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Exploration of structure and form of wooden bridge: A Report of 2023 Sino-Canadian Joint Teaching Program on Wooden Bridge Design

Junyi Wang[1] Zhenyu Hu[1] Yawen Cheng[1]

1.School of Architecture, Nanjing Tech University, China

Abstract

The paper reviews the history of the joint teaching of wood structure architecture between the School of Architecture of Nanjing Tech University and the School of Forestry of The University of British Columbia, discusses the content and method of the joint teaching of the design of timber bridges between China and Canada in 2023 in which the author participated, and combines the case study in Canada and the analysis of the winning scheme of the Eighth National Senior Education Schools' Wooden Structure Design Competition, which preliminarily explored the spatial and morphological design of the timber bridges from the perspective of the modern timber structure design, providing new ideas for the reconstruction program of traditional wooden bridges. The results of the joint teaching show that through the field study of the advanced technology of modern wood structure, the international vision of the students has been greatly expanded, and the interdisciplinary research ability and innovative design ability have been obviously improved.

Keywords: wooden bridge; joint teaching; structural thinking; space and form; The University of British Columbia

In recent years, the development of China's wood structure building continues to improve, the relevant state departments on the design, construction and acceptance of wood structure has developed a number of technical standards and norms, many important public buildings and landscape bridges using modern wood structure, space and image is refreshing, energy saving and

emission reduction benefits are obvious. In the face of growing social demand, the relevant universities in China are further increasing the reform of education and teaching, introducing new ideas and new technologies, updating the teaching content, and focusing on cultivating composite talents in wood structure construction to meet the requirements of high-quality development of China's construction industry.

Canada is technologically advanced in wood structure construction, and The University of British Columbia (hereinafter referred to as UBC) located in Vancouver, British Columbia (hereinafter referred to as B.C.), is a world-class university, which is perennially ranked among the top 50 colleges and universities in the world, and the forestry science and other specialties of its forestry school have a great reputation. The School of Architecture of Nanjing Tech University (hereinafter referred to as NJTECH) attaches great importance to the teaching and scientific research of wood construction, and has established a long-term academic exchange and cooperation relationship with the School of Forestry of UBC since 2014, which builds a good international platform for the students of the School of Architecture of NJTECH to learn about the latest progress of modern wood construction and to study the design of modern wood construction.

1 The history and significance of co-teaching in wood construction

1.1 Current situation of teaching wood structure courses in Chinese colleges and universities

Many Chinese colleges and universities have civil engineering and architecture undergraduate majors, and in the curriculum system of architecture majors, basically only the course <History of Chinese Architecture> involves the traditional Chinese wood structure buildings, and there is almost no course about modern wood structure building design. Wooden structure course was originally a traditional course for civil engineering majors, but due to the scarcity of wood resources in China and the cancellation of the course in most schools civil engineering majors for a period of time [1], at present, most of the civil engineering majors are still very little training in the study of wood structure. Some colleges and universities, such as forestry universities, have opened the required courses related to wood structure, but most colleges and universities are still elective courses [2]. In recent years, some colleges and universities have added wood structure building elective courses in the teaching system of graduate students, but due to the small number of class hours and the wide coverage of wood structure knowledge, coupled with the lack of faculty members with wood structure professional background, it is more difficult for students to systematically and deeply learn wood structure building knowledge.

1.2 Joint Teaching History between NJTECH and UBC

Since 2002, the School of Architecture of NJTECH has included the content of timber frame buildings and landscape bridges in the teaching of the graduate <Green Building> course. After 2006, under the guidance of the general direction of green building, NJTECH has worked closely with the School of Civil Engineering of NJTECH, actively explored the teaching, research and engineering practice of timber frame buildings, and successively opened undergraduate graduation design and postgraduate courses of <Development and Application of Timber Frame Buildings>; after 2012, it started academic exchanges with UBC School of Forestry in wood structure, and several teachers went to UBC for training, established a teaching team of wood structure building, and several graduate students' dissertation topics came from the field of wood structure building; since 2017, it has been utilizing the summer time every year to conduct a 3-week Joint teaching in wood construction, each time centered on a small timber building or timber bridge topic. in 2020-2022, due to the new Crown pneumonia outbreak, the joint teaching was held through an online format, and in 2023, the original mode was resumed.

