

Technical Paper

A Comparative Study on the Construction Techniques of Covered Bridges in Northeast Fujian and the Dong Ethnic Group in Western Hunan

Mengxin Chi

College of Art and Design, Jimei University, Xiamen 361021, Fujian, China; 202411130004@jmu.cn

Received: Mar 09, 2026; Revised: Apr 16, 2026; Accepted: Apr 16, 2026; Published: Jun 30, 2026

Abstract: Covered bridges in northeastern Fujian and those of the Dong ethnic group in western Hunan share the same system but feature distinct core structural techniques, rooted in the craftsmen's value expressions, technical inheritance, and practical innovations. Focusing on craftsmen, this study combines fieldwork and literature analysis to compare their heavy timber structures: the Dong's bridges adopt laminated wooden arch beams and cantilever bracket simply supported beams, embodying environmental adaptation wisdom; those in northeastern Fujian achieve long-span breakthroughs via woven wooden arch technology, reflecting technical innovation. Through typical case studies, this paper argues that such structural differences essentially manifest humanistic values rather than mere technical rationality, aiming to deepen understanding of the complexity of China's traditional wooden bridge technical lineage and highlight craftsmen's core role in traditional architecture.

Keywords: Northeastern Fujian, Dong Ethnic Group in Western Hunan, the covered bridges, Construction techniques, Timber architecture

1. Introduction

Covered bridges, also known as Fengyu bridges or house bridges, are a unique type of bridge characterized by the construction of covered corridors over the bridge structure. They serve diverse functions, including transportation, rest, social interaction, and ceremonial purposes. In the history of world bridge architecture, covered bridges are among the most distinctive examples of traditional Chinese timber-framed bridges, celebrated for their intricate structure, elegant design, and multifunctionality, often hailed as "living fossils of bridge engineering." The number of surviving covered bridges in China is limited. In Fujian Province, these bridges are mainly concentrated along the Fujian-Zhejiang border, particularly in northeastern Fujian, such as Shouning and Pingnan. According to data from the Third National Cultural Relics Survey, there are 167 surviving covered bridges in Nanping City, Fujian Province. Additionally, the Dong ethnic region is home to the largest concentration of covered bridge architecture in China. As recorded in "Ancient Covered Bridges of Hunan", Hunan Province currently preserves approximately 368 covered bridges. Although the Fengyu bridges of northeastern Fujian and those of the Dong ethnic group in western Hunan both belong to the covered bridge system, they exhibit distinct regional differences in structural techniques, material choices, and cultural expression.

Fujian wooden arch corridor bridges represent the most technically sophisticated category among China's traditional timber-framed bridges. Over a hundred such bridges survive today, primarily distributed in the mountainous regions of northeastern Fujian. Among them, the Ningde area boasts 51 such bridges, while Shouning County has earned the title "Hometown of World Through-Type Wooden Arch Corridor Bridges" due to having the "largest number, the longest single-arch spans, and the most complete chronological sequence of construction." Academic research in this field has evolved into a multidimensional and interdisciplinary system. Dai Zhijian's "Chinese Corridor Bridges" provides a macroscopic analysis of the typology, regional distribution, and cultural value of wooden arch corridor bridges, establishing the core paradigm for typological studies. Relying on extensive fieldwork, Gong Difa documented firsthand information on over 200 ancient corridor bridges in Shouning and multiple areas of Fujian and Zhejiang, collecting precious bridge contracts and compiling works such as "Survey Report on Fujian Wooden Arch Bridges". Liu Yan, from the perspectives of architectural archaeology and cross-cultural studies, authored monographs like "Woven Wooden Arch Bridges: Technology and Social History", showcasing the exquisite construction techniques and the dissemination of technology, while revealing the underlying logic of traditional timber structures in adapting to local conditions. In the fields of construction technology and documentary research, Xue Huaigang focuses on three types of documents—bridge contracts, design drawings, and ink

inscriptions on beams—analyzing traditional construction thinking and spatial cultural representation through fieldwork and textual research. Zhang Ying constructed a model of a single-span wooden arch corridor bridge, conducting an in-depth analysis of the mechanical characteristics of components such as "sanjie miao" and "wujie miao," and their relationship with the bridge structure. He proposed a two-dimensional planar mechanical decomposition model. Yang Yan and Chen Baochun surveyed the core parameters of 130 wooden arch bridges in Fujian and Zhejiang, noting their technical connection to the Rainbow Bridge of the Bian River and highlighting the limitations of existing analytical methods. In terms of conservation and transmission research, Liao Jin focuses on the impact of tourism development on corridor bridges in northeastern Fujian, proposing sustainable transmission strategies such as strengthening conservation awareness, improving mechanisms, and deepening technological research to advance conservation studies from advocacy to practical implementation.

The Fengyu Bridge (Wind-and-Rain Bridge) of the Dong ethnic group in western Hunan serves as both a core vehicle of Dong architectural culture and a regional cultural symbol of western Hunan, with a rich foundation of academic research on the subject. Wu Hao's "The Architectural Treasures of China's Dong Ethnic Group—Drum Towers and Fengyu Bridges" provides a detailed introduction to the architectural forms, construction techniques, and central social role of Dong Fengyu Bridges in western Hunan and other regions, establishing a macro-level research framework and laying the groundwork for categorical studies. Liu Hongbo's "The Architecture and Culture of Dong Fengyu Bridges", based on fieldwork and primary materials, traces the historical evolution, cultural connotations, and construction techniques of Fengyu Bridges across Hunan, Guizhou, and Guangxi, clarifying their stylistic classifications and development, thereby filling gaps in specialized research on western Hunan. In the field of specific structural research, scholars such as Li Xuemei have integrated anthropological methods with fieldwork to explore the cultural inheritance, craftsmanship techniques, measurement systems, and construction rituals underlying the building of Fengyu Bridges in western Hunan, revealing the cultural significance of tools like the "jianggan" (craftsman's rod) and related rituals. Zhang Ying, drawing on semiotics, highlights the dual role of these bridges as both practical connectors in geography and symbols of ethnic identity, giving tangible form to the historical memory and emotional attachment of the Dong people. Luo Weili focuses on ecological aesthetics, proposing that their construction embodies the philosophy of "conforming to nature" and explores pathways for innovation and transmission. Jiang Weiping delves into decorative arts, systematically explaining related techniques and artistic characteristics, using the Tongdao Huilong Fengyu Bridge as a case study to analyze design and component decoration, pointing out its dual function as a religious site and a space for ethnic order. Jiang Guojing and Cai Xinping conducted specialized research on the Zhijiang Longjin Fengyu Bridge, enriching the corpus of case-specific studies. Additionally, Zhao Qiaoyan reviews the current state of research on traditional Dong architecture, clarifying the systematic positioning of Fengyu Bridges in western Hunan and outlining future research directions. Zhang Xiaochun's case study on the drum tower of Yanglan Village in Tongdao, with its analytical framework linking "architectural spatial language—cultural concepts" offers methodological insights for understanding the connection between Fengyu Bridges in western Hunan and the Dong worldview, demonstrating the symbiotic relationship between the two within the Dong architectural cultural system.

These studies have verified the respective technical values and cultural connotations of the two types of bridges. In view of existing research, however, there is a lack of specialized discussion from cross-cultural and cross-regional perspectives on the root causes of differences in their construction techniques, the evolutionary logic of their cultural connotations, and the adaptability of conservation strategies. Furthermore, insufficient attention has been paid to the dominant role of people in the construction of corridor bridges. Craftsmen are the central actors in bridge construction.

