBT buildings constructed under special geological conditions, CLBT structures combined with steel structures, high-rise CLBT buildings and so on remain to be carried out.

ACKNOWLEDGEMENTS

The research described in this paper is sponsored by the SRTP program and the distinguished professorship provided by the Zhejiang University.

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