The teaching system of wood structure architecture in the School of Architecture of NJTECH aims to cultivate modern wood structure talents, takes joint teaching and design practice as the way, links the teaching mode of UBC School of Forestry and the application software of different disciplines, combines architecture with forestry science, civil engineering and mechanical engineering, and carries out theoretical lectures, visits and research, program design, disciplinary competitions, and other modules of learning for students guidance [3], with the characteristics of multidisciplinary, internationalization and practice-oriented.

1.3 The significance of joint teaching between NJTECH and UBC

Under the current situation that the teaching of wood structure in domestic universities is relatively weak, as a provincial university, NJTECH is able to carry out regular interdisciplinary and internationalized teaching activities with such a first-class international university as UBC, which is a very successful mode of academic exchanges and cooperation, conducive to broadening the international vision of students and enhancing the ability of designing wood structure buildings; conducive to the introduction of advanced teaching concepts, and to improve the level of teaching and researching of teachers; It is conducive to promoting the cross-fertilization of disciplines and the formation of advantageous characteristic directions. Students participate in joint teaching gains are multifaceted, improve the scientific research ability and creativity, in teamwork with students from other schools to complement each other's strengths and weaknesses, to help and promote each other; interdisciplinary teaching form also avoids students to think about the problem in a single narrow-minded concept [4].

2 2023 Joint Teaching of Wooden Bridge Design in China and Canada

The 2023 China-Canada Wooden Bridge Design Joint Teaching is co-organized by UBC Faculty of Forestry, School of Architecture of NJTECH, School of Architecture of Southeast University, and School of Architecture of Harbin Institute of Technology, and co-organized by Canada Wood. The first stage is the pre-study of wood structure, students are selected by the architecture schools of the above three Chinese universities to do the pre-study of wood structure (buildings and bridges) knowledge, and apply for approval of the procedures for teachers and students to go abroad, etc. The second stage is the teaching of the Sino-Canada Wooden Bridge Design Camp at the UBC College of Forestry, sponsored by the UBC College of Forestry and co-sponsored by Canada Wood, which is combined with the 8th National Higher Education Wood Structure Design Competition. The second phase of the task is to teach the Sino-Canadian timber bridge design camp in UBC Forestry College, sponsored by UBC Forestry College and co-sponsored by Canada Wood. After returning to their home countries, students from each school can continue to work with civil engineering students to analyze, calculate and optimize the structure of the timber bridge in order to complete the final proposal according to the requirements of the competition.

2.1 Timber frame pre-study work

The pre-preparation work of the School of Architecture of NJTECH mainly includes student selection, wood structure knowledge learning and procedures for going abroad. After application and selection by the college, the author finally became one of the members of the 2023 China-Canada Wooden Bridge Design Camp. Architecture students, in their previous courses, paid much attention to the function, space, flow and shape of the building, but little or not enough in-depth study of wood properties and wood structure selection. Therefore, before leaving for UBC, the college provided remedial courses and training on wood structure to the students, and the textbook was chosen to be <Wood Structure Design> (Second Edition) edited by Prof. He Minjuan from Tongji University and Prof. Frank Lam from UBC.

Given the prior knowledge of reinforced concrete structure and structural selection acquired by graduate and senior students majoring in architecture, the instruction on wood structure merely necessitates a comprehensive understanding of basic theory, design methodology, and construction techniques. This encompasses discerning between different types of wood, evaluating the pros and cons of each structural choice, as well as selecting and installing various wooden anchor points. There are no specific demands for intricate calculations pertaining to wooden structures [5].In addition, students also learn the current national wood structure design codes and technical standards, such as <General Code for Wood Structures> GB 55005-2021、