Accordingly, I argue that the differences in construction techniques between the corridor bridges of the two regions are not merely technical divergences. Essentially, they result from the combined effects of the value orientations, craft inheritance, practical wisdom, and regional demands of craftsmen and builders as the main agents of construction. The structural particularities and technical uniqueness of the bridges originate from the flexible value expression and practical creation endowed by people during the construction process. Therefore, this paper focuses on a comparative study of timber arch corridor bridges in northeastern Fujian and Dong wind-and-rain bridges in western Hunan. Using methods including textual research and comparative case studies, it takes craftsmen and builders as the core entry point to explore the key differences and internal connections between the two bridge types in their technical systems, cultural connotations, and conservation requirements. It reveals the core value of human agency in the construction of traditional timber corridor bridges and demonstrates the regional diversity and cultural integration embodied in such structures. In doing so, it aims to provide more universally applicable theoretical support and practical approaches for the conservation of timber architectural heritage.

2. Methods and Materials

Based on the research hypothesis that “the differences in the construction techniques of wind-and-rain bridges in the two regions are essentially different solutions shaped by the value orientations, craft inheritance models, and cultural choices of craftsmen as the main actors in construction”, this study adopts a comparative case study method and purposive sampling.

It selects Puji Bridge in Tongdao County, Hunan (a representative of the Dong stacked cantilever type) and Luanfeng Bridge in Shouning County, Fujian (a representative of the interlocked timber arch type in northeastern Fujian) as core comparative cases, supplemented by an integrated analysis of other wind-and-rain bridges in both regions.

This methodological framework is employed because comparative case studies can effectively control common variables such as natural conditions and material properties, thereby focusing on the subjective role of people in the construction process. Purposive sampling ensures that the selected cases are typical and comparable, helping to reveal the cultural origins of the technical differences between the two types of wind-and-rain bridges.

In practice, this study comprehensively uses literature research, image analysis, and physical comparison. Relying on recorded interviews with master craftsmen from existing literature, it gradually distinguishes the interactive boundaries among environment, materials, and cultural choices.

It should be noted that no independent fieldwork was conducted in this study. All case data, master craftsman interview records, and technical details are derived from publicly available academic literature, local cultural relics survey reports, architectural heritage investigation reports, and publicly accessible bridge images and surveying data. The sources and types of materials are cited at appropriate locations in the text to ensure traceability.

3. Results

3.1 Comparative Study of Construction Techniques

3.1.1 Material Selection

Northeastern Fujian is located on the southeast side of the northern section of the Wuyi Mountains. The terrain is characterized by high mountains, dense forests, and crisscrossing streams and ravines. The region has a subtropical maritime monsoon climate with an average annual rainfall of 1,684–1,780 millimeters. The core materials for local covered bridge construction are Chinese fir and granite: Chinese fir is used for the wooden structural parts of the bridge, while granite is applied to load-bearing structures such as bridge piers and foundations. Due to the relatively high costs of quarrying, transportation and construction, craftsmen rarely used granite due to cost in local covered bridge building.

The Dong-inhabited area of western Hunan lies at the intersection of the northeastern edge of the Yunnan-Guizhou Plateau and the southern side of the western Hubei mountains, dominated by mountainous and hilly landforms. It features a subtropical humid monsoon climate with abundant rainfall in spring and summer, and dry, cold weather in autumn and winter. Local covered bridge construction follows the principle of using local materials, mainly employing Chinese fir and locally quarried bluestone and granite. Chinese fir is used for wooden structural members such as beams and columns in vernacular dwellings and covered bridges, while bluestone and granite are used to build bridge piers. All stone piers and abutments are designed with water-dividing tips, suitable for construction in rivers prone to seasonal flooding.

3.1.2 Main Span Heavy Timber Construction Technique

Dong Ethnic Group

The bridge erection techniques for Dong ethnic Fengyu Bridges (Wind-and-Rain Bridges) are diverse. The more traditional approaches mainly include three types. The first is for smaller-span Fengyu Bridges, often built over streams or creeks, which typically involve directly placing several large logs on abutments as beams—a relatively simple technique. The second uses square-cut stones to construct arched beams, forming stone-arched beam bridges. The third involves inserting multiple rows of logs diagonally into the abutments, extending them layer by layer to form an arch, and then placing cantilever simply-supported beams on the wooden arch, known as the stacked wooden arch beam technique. The fourth method involves first laying multiple layers of logs on piers as bracket beams and then installing cantilever simply-supported beams between the upper layers of bracket beams, which is architecturally referred to as a densely arranged cantilever bracket simply-supported beam system. However, this paper primarily focuses on the two structures that are predominantly wooden in construction.

Stacked wooden arch beam is an important structural type in traditional Chinese timber bridges, also known as the cantilevered inclined beam type. Its construction technique primarily relies on timber as the core material, employing a method that combines "stacked timber projection" and "mortise-and-tenon joints" to form a stable structural system. This technique involves embedding

multiple rows of assembled logs diagonally into the abutments on both banks, with pebbles used for support at the base. The logs extend outward layer by layer, with each layer's inclination and length corresponding to one another, thereby forming an arch spanning the river. One or two layers of cantilever simply-supported beams are then erected atop this arch. The arch serves both to reduce the span of the main beams. The use of such wooden arch bridges is closely related to the span of the river channel, as this structure is not feasible in areas where the river surface is too wide. In Dong ethnic regions, surviving bridges employing this construction technique are rare. To date, only two bridges confirmed to utilize this structure have been identified, both located in Pingtan Township, Tongdao Dong Autonomous County, Hunan Province.



Fig. 1. Stacked Wooden Arch Beam Structure of Puji Bridge in Pingtan Township, Hunan.

Cantilever bracket simply-supported beams, also known as single or double-direction cantilever beams, are constructed by arranging several large logs into rows. Grooves are carved at the ends of the logs, and horizontal timbers are embedded into these grooves to connect them into rows. Multiple rows are then stacked on piers or abutments, separated at regular intervals by horizontal timbers, with each layer extending outward to form bracket beams, typically in two to three layers. On the ends of the uppermost bracket beams, cantilever simply-supported beams, or main beams, are erected. The cantilever simply-supported beams are composed of several large timber planks connected into rows, using the same joining method as the bracket beams, and can be either single-layered or double-layered. The arrangement of bracket beams reduces the span of the main beams (cantilever simply-supported beams). Depending on the span, the number of layers of bracket beams varies accordingly. The length of the uppermost bracket beams is typically about one-third longer than that of the lower layers, increasing progressively with each layer.



Fig. 2. Cantilever Bracket Simply-Supported Beam Structure of Huilong Bridge in Pingtan Township.

Northeastern Fujian

Chinese timber arch bridges originated in the Kaifeng area during the Mingdao period of the Northern Song Dynasty. Through dissemination and development, woven timber arch bridges can be categorized into two structural types. Two types of woven timber arch bridges exist: the Bianshui Rainbow Bridge and the Fujian-Zhejiang Timber Arch Bridge. This paper discusses the latter. One is the Rainbow Bridge, widely used in the Central Plains of the Northern Song Dynasty, known as the "Bianshui Rainbow Bridge." The other is the timber arch bridge currently found in Fujian and Zhejiang, referred to as the "Fujian-Zhejiang Timber Arch Bridge." The distinction between the two lies in the fact that the Bianshui Rainbow Bridge does not feature a corridor structure, whereas the

Fujian-Zhejiang Timber Arch Bridge is consistently built with a corridor structure (Wu, 2008). This paper primarily discusses the latter type of woven timber arch structure found in northeastern Fujian.



Fig. 3. Woven Wooden Arch Structure of Wan'an Bridge in Pingnan

The woven timber arch uses nearly raw, straight logs assembled via mortise-and-tenon joints. This assembly primarily revolves around mortise-and-tenon joints, forming a stable load-bearing system through the construction of various components. The core process includes constructing the arch frame, installing the “scissor miao” (cross-bracing members), and setting the bridge plank “miao” and “horse legs” (support elements).

Constructing the arch frame is critical to establishing the load-bearing structure of the arch. After the abutments are built, the “sanjie miao” (three-section members) structure must be installed—the first structural system of the bridge. This begins with placing the “sanjie miao” base (known as “dianqiao mu” for timber bridges or “dianqiao shi” for stone bridges). The lower end of the inclined “sanjie miao” is carved with a concave notch called “yazuijia” (duckbill tenon), while the upper end is shaped into a dovetail tenon. After hoisting into position, a transverse “da niutou” (large bull head) is installed at the upper end, the lower end is inserted into the base, and the upper end is half-tenoned into the “da niutou”. Subsequently, the horizontal “sanjie miao” is driven in from top to bottom, connected to the “da niutou” via a dovetail tenon to form the primary load-bearing skeleton.

Next, the “wujie miao” (five-section members)—the second structural system of the bridge—is installed. A “dianqiao mu” is placed in the angle formed by the “sanjie miao” and the “jiangjun zhu” (general pillar). The lower inclined “wujie miao” interlocks alternately with the inclined “sanjie miao”, with its lower end pressing against the “dianqiao mu” and its upper end inserted into the “xia xiao niutou” (small lower bull head). The upper inclined “wujie miao” is connected at its lower end to the “xia xiao niutou”, passes beneath the “da niutou” at its upper end, extends above the horizontal “sanjie miao”, and is fitted with a “shang xiao niutou” (small upper bull head). Finally, the horizontal “wujie miao” is driven in, interlocking the two systems to form an integral, stable statically indeterminate structure.

If described in terms of warp and weft, the “miao” (members) represent the warp, while the “niutou” (bull heads) represent the weft. “Jiangjun zhu” are erected on both sides of the abutments, either as through-pillars or half-pillars, with beams spanning between them to support the subsequent laying of bridge planks. To enhance lateral stability, one or two sets of “jian dao miao” (scissor members) are installed, tenoned between the “jiangjun zhu” and the “niutou” components. Cross-joints are reinforced with iron fittings, effectively reducing bridge sway.

Finally, the bridge plank system is laid. “Ma tui” (horse legs) are set on the arch frame, with short timbers inserted into the “xia xiao niutou” on both sides beneath the beams, and fir logs connecting to the “jiangjun zhu”. The bridge plank “miao” are placed atop the beams, with one end connected to the “shang xiao niutou” and the other to the beams of the “jiangjun zhu”, after which bridge planks are laid to complete the deck.

Notably, the “miao” system is not limited to a single numerical combination; variations such as “sanjie miao + sanjie miao” or “sanjie miao + sijie miao” exist, with specific applications determined by practical considerations such as terrain and span.



Fig. 4. Puji Bridge in Pingtan Village, Pingtan Township, Tongdao County, Huaihua City, Hunan Province.



Fig. 5. Luanfeng Bridge in Xiadang Village, Xiadang Township, Shouning County, Ningde City, Fujian Province.

A comparative analysis is conducted using two typical cases: the Puji Bridge of the Dong ethnic group in western Hunan and the Luanfeng Bridge in Shouning, Fujian. Both are the wind-and-rain bridges with the largest spans in the region, and both are typical surviving examples of traditional Chinese wooden arch bridges, and in terms of material usage, they primarily employ locally sourced fir wood as the core material for bridge construction. They employ different structural systems. Located in the Wuling mountainous area, the Puji Bridge adopts a stacked wooden arch beam structure, using layered fir beams to adapt to the valley terrain, forming an integrated "bridge-and-corridor" form. In contrast, the Luanfeng Bridge is situated in the mountainous region of eastern Fujian. To cope with rapid water flow and wide river channels, it employs a "woven beam wooden arch" structure, constructing large-span arch frames with fir arch ribs interconnected through mortise-and-tenon joints.

Name	Span	Timber	Bridge Structure	Timber Specifications	Processing Technology	Processing and Assembly Methods	Comparative Conclusions
Xiangxi Tong Ethnic Pujing Bridge	Single span, 19.8 m	Chinese fir	Cantilevered timber arch	<ul style="list-style-type: none"> Abutment Load-bearing Sleepers: Seven round Chinese fir logs are placed horizontally on the riverbank abutment. The diameter of a single log is not clearly recorded, but it needs to bear the weight of the three-jump laminated timbers. Cantilever Beam Components: Each jump of laminated timbers uses an entire round Chinese fir log, which is hard in texture and free of cracks; the length of a single log increases with the overhang amplitude. Joint Load-bearing Timbers: Eight round Chinese fir logs are laminated at the joint of the east and west arch shoulder frames, serving as the core load-bearing components of the arch top, with diameters matching the sleepers. 	<ul style="list-style-type: none"> Timber Debarking and Rough Trimming: All load-bearing Chinese fir timbers are naturally dried to remove moisture, so as to reduce later deformation; the surfaces are polished smooth to remove burrs. Timber Lamination Slotting: Precise slots are cut at the lamination positions of cantilever beams according to the timber diameter, ensuring that the laminated timbers fit closely without loose gaps. Consolidation Processing: The round timbers at the joint adopt the traditional Dong nationality "column-holding and beam-clamping consolidation method". Grooves are chiseled on the contact surface between the beam timbers and the round timbers, and fixed by driving wooden wedges, without metal components. 	<ul style="list-style-type: none"> Abutment Construction: The foundation is built on the natural soil mound along the riverbank, reinforced by laying stone blocks externally. Seven sleepers are placed horizontally as the force-bearing base; two-fifths of each sleeper is cantilevered out, and large pebbles are placed at the root for counterweight, forming a 45° inclined surface force-bearing fulcrum, adopting the technique of "pressing wood with stone". Cantilever Arch Assembly: Starting from the sleepers, the traditional "laminated timber jumping" technique is adopted. Three jumps are constructed symmetrically at both the east and west ends, and the number of laminated timbers in each jump decreases layer by layer. The arch shoulder support is formed through the self-weight of the timber and the laminated friction, without the need for additional load-bearing components. Arch Top Closure: At the joint of the cantilever beams from both ends to the arch top, 8 Chinese fir logs are laminated for connection, forming an integral arch frame through the consolidation method. Short timbers are laid horizontally on top as the bridge deck keel, realizing the force-bearing system of "wood bearing wood and wood fixing wood". 	<p>In terms of structural adaptation, the laminated timber arch beam of the Xiangxi Tong Ethnic Pujing Bridge is more suitable for medium and small spans, with a simple structure, reflecting the practicality and flexibility of Dong wooden structures; the woven timber arch beam structure of the Shouning Luofeng Bridge is designed for large spans, with a relatively complex structure and higher durability, showing a technical breakthrough in the construction of traditional wooden structures for large spans.</p>
Shouning Luofeng Bridge	Single span, 37.6 m	Chinese fir, Masson pine	Woven timber arch	<ul style="list-style-type: none"> Bridge Foundation: Pine pile foundations with a diameter of 40 cm are adopted, with a depth of 6 meters into the soil. A 50 cm thick gravel cushion is arranged on the top of the piles to evenly transmit force. Arch Rib Components: Each arch rib is accurately calculated, and its cross-sectional dimensions are determined according to the bridge span and load. The common cross-sectional height is between 25 and 40 cm, and the width is between 15 and 30 cm. 	<ul style="list-style-type: none"> Pile Foundation Treatment: Pine piles are tapered, driven into the riverbed, and coated with tung oil for corrosion protection. Horizontal Measurement: The "bamboo trough leveling method" is adopted, using bamboo tubes filled with water to calibrate the height of both banks with the water surface as the benchmark. Component Hoisting: Wooden winches and hemp ropes are used, with manual command and positioning. Tenon-and-Mortise Connection: Chiseled by hand with millimeter-level precision to achieve a seamless fit. 	<ul style="list-style-type: none"> Abutment Construction: Dense pine pile foundations are driven under the south abutment to form a pile foundation for bearing the weight of the abutment; the north abutment is chiseled and built using natural cliffs to reduce the usage of artificial pile foundations. Composite Arch Frame Support: A parallel composite structure of "three-fold arch + five-fold arch" is adopted. The three-fold arch serves as the main load-bearing system to bear most of the load, while the five-fold arch assists in force bearing. The two are connected with tenon-and-mortise joints through horizontal beams to form a three-dimensional support network. Abutment Connection: Both ends of the arch frame are embedded into the reserved notches of the abutment, and the notches are filled with wooden wedges for reinforcement, making the arch frame and the abutment form a rigid connection to disperse the supporting force to the foundation. 	<p>Although the two are significantly different, neither relies on metal components. Both adopt traditional connection methods such as tenon-and-mortise joints or wooden wedge consolidation, and the bridge components are standardized. They are typical technical paradigms displayed by traditional timber arch covered bridges to meet different span requirements.</p>