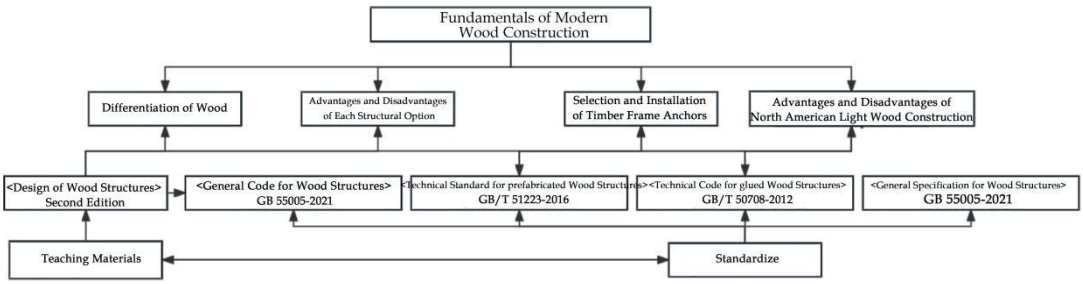

Fig.1 Basic knowledge of modern wood structure
(picture source: self-drawn by the author)

<Technical Standard for prefabricated Wood Structures> GB/T 51223-2016、<Technical Code for glued Wood Structures> GB/T 50708-2012,etc. (Fig.1).Reference books include <New Architecture in Wood: Forms and Structures>① <Modern Wood Architecture Design Basis> ②<History of Science and Technology in China: Bridge Volume>③,etc. In the process of learning, students gradually familiarize themselves with the basic knowledge of wood structure construction, understand the policy change of wood structure construction in China in recent years and the broad prospect of the development of wood structure construction.

In addition to participating in the college's unified training program, since May, under the guidance of the instructor, the author have organized numerous typical cases of wooden structure buildings and bridges in Canada, particularly in BC Province. This has allowed me to gradually become familiar with UBC's relevant campus buildings and professional structures while studying English literature related to wooden architecture, thereby enhancing my oral and professional English expression.

2.2 Teaching contents and methods of wood design camp

Fig.2 2023 Summer Design Camp at UBC School of Forestry
(Photoed by Dr. Kilian Krauss)

From July 20 to August 9, 2023 local time in Vancouver, a total of 16 students and 6 teachers from three Chinese universities participated in the wooden bridge design camp (Fig.2). The teaching content of joint design includes three parts: (1) Study of modern wood structure theory (2) Site inspection of modern wooden structures and Bridges; (3) Modern wood structure design practice. Through the study of the above three parts, combined with the Eighth National Senior Education Schools' Wooden Structure Design Competition, students initially master the design principles and methods of modern wood structures and apply them. Prof. Frank Lam from UBC School of Forestry is responsible for the theoretical course, which mainly includes three parts: The first part is the cognitive introduction course, which discusses the advantages and necessity of applying and promoting modern wood architecture in the context of global warming by analyzing data such as carbon dioxide emission and forest coverage rate. The second part is the system knowledge teaching, explaining how to distinguish different woods, how to choose the appropriate wood materials and joint connection methods, pointing out that the core of modern wood structure construction is glulam and structure selection. The third part is the case analysis and explanation, showing the famous examples of wooden buildings and Bridges in B.C. to the teachers and students. Such as the VanDusen Botanical Garden、Richmond Oval、UBC Brock Commons,etc.The teaching adopts a multi-dimensional interactive way in English, combining theory with practice to stimulate students' innovative thinking and encourage students to explore in the frontier field of modern wood structure.

2.3 Case study of timber construction and bridge

The study of modern wood structure is familiar with the study of architectureal,students need to understand the space entity through a lot of field research, investigation and measurement, so as to apply theoretical knowledge in practice and master the main points of wood structure construction as a whole. Dr. Tom Chao and Dr. Kilian Krauss of UBC led the students and students to visit the famous wooden structures and Bridges on the UBC campus and in the province, such as the UBC NEST, the King's Way Pedestrian Bridge, the VanDusen Botanical Garden Visitor Centre and the Central City of Surrey; Through the explanation and inspiration of the Chinese and foreign teachers, the students opened their structural thinking, comprehensively considered the relationship between structure, space and form, and applied it to the later design competition.