Table 1. Comparison Between Puji Bridge and Luanfeng Bridge.

In terms of materials and specifications, the Puji Bridge primarily uses whole, rounded fir logs. Seven horizontally arranged fir logs serve as the bridge foundation sleepers, with the length of the cantilever beams progressively increasing as they extend outward. The arch crown is closed using eight fir logs, with diameters matching those of the sleepers. In contrast, to accommodate its large span, the Luanfeng Bridge incorporates pine pile foundations. Its arch ribs feature standardized cross-sections measuring 25–40 cm in height and 15–30 cm in width to suit load requirements. Regarding processing techniques, the Puji Bridge employs natural drying to remove the outer layer of fir wood and prevent deformation. The cantilever beams are precisely grooved to ensure a tight fit, and the closure section uses the "column-clamping beam consolidation method." The Luanfeng Bridge, on the other hand, utilizes millimeter-precision mortise-and-tenon connections between components. Its pine pile foundations are tapered and coated with tung oil for preservation. The "bamboo leveling method" is employed to calibrate heights, while wooden winches are used for hoisting during construction, achieving precision in both processing and assembly. In terms of structural composition, the Puji Bridge uses "stone weights on timber" as its foundation and adopts the "stacked timber projection" technique to form a three-tiered cantilever arch. After stacking fir logs at the arch crown for consolidation, short timbers are laid as bridge deck joists. The Luanfeng Bridge employs pine pile foundations on its southern side and leverages a cliff for the abutment on its northern side. It uses a parallel combination of "sanjie miao and wujie miao", with the arch frame embedded into slots in the abutments and reinforced with wooden wedges, creating a three-dimensional support system tailored for large spans.

3.1.3 Artisan Tools and Inheritance Mechanisms

Craftsmen engaged in traditional architectural construction in the Dong areas of western Hunan are known as 'zhangmoshi' (masters of the ink line), referring to those who master the ink marker. Proficient in the entire architectural construction process, 'zhangmoshi' can independently take charge of projects and also perform cost accounting duties, including verifying material quantities and formulating detailed material specifications.

In the Dong region, craftsmen are referred to as 'Zhangmoshi.' Their responsibilities include overseeing the entire construction process, from material preparation to final assembly. No written drawings are used; instead, tools such as the ink pot, jianggan, and

bamboo slips serve as the primary media for design and measurement. They also take on cost-accounting responsibilities, which include determining material quantities and preparing detailed lists of required materials.



Fig. 6. Ink Pot.



Fig. 7. Staff Rod.



Fig. 8. Bamboo Slip Ruler.

In the past, Zhangmoshī (master builders) carried out design and construction without relying on drawings. Their work primarily depended on traditional tools such as the ink pot, jianggan (craftsman's measuring rod), and bamboo slips. The Dong carpenter's ruler was created based on the physical dimensions of the Zhangmoshī's body. Its measurement system consists of three basic types of carpenter's rulers: the Luban foot ruler, approximately 30–32 cm in length; the jianggan, about 3 meters long; and the mortise-and-tenon bamboo slip ruler, each slip measuring around 33 cm in length. Local craftsmen used different Luban rulers for constructing buildings within their respective communities (Li et al., 2018). The ink pot plays a crucial marking role in the construction process of Dong wooden architecture. The accuracy of the ink lines drawn directly affects whether the mortise-and-tenon joints between various structural components can fit together precisely. The jianggan, also known as the staff rod or xianggan, is typically made from half of a southern bamboo culm. Its length is determined by the height of the building under construction, while the markings on it are based on the Luban foot ruler used by the Zhangmoshī. This allows dimensions to be selected from the auspicious measurements prescribed by the Luban ruler to fulfill positive symbolic intentions. The jianggan functions as a large, specialized ruler for the Zhangmoshī, serving both as a blueprint and a measuring tool. "Bamboo slips" refer to the mortise-and-tenon bamboo slip rulers. These slips bear inscriptions written in the Zhangmoshī's script, which serves as the primary medium for this notation system. Each slip records the orientation and mortise-and-tenon specifications of individual wooden components. Although Zhangmoshī did not work with drawings, they typically began by creating small-scale models to complete the design phase. They then used the "staff rod" and "bamboo slips" to manage the construction process.

Unlike the Dong craftsmen, those who build wind-and-rain bridges in northeastern Fujian work in groups and have formed a specialized construction system consisting of bridge sponsors, director organizations, and bridge-building craft guilds. The bridge sponsor serves as the initiator of the project. The director organization is composed of local residents who participate in deliberation and donation. It signs a written bridge contract with the bridge-building guild, clarifying the duties of the sponsor, construction materials, bridge dimensions, wage payment, breach clauses, folk rituals, and other relevant matters. Carpenters are the primary builders of these bridges. In Fujian, they usually form groups based on family alliances, such as the craftsmen from Xiajian and Kengdi. Through continuous inheritance, these groups have developed into distinguished bridge-building families with their own characteristics. Carpenters are further divided by roles, generally including chief rope (chief ink master), deputy rope (deputy ink master), supervisor rope, deputy master, assistant, carpenter, wood technician, and arch bridge technician. The chief rope or chief ink master acts as the main designer and constructor of the bridge (Shen, 2020). They master the core technical knowledge of bridge construction, which is only passed down within one or two closely related families by blood and marriage. Such families maintain a leading position in the alliance and are responsible for organizing carpenters to fabricate and install wooden structural components. They also maintain timely communication and coordination with stonemasons for pier construction, tilers for roof tiling, wood carvers, porters, and other craftspeople to ensure the smooth implementation of the traditional construction techniques of timber arch bridges.