2.3.1 King's Way Pedestrian Bridge

The bridge spans 44m across a major artery in Burnaby, B.C., connecting a large shopping mall with booming commercial and residential areas to the north, and when it was built in 2009, it was believed to be the first bridge in BC to use a combination of long-span wooden arches with steel and concrete (Fig.3). The arch bridge has a post-tensioned concrete walkway suspended by vertical steel tie rods. For economic reasons, the design team used the walkway itself to hold the arch in place to resist the outward thrust and avoid expensive buttresses. The sturdy arch form has an elegant aesthetic appeal.

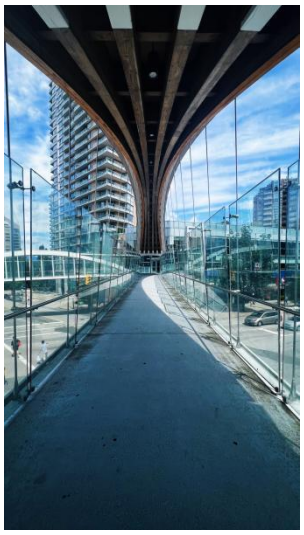

Fig.3 King's Way Pedestrian Bridge (Photoed by the author)

To minimize traffic disruption during the construction process, the design team chose a quick and quiet solution: While construction was underway, the entire timber section of the bridge, including the sheet steel roof covering, was prefabricated in a parking lot near the site, and two cranes were used to lift the assembly into place. The road was closed for only one day, making the construction process convenient and efficient.

2.3.2 VanDusen Botanical Garden Visitor Centre

The visitor centre is located on 55 acres in downtown Vancouver and was completed in 2011. Inspired by the petals of orchids, the concrete walls support a curved, undulating wooden roof that droops seamlessly into the surrounding landscape like a dramatic extension of the garden itself. The design team rationalized the complex geometry of the structure and petal shape by constructing parametric three-dimensional models used to generate manufacturing information to shape each beam. Most of the paneling sections of the roof are tapered, each with its own composite curve, spaced 2.5m to 3.5m apart, forming the longitudinal edges of the paneling

sections.

A cylindrical radiator in the center of the roof (Fig. 4) acts as a solar 'chimney', converting solar energy into convective energy and promoting air flow in the hall. The undulating wooden roof resembles a cluster of orchid petals, with one petal collecting rainwater and the other acting as a solar hot water pipe. These innovative designs have injected new vitality into the garden, which has a history of more than 40 years.

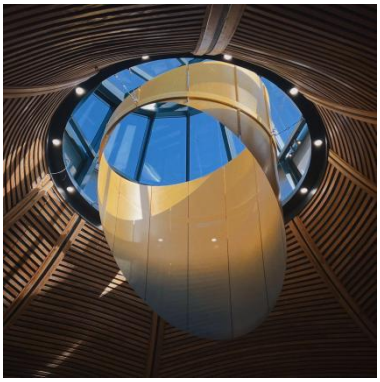

Fig.4 the 'chimney' of VanDusen Botanical Garden Visitor Centre(Photoed by the author)

2.3.3 Brock Commons

UBC Brock Commons student residence Phase I building is 53m high, 18 floors, construction area of 15120m2, completed in 2017. Able to provide 404 accommodation rooms for students, the building combines functional Spaces such as student accommodation, teaching and leisure centers, and was the tallest wooden structure in the world for quite some time after its completion. The structure is made of prefabricated heavy mixed wood: the bottom two floors are made of a concrete podium with a concrete core, and the upper 16 floors are made of heavy wood, with the concrete core running from the ground floor to the top floor. The combination of these materials ensures lateral and vertical seismic stability.

In the design stage of the building, BIM and other design software were used, which significantly shortened the construction period of the wooden structure, and the construction of the wooden structure was completed in only 9.5 weeks, far less than the expected number of days. Its completion is a sign that the high-rise wooden structure is feasible and safe.

3 Wooden structure bridge competition scheme design

After the course study at UBC and the field research in B.C., the teachers and students of the three Chinese universities participating in the joint design teaching, combined with the Eighth National Senior Education Schools' Wooden Structure Design Competition: Reshine of Ancient Bridge -- Reconstruction of Wan 'an Bridge in Pingnan, Fujian Province. Students were required to appliy their knowledge to the design of competition scheme, including preliminary analysis, conceptual conception, form generation, structure selection, joint articulation, etc. Students were divided into groups for the final defense report, and Prof. Frank Lam, Dr. Kilian Krauss from UBC and teachers from three Chinese universities made final defense comments on the project design results.