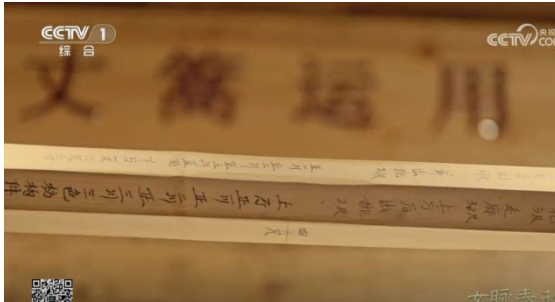


Fig. 9. Zhang gao.



Fig. 10. Mu cha ma.

The technique of constructing wooden arch corridor bridges follows strict principles, often summarized as the "Five Methods of Carpentry": "In work, the square is measured by the "ju"(try square), the circle by the "gui"(compass), straightness by the "sheng" (ink line), verticality by the "xuan" (plumb bob), and levelness by the "shui" (water level)." Consequently, the tools used by carpenters in bridge building are specific and varied. The Luban ruler is employed during the construction of wooden arch bridges, and a special type known as the "zhanggao" is used—a measuring stick imbued with symbolic significance. Typically rectangular in shape, its length varies by region but often aligns with auspicious numbers such as 1, 6, or 8. Each bridge has its own "zhanggao", which is placed beneath the bridge upon completion. The ink pot, also called "xianmo" or "shengmo", is the source of the title "zhumo" (chief ink) for the inheritors of wooden arch bridge construction techniques. It is primarily used for drawing long straight lines, making markings, or creating vertical lines. The plane, referred to as "tuidao" (pushing knife) in eastern Fujian, consists of a blade and a body. The saw is mainly used for processing wooden components, particularly for cutting timber. The chisel is one of the primary tools for traditional wooden joinery, used for carving holes, hollowing, and grooving wooden parts. The hammer, often a large wooden mallet in wooden arch bridge construction, is used in beam-raising ceremonies, serving a ritualistic function. The axe is specifically used for felling trees and chopping timber. In heavy timber construction, two types of knives are commonly used: the chopping knife and the file knife. The wooden sawhorse ("muchama") and the "qiao" (workbench) are essential. The wooden sawhorse is a simple frame made by crossing two fir logs about one meter long, with a wooden rod passing through the intersection to support timber and serve as a work platform for heavy timber construction.

The "qiao", also known as "qiaoban" or "chaiqiao", is an indispensable work platform in heavy timber construction. Typically made from a fir plank about 30 cm wide, 3 meters long, and 10 cm thick, a 50 cm-long log segment with a deep groove is inserted at one end. Additionally, square or triangular wooden wedges of varying thicknesses are used to clamp wooden components during planing and fabrication. The "qiao" is always used together with two wooden sawhorses to form the work platform for constructing heavy timber components (Traditional Construction Techniques, 2025).

3.1.4 Construction Process

The construction process of the Dong ethnic Fengyu Bridges (Wind-and-Rain Bridges) begins with selecting the bridge site, followed by the preparation of tools by the Zhangmoshī (master builder), such as the jianggan (craftsman's measuring rod) and mortise-and-tenon bamboo slip rulers. Once the tools are ready, the formal stages of material selection and bridge construction commence. The site for a Fengyu Bridge is typically chosen at the outlet of the river in front of the village, though a few are built within the village itself or at the inlet of the river at the village entrance (Cheng & Xiao, 2017). The materials for the bridge are predominantly solid timber. Load-bearing components of the bridge structure are generally made from thick, sturdy logs, which undergo minimal processing to preserve their natural shape and mechanical properties. Columns and beams for the bridge house are usually selected from straight, rounded fir trees grown in shaded mountain areas and of older age. Components such as brackets and planks are typically made from the heartwood of fir trees. After material selection, the fabrication of bridge components begins. A Fengyu Bridge consists of hundreds to thousands of different components, and accurately marking each one is crucial to avoid errors during processing and subsequent assembly. The Zhangmoshī has developed a unique spatial identification system for this purpose. Timber processed into components is determined by the type of component and its required mechanical performance, ensuring maximum efficiency in material usage (Liang, 2024). Once component fabrication is complete, the stage of heavy timber construction begins. This phase includes building the bridge foundation, erecting the bridge structure, and constructing the bridge house. The foundation construction stage often proceeds simultaneously with component fabrication. The foundation consists of abutments and piers, with abutments typically built from layered stone slabs. Pier construction methods vary, such as the long stone embankment method, the sleeper log foundation method, or the wooden pile fence stabilization method, with the specific choice

made by the Zhangmoshi. After the foundation is completed, the erection of the bridge structure begins. The Zhangmoshi assigns different craftsmen to participate in various stages of the assembly. Finally, the construction of the bridge house takes place. The bridge house includes two types: bridge pavilions and bridge corridors. The construction method of the bridge house is similar to modern prefabricated housing. Before assembly, bent frames are fabricated at the component production site. Once assembled, these bent frames are transported to the completed bridge structure and integrated using horizontal components to connect the bridge body with the frames. This process is known as "frame arrangement" or "house arrangement." If the Fengyu Bridge includes pavilions, the construction sequence begins with the pavilions, followed by the corridors connecting them. If there are no pavilions, only the corridors are constructed.

Table 2. Composition of the Traditional Construction Techniques of Through-Type Timber Arch Corridor Bridges.

Techniques for Constructing the Main Body of Through-Type Timber Arch Corridor Bridges		Auxiliary Techniques for Constructing Through-Type Timber Arch Corridor Bridges
Techniques for Constructing the Arch Bridge Superstructure	Techniques for Constructing the Upper Corridor Structure	
Building abutments, installing "sanjie miao", installing "wujie miao", erecting "jiangjun zhu" and cross braces, and setting up "ma tui" and deck panels.	Heavy timber work for the bridge house, constructing the roof ridge structure and decorations, building the shrine, and installing wind-and-rain boards.	Selecting the bridge site, measuring level alignment, setting up the water-support columns and Tianmenche (sky gate hoist).

The construction of Fengyu Bridges (Wind-and-Rain Bridges) in northeastern Fujian involves steps such as selecting the bridge site, building the abutments (also known as "jingangqiang" or "diamond walls"), erecting the arch frame, setting up the "jiangjun zhu" (general pillars) and "jian dao miao" (scissor members), installing the "ma tui" (horse legs) and bridge plank "miao", and finally constructing the bridge house. When selecting the bridge site, locals place great emphasis on the influence of "feng shui" (geomancy), generally aiming to balance the village's "feng shui" with the geographical and environmental conditions of the bridge location. Regarding "feng shui", most sites are chosen at the downstream section of a village stream, commonly referred to as "shuiwei" ("water tail"), to mitigate wind currents formed by the stream and preserve the village's "feng shui". Additionally, the site must have solid rock on both banks for constructing the abutments. Whenever possible, narrower sections of the stream are preferred to reduce the span of the bridge arch (Yao & Gong, 2007). Once the location is determined, the bridge foundation construction begins. Locally referred to as "qiaotu" or "jingangqiang" (diamond walls), the abutments are crucial for the stability and safety of the bridge. There are generally three methods for building abutments: first, utilizing and modifying natural cliff faces or rock walls; second, constructing with stone slabs or blocks on existing riverside rocks; and third, building abutments on the riverbank or creating boat-shaped piers on flat ground near the shore. Sites with narrower water surfaces and protruding rocks on one or both sides are often preferred (Yao & Gong, 2007). After completing the abutments, craftsmen use the "zhu jian" (bamboo conduit) leveling method to test and ensure the horizontal alignment of the bridge structure, guaranteeing balance during construction. Once the horizontal position is confirmed, the assembly of the substructure begins—erecting the arch frame. This process involves multiple steps, starting with installing the "sanjie miao" (three-section members). After the "sanjie miao" are in place, "jiangjun zhu" (general pillars) are erected on both sides atop the "sanjie miao" stones. Once the "jiangjun zhu" are set, the installation of the "wujie miao" (five-section members) begins, which includes numerous intricate steps that will not be elaborated here. To stabilize the arch frame structure, craftsmen install "jian dao miao" (scissor members), typically in one or two sets, with the specific number determined by the chief ink craftsman. Next, the bridge plank "miao" and "ma tui" are installed. The bridge plank "miao", also known as longitudinal and transverse beams, are supported on the arch frame by A-shaped wooden braces called "ma tui" (horse legs) to ensure even load distribution. Finally, the bridge house is constructed. In northeastern Fujian, the bridge house is built from the center outward, with its width and height following the principle of "qi jiao ba ma" ("seven sedan chairs, eight horses"), meaning the pedestrian walkway is seven feet wide and eight feet high. The process concludes with the decoration and finishing touches of the bridge house.

3.2 Sources of Knowledge in Materials Mechanics

The core craftsmanship of Fengyu Bridge construction lies fundamentally in the precise understanding of timber characteristics and the deep integration with traditional construction techniques. The inheritance and practice of this set of skills are not developed arbitrarily but are gradually formed through generations of accumulated practical experience. This has resulted in a comprehensive technical system covering timber selection, processing, and structural application, which not only effectively ensures the stability of the structure but also maximizes the natural advantages of timber.

3.2.1 Cognition and Control of Wood Characteristics

In the construction of Dong covered bridges in western Hunan, craftsmen classify and select wood according to the load-bearing function and application scenarios of components: Chinese fir is used for main beams, columns, and primary load-bearing frames; pine is used for secondary load-bearing components such as purlins and rafters; and camphor wood is chosen for non-load-bearing parts including decorative and carved components. During material selection, craftsmen judge the quality, strength grade and durability of wood by visually inspecting its grain density, straightness, knot distribution and compactness, combined with the clarity of sound produced by tapping the timber. For the drying treatment of wooden components, Dong craftsmen in western Hunan adopt a combined process of natural drying and steam degreasing: core load-bearing wooden components must undergo 18 months of natural air drying followed by steam degreasing; decorative wooden components receive refined drying treatment with moisture content controlled within 12%, so as to reduce the possibility of later deformation, cracking and warping. Craftsmen of timber arch covered bridges in northeastern Fujian have established clear standards for wood used in load-bearing components: key components such as arch ribs, main beams and columns are made of Chinese fir over 20 years old with a trunk diameter of more than 30 centimeters; pine is used for auxiliary components such as purlins and rafters; camphor wood is also selected for decorative and carved components. Chinese fir arch ribs are processed with standardized cross-sections, with the section height controlled at 25–40 cm and width at 15–30 cm, forming load-bearing components of uniform specification. Pine pile foundations are tapered at the ends during processing, and coated with tung oil as a whole to improve their corrosion resistance, water resistance and mothproof performance.

3.2.2 Core Construction Techniques Based on Wood Characteristics

The wooden components of Dong covered bridges in western Hunan are connected using a traditional mortise-and-tenon system. The main mortise-and-tenon forms include dovetail joints, through mortise-and-tenon joints, half-tenon joints, etc. Different types are applied according to the stress direction of components and connection requirements. Before formal installation, wooden components undergo two pretreatment processes: tung oil impregnation and cinnabar coating. For exposed wooden components subject to long-term wind and rain erosion, a mixture of tung oil, cinnabar and lime is applied as an overall coating, repeated three times to form a complete protective layer.

Craftsmen of timber arch covered bridges in northeastern Fujian follow millimeter-level precision standards in mortise-and-tenon processing. The gaps and fitting accuracy of component joints are strictly controlled; the fitting clearance between tenons and mortises is required to be extremely small, even reaching an interference fit to enhance structural integrity. Mortise-and-tenon types are distinguished by the stress function of components: dovetail joints are used at tension zones and critical load-bearing joints; through mortise-and-tenon joints are adopted at force transmission and frame connection positions. At the junction between the interwoven wooden arch frame and the abutment, wooden wedges are used for filling, tightening and reinforcement, so that the frame and abutment form a tight interlock. All wooden bridge components are coated with tung oil before and after installation to improve durability through anti-corrosion treatment.

3.2.3 Inheritance of Craftsmanship and Practical Verification

The timber construction techniques of the Dong people in western Hunan are mainly inherited within families and through oral instruction and personal demonstration between masters and apprentices. Technological processes, operational key points and dimensional control are all realized through on-site demonstration and oral teaching. For instance, the Yang carpenter groups in the Eight Villages of Chengyang have formed standardized construction procedures through long-term practice, following fixed workflows from material selection, processing and framework assembling to installation. The stone piers of Longjin Wind and Rain Bridge are built and bonded with glutinous rice mortar; the main structure of Fuquan Wind and Rain Bridge adopts a three-tier cantilever beam system, forming a stable load-bearing structure through progressive overhangs.

The construction techniques of timber arch covered bridges in northeastern Fujian take blood-related families as the core inheritance units. Core construction techniques, structural know-how and construction dimensions are only passed down within families connected by blood or marriage. During the construction of Luanfeng Bridge, pine pile foundations are used as the base support on the southern side of the bridge, while the northern side directly relies on the natural cliff face, which is trimmed to serve as the abutment. After the overall installation of the arch frame is completed, iron components known as “scissor braces” are applied for lateral reinforcement to improve the overall stability and anti-lateral displacement capacity of the arch structure.

4. Discussion

4.1 Factors Influencing Technical Differences

4.1.1 Nature

The material selection patterns documented in 3.1.1 reflect craftsmen's responses to differences in natural environments. Differences in the natural environment directly influence the selection of appropriate bridge span structures. In northeastern Fujian, influenced by the Wuyi Mountains, the terrain is predominantly characterized by mid-low mountains and hills, with deep gorges and valleys and significant topographical variations. Bridges must adapt to complex spans, and the diverse distribution of auxiliary resources such as stone provides material support for decorative techniques like stone carving and plaster molding. The region's subtropical maritime monsoon climate brings distinct seasons and is often strongly affected by monsoons from the Pacific Ocean. Annual precipitation ranges from 1,400 to 1,800 millimeters, contributing to abundant rainfall. This necessitates attention to material protection during the construction of Fengyu Bridges. In terms of natural material selection, the yellow and red soils in northeastern Fujian support the growth of natural vegetation. Some areas remain covered by primary forests, while in others, human activities have transformed primary forests into secondary forests dominated by fir, camphor, and bamboo.