The theme of this competition is the reconstruction of Wan 'an Bridge. Wan 'an Bridge, also known as Changqiao, Rainbow Bridge and Longjiang Gongji Bridge, is located in Changqiao Changqiao Village, Pingnan County, Ningde City, Fujian Province. It is a wooden arcade house bridge with 5 piers and 6 holes. The bridge length is 98.2m, the width is 4.7m, and the height from floor to water surface is 8.5m. The longest arch span is 15.3m, and the smallest arch span is 10.6m[6]. The bridge was built in the fifth year of Yuanyou in the North Song Dynasty (1090), and has been repaired in subsequent dynasties. Before it was destroyed by fire on August 6, 2022, it had a history of 932 years, and is the longest existing ancient multi-span wooden arch bridge in China (Fig.5). The competition requires the expansion of new connotations on the basis of the original bridge, combined with the local architectural style, natural environment, and humanistic uniqueness, to provide residents and tourists with good access, leisure and functional places, and to examine the students' comprehensive grasp of the three requirements of structure selection, space shaping and beautiful shape.

Fig.5 Pingnan Wan 'an Bridge before it was destroyed by fire (Photo from the 8th National Wood Structure Design Competition)

In the face of the requirements of the competition, the author has repeatedly thought and determined the basic principles of the scheme design as follows: (1) The modern wooden structure is adopted to provide a new scheme for the reconstruction of the historical old bridge with modern design concepts and techniques; (2) Continue the long roof covering style of the old bridge, but add a skylight on the roof to facilitate the passage of pedestrians and stop for viewing; (3) The bridge deck and roof have been burned, but the pier still exists, and its structural safety performance should be identified and evaluated. If it cannot meet the current bridge design standards in our country, it needs to be strengthened or rebuilt.

3.1 Wooden bridge scheme one

In the structure, the glulam triangular brace is used as the main load-bearing member, and the hermitage brace is extended to bear the weight of the roof. The fulcrum of the upper bridge falls on the triangular brace, the lower bridge is suspended by the steel suspension cable, and the upper and lower Bridges are connected by the steel stairs. The bottom of the triangular brace and the concrete pier are connected internally by cross steel plates,

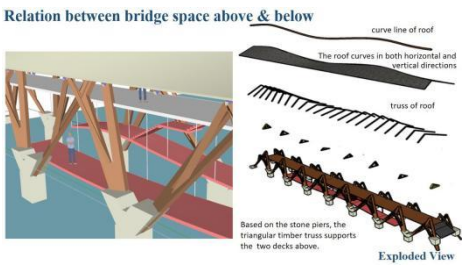

Fig.6 Scenario 1 analysis diagram(Photoed by the author)

and the steel plates are tightly fastened between the struts. The roof forms a free-undulating curved surface both horizontally and longitudinally. The butterfly brace is used as the key load-bearing component connecting with the triangular brace. The size of the butterfly brace varies, and the value of the height and Angle change with the change of the roof ridge, and the corresponding beam length varies（Fig.6).

In terms of space, the upper bridge is flat and straight, mainly for the traffic function; The lower bridge fluctuates regularly, mainly for stopping and viewing functions; The two Bridges are connected to each other, extending the line of sight of the pedestrian when walking. The bridge deck is properly expanded at the viewing point to form a viewing platform, and pedestrians can freely choose the path to cross the bridge. Combined with the bridge floor crossing, the roof forms a gentle curve along the long ridge direction, which is undulating, echoing the landscape and rich in form.

In terms of shape, local residents in Pingnan County have the custom of weaving bamboo strips for sale. The crossed bamboo strips inspired the author's structural thinking, resulting in the concept of using wooden triangular struts as the main structure of the bridge, and distributing them evenly in the middle of the piers. From the facade, the steel cable suspension bridge and the roof are connected in series by triangular braces, making the wooden structure bridge form a stable and solid whole; From the section, the roof ridge, butterfly brace, triangle brace, bridge and pier are clearly layered, and the load-bearing relationship between the components is clear.

This program was well received by the teachers in the final defense of the Sino-Canadian Wooden Bridge Design Camp in 2023 and won the best scheme.

3.2 Wooden bridge scheme two

Structurally, the whole bridge adopts space shaped braided structure with uniform force, and the main part is mainly glulam wood, supplemented by steel as supporting members. The bridge deck and the braided surface form a self-balancing system to control the displacement of the bridge deck and ensure its stability.

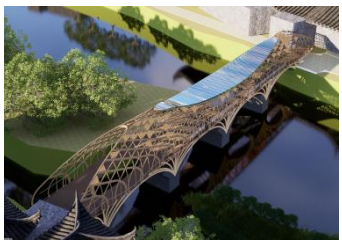

Fig.7 Scenario 2 perspective view(picture source: self-drawn by the author)

Spatially, the passage is the main function, conforming to the change of sight when walking, and the roof undulates accordingly; And reduce the density of pottery in the viewing area to form a viewing entrance; A fish-belly glass skylight is opened on the lowest part of the roof to introduce light, and the blue sky above the bridge and the green water below the bridge are projected on the skylight, which reflects each other. The deck and roof of the bridge as a whole maximize the perception

and experience of pedestrians (Fig. 7).

Modeling, the bridge overall weaving shape inspired by the local residents of the tradition of making bamboo gabions for sale, combined with the East Fujian Demoiselle hats and fishing clothes; the top of the skylight set up for natural lighting, the formation of a dynamic undulating half-wrapped space, but also a metaphor for the swimming fish; wrapped structure and the piers of the bridge piers naturally connected to the natural connection of umbrella-shaped "piers" to support the bridge deck, the deck echoing the weaving shell The bridge deck echoes the woven shell with regular undulations, and is partially divided into two strands, forming a good viewpoint; the skin is made of ceramic pieces and glass parapets, following the undulating bridge deck, with the ceramic pieces densely packed on top and sparsely packed on the bottom (Fig. 8).

The program won the merit award in the the 8th National Wood Structure Design Competition.

The above two proposals, starting from the characteristics of modern timber structure, shape a new bridge space and form, trying to present the technological power and aesthetic interest of the 21st century. As a student's proposal, there are still many immature points, but we hope that on the basis of respecting the historical tradition and regional culture, we can provide an innovative design idea based on modern timber structure technology for the reconstruction of Wan'an Bridge.

Fig.8Scheme 2 North Elevation(picture source: self-drawn by the author)

Conclusions

The 2023 China-Canada Wooden Structure Design Joint Teaching was conceived at the beginning of the year, and was successfully held at UBC in the summer under the joint efforts of UBC, Nanjing University of Technology, Southeast University and Harbin Institute of Technology, etc. As one of the teaching achievements, the student's design plan was adjusted and optimized, and then participated in the Eighth National Higher Education Schools Wooden Structure Design Competition in December, and gained a better result. As a student who participated in the whole process, the author was deeply rewarded, and here I would like to

record and discuss the results, which are summarized as follows:

(1) By participating in the 2023 Joint Teaching on Wooden Bridge Design among Four Universities in China and Canada, students from the School of Architecture of NJTECH have learned the international advanced wood structure technology on the ground in Canada, expanded their academic horizons, and enhanced their interdisciplinary research ability and innovative design level.

(2) Combined with the 8th National Wood Structure Design Competition, based on the safety, durability and plasticity of modern wooden structures, a new research idea and design scheme for the reconstruction of the Wan'an Bridge in Pingnan, Fujian Province, which has a certain reference value, has been provided.

(3) In the face of the good situation of the development of wood structure architecture in China, the relevant universities and colleges specialized in civil engineering and architecture disciplines have continued to promote the teaching reform, strengthened the international cooperation and exchange, carried out the multi-college joint teaching, and accelerated the cultivation of composite wood structure architectural design talents, which has been very effective.

Marginal Notes:

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