In contrast, the terrain of the Dong ethnic region in western Hunan is relatively gentle, primarily consisting of mountains and hills, with an overall characteristic of "many mountains, little flat land, and gently undulating terrain." Streams flow at a slower pace, and the concentrated reserves of high-quality fir forests serve as the foundational material for Dong wooden architecture. The subtropical monsoon-influenced humid climate in western Hunan, with stronger continental characteristics, along with temperature variations and high humidity resulting from vertical mountain climates, has led to a focused development of moisture-proof and insect-resistant techniques such as painted decorations. This has formed a construction logic highly adapted to the local environment.

4.1.2 Humanities

In northeastern Fujian, the mountainous population largely consists of migrants from the Central Plains, resulting in a profound influence of Han culture in the region. This is blended with remnants of the Min-Yue culture, creating a diverse belief system where concepts of yin-yang and the five elements, folk legends, and religious consciousness are intricately interwoven. This is reflected in the decoration of Fengyu Bridges, which features a variety of auspicious motifs such as gourds and vases. The layout follows a practical aesthetic principle of "highlighting key elements with clear hierarchy." In contrast, the Dong ethnic region of western Hunan is centered around the ethnic culture of the Dong people, characterized by distinctive minority cultural traits and a strong sense of ethnic identity. The Dong regard Fengyu Bridges as embodiments of dragons and believe that many reborn souls first enter "this world" via these bridges (Li et al., 2018). Their belief expressions are focused and vivid, with decorative themes primarily centered on dragons, phoenixes, and gourds. Utilizing Dong decorative techniques such as interior painted patterns and exterior carvings, these bridges highlight their ethnic cultural identity. Moreover, as vital spaces for community gatherings, rituals, and ceremonies, Fengyu Bridges in Dong society carry richer cultural functions and significance.

4.1.3 Society

The craft organization systems presented in Sections 3.1.2, 3.1.3 and 3.1.4 reflect the underlying social structures. The differences in the social environments of the two regions fundamentally lie in the distinctions in ethnic composition and cultural identity. In northeastern Fujian, the Han ethnic group constitutes the majority, and its social culture has long been shaped by the integration of Central Plains Han culture and indigenous Min-Yue culture. The community structure here exhibits loosely organized and diverse characteristics. Correspondingly, the function of Fengyu Bridges in this region leans more toward practical purposes, primarily serving transportation and public rest, with their decorative arts bearing the imprint of multicultural fusion. The choice of themes and application of techniques are more aligned with popular aesthetic preferences and practical needs.

In contrast, the Dong ethnic region in western Hunan is a concentrated settlement of the Dong people, where ethnic cultural identity is particularly strong. The community structure revolves around clans and villages as core bonds, forming a rigorous and comprehensive system for the transmission of ethnic culture. In this context, Fengyu Bridges have long transcended their role as mere transportation facilities and have become central venues for collective activities such as ethnic rituals, community meetings, and festive celebrations. Their decorative arts are imbued with profound ethnic cultural symbolism. Whether in theme selection, technique application, or compositional layout, they revolve around the expression and preservation of ethnic culture, ultimately serving as vital cultural symbols that sustain the ethnic identity of the Dong people.

4.2 Complexity Characteristics of Chinese Traditional Timber Bridge Technology Pedigree

Mr. Liang Sicheng once remarked, "The art of architecture has been transmitted through master-apprentice relationships rather than relying on written texts. In China, architecture has long been regarded as a craft, not the concern of scholars and officials. This is because architectural techniques have become so intricate that only those who undergo practical training and devote their lives to the craft can master them, unlike other arts or literature, which can be pursued casually by the educated elite in their leisure time. However, craftsmen often lack proficiency in writing, so they depend on oral instruction and hands-on practice to pass on their skills, placing little emphasis on books (Liang, 2023). "Traditional Chinese architectural construction techniques originate from the accumulated experience of craftsmen during the building process. They prioritize practical perception over written records, with most skills passed down orally from master to apprentice. As a branch of traditional Chinese architecture, the construction techniques of covered bridges largely follow this pattern—rarely documented in writing but transmitted across generations through hands-on master-apprentice instruction. This transmission is not merely a one-dimensional transfer of technical skills. Instead, it represents a composite technical system formed by craftsmen through the deep integration of environmental understanding, material mastery, and adaptive wisdom. This complexity stems from the core characteristics of traditional timber construction techniques: being practice-oriented, multidimensional, and dynamically adaptable. These characteristics are not abstract technical attributes but are concretely realized through the craftsmen's decisions in material selection (see 3.1), structural design (see 3.2), tool use (see 3.3), and process management (see 3.4). It reflects both the deep coupling of technology with the natural and human environments and highlights the creative agency of traditional craftsmen as technical practitioners. The core features of this system can be elaborated in three specific aspects.

4.2.1 Practicality and Adaptability of Environmental Perception

Regional differences in physical geography and climatic endowments are the core natural driving forces behind the divergent development of covered bridge construction techniques between northeastern Fujian and the Dong-inhabited areas of western Hunan. The environmental perceptions formed by craftsmen in both regions through long-term on-site practice were directly translated into technical decisions regarding material selection and technological design, enabling covered bridge construction to be highly adapted to local natural conditions. This also embodies the essential principle of traditional timber bridge technology: "designing according to local conditions and conforming to nature".

Both regions feature warm, humid, and rainy mountainous environments. Their natural abundance of forest and stone resources directly determined that Chinese fir and stone became the dominant building materials for covered bridges in the two areas, a direct reflection of the traditional construction principle of "obtaining materials locally". The subtle differences in material utilization, in fact, represent precise adaptations to regional resources and environmental characteristics. In northeastern Fujian, granite was not widely used due to its high construction cost, reflecting comprehensive considerations of resources, craftsmanship, and economic efficiency. In the Dong areas of western Hunan, craftsmen combined the compression-resistant and water-resistant properties of stone with the pointed water-dividing shape in response to the hydraulic characteristics of river flood seasons, forming a targeted adaptation to the local hydrological environment. Such differences in material selection based on regional environments also laid an important foundation for the distinct developmental paths of heavy timber construction technologies in the covered bridges of the two regions.

Structural differences between the covered bridges likewise reflect craftsmen's flexible responses to geographical features. The deep mountains, steep valleys, rapid currents, and demand for large spans in the mountainous areas of northeastern Fujian encouraged craftsmen to innovate and develop the interwoven timber arch structure. The interlocking assembly of the "three-section arch" and "five-section arch" forms a flexible arch system that not only satisfies large-span crossing requirements but also dissipates flood impacts and seismic stresses through structural deformation. In contrast, the humid climate, concentrated rainfall, and gently undulating terrain in western Hunan determined that the wind-and-rain bridges are mainly structured with stacked timber arch beams and cantilevered simple beams. Craftsmen designed stone piers and abutments with streamlined water-dividing tips to reduce lateral flow impacts on the bridge during flood seasons. The high eaves and deep corridors of the bridge houses not only provide shelter from heavy rain but also reduce the risk of wood decay due to moisture through natural ventilation.

This logic of material and structural adaptation centered on the regional environment typifies the "practice-oriented" nature of traditional timber construction. Without relying on written theoretical guidance, craftsmen developed targeted material selection strategies merely through long-term practical observation of the local natural environment and resource endowments. This is the core manifestation of "designing according to local conditions" within the technical lineage of traditional Chinese timber bridges.

This also explains why unified standard construction drawings do not exist in the inheritance of wind-and-rain bridge techniques in northeastern Fujian and western Hunan, demonstrating the flexibility and practicality of environmental cognition.

4.2.2 Systematic and Deep Integration of Material Control

Craftsmen have developed a systematic set of techniques for mastering core materials like timber, covering the entire process from material selection, processing, and application to protection. This approach not only precisely harnesses the natural properties of materials but also achieves the integrated goal of "maximizing material utility while leveraging strengths and mitigating weaknesses" through technical innovation. In the material selection phase, craftsmen from both regions prioritize fir wood as the core building material. This choice is rooted in a profound understanding of the mechanical properties of fir—its straight grain, moderate strength, and natural antiseptic oils make it easy to work with and well-suited to humid environments, establishing it as the optimal material for traditional timber bridges. Furthermore, craftsmen engage in targeted material selection based on the functional differences of components. Load-bearing components are chosen from robust fir trees over 20 years old and with diameters exceeding 30 centimeters to ensure structural load-bearing capacity. Purlins and rafters, which require better flexibility, are made from pine wood to facilitate bending and processing. Decorative components, on the other hand, utilize camphor wood, valued for its strong insect resistance and aromatic qualities, balancing practicality with aesthetic needs.

In the material processing and application stages, craftsmen achieve a deep integration of material properties and structural requirements through precise craftsmanship. In northeastern Fujian, craftsmen employ millimeter-level precision in mortise-and-tenon work for the core components of woven timber arches. The selection of different mortise-and-tenon types, such as dovetail tenons and through tenons, is entirely based on the load-bearing characteristics of the components. Areas subjected to tension use dovetail tenons, which are narrow on the outside and wide on the inside, ensuring that they tighten under load. For parts responsible for transferring loads, through tenons are used to penetrate and connect components, enhancing the structural integrity. In the Dong ethnic region of western Hunan, craftsmen utilize a combined treatment process of natural drying and steam degreasing to control the moisture content of core components to within 15%, reducing the risk of deformation and cracking over time. For wooden components exposed to the elements, a mixed coating of tung oil, cinnabar, and lime is applied in three layers. This approach leverages the waterproofing and antiseptic properties of tung oil, the insect-repellent effects of cinnabar, and the hardening action of lime, forming a multi-layered protective system.

This mastery over materials does not exist in isolation but is deeply integrated with structural design and technical choices. For instance, the elastic properties of fir wood gave rise to flexible structures utilizing mortise-and-tenon joints, while the workability of timber supported the realization of complex woven arch techniques. In western Hunan, the Puji Bridge employs the "stone weights on timber" technique, using stone counterweights to balance the mechanical tension of timber cantilevers. Meanwhile, in northeastern Fujian, the Luanfeng Bridge adopts a combination of "three-section arches and five-section arches" to maximize the compressive performance of fir arch ribs (see Table 1: Comparison of Puji Bridge and Luanfeng Bridge). Both cases exemplify how material characteristics and technical innovation mutually reinforce each other.

4.2.3 Dynamic Adaptation and Responsiveness in the Manufacturing Process

The construction of Fengyu Bridges (Wind-and-Rain Bridges) is not a standardized process bound by fixed models but rather a practice characterized by dynamic adaptation. The craftsmen's ability to respond flexibly to on-site conditions forms the core of engineering quality assurance. This adaptability is rooted in the intuitive experience accumulated through long-term practice and is further built upon the accurate assessment and immediate response to multiple variables in the construction context, reflecting the practical wisdom of "adapting to change with change" in traditional timber construction techniques.

In the construction of woven timber arch bridges in northeastern Fujian, although the chief ink craftsman uses tools such as the "zhanggao" (measuring pole) and bamboo slips as measurement benchmarks, the assembly of core structures still relies on on-site dynamic optimization. The crossing angle of the "jian dao miao" (scissor members) requires real-time fine adjustments based on feedback from the arch's stress distribution, while the precision of mortise-and-tenon fit is calibrated through the craftsman's visual inspection and tactile perception, ensuring balanced load distribution across the arch frame. The bridge house is constructed using a "symmetrical progression from the center outward" approach. Deviations in beam levelness are immediately corrected by filling with wooden wedges or compensating with offset placement of beams, ensuring structural flatness and stability.

The adaptive logic of the Dong ethnic Fengyu Bridges (Wind-and-Rain Bridges) in western Hunan similarly highlights on-site adaptability: although the Zhangmoshī (master builder) conducts preliminary structural simulations using 1:10 scale wooden models, the construction phase requires flexible adjustments based on the natural properties of timber and processing deviations of components. For instance, if the curvature of fir wood exceeds expectations, defects are mitigated by reassigning component functions or employing complementary angles. When gaps occur in mortise-and-tenon connections, techniques such as "fine wood shim filling and lateral tightening with wooden wedges" are applied to strengthen the joints without damaging the components themselves.

This adaptive capability permeates the entire construction process, from responding to geological conditions during foundation excavation to optimizing component configurations through load testing after structural formation. Craftsmen remain in a dynamic cycle of assessing different sites and determining solutions. Its core value lies in effectively mitigating construction risks posed by complex variables such as the natural variability of timber and environmental uncertainties through flexible adjustment mechanisms, highlighting the adaptive nature of traditional timber construction techniques.

4.2.4 Materialization and Practice-Oriented Inheritance of Construction Skills

Craftsmen in both regions take their exclusive physical tools as the core carrier for construction and skill inheritance. Despite the absence of formal written blueprints, they have still achieved accurate transmission of construction techniques. The Zhangmo masters (chief carpenters) of the Dong people in western Hunan mainly use ink markers, measuring gauges and bamboo slips to convert abstract architectural designs into tangible physical markers. The measuring gauge serves both as a measuring tool and a construction drawing, while bamboo slips record component positions and mortise-and-tenon specifications in the form of ink-marker inscriptions, enabling standardized inheritance of complex wooden construction techniques through tools. Their measurement system is based on human body scales, and each craftsman uses a customized Luban ruler, which not only fits the inheritance context of Dong folk craftsmanship but also endows construction scales with flexible regional adaptability. For bridge builders in northeastern Fujian, the measuring pole acts as the key measuring tool, integrating religious implications and measurement standards into tool making. Supported by special construction tools such as ink markers and wooden trestles, they have established a practical operation system for woven timber arch techniques. The division and coordination of various tools precisely match the complex structural construction requirements of the “three-section and five-section woven timber arches”, enabling the practical implementation of large-span timber arch construction techniques. Differences in tools fundamentally reflect the distinct construction approaches of the two regions.

Influenced by regional culture and community structures, the two inheritance mechanisms have formed distinct practical models, yet both follow the essence of practice-centered inheritance. In western Hunan, the Dong people take the Zhangmo master as the sole core figure, who takes full charge of the whole process including design, construction and cost accounting. Through the practical chain of model making, tool fabrication and on-site construction, skills are passed down orally and through on-site instruction, which suits the clan-dominated community structure of Dong villages. In northeastern Fujian, an organizational craft guild and familial inheritance model has been formed. Written bridge contracts between director organizations and craft guilds specify practical operation details; core techniques are only inherited within blood-related families, and the internal job division in the guild realizes professional collaboration in bridge construction. This model adapts to the diverse and loosely structured community of Han settlements in northeastern Fujian and meets the demand for professional division of labor in woven timber arch techniques.

In addition, the detailed design of tools and inheritance practices in both regions reflects the traditional craftsmen’s wisdom in integrating technology and culture. The auspicious markings on the measuring gauges in western Hunan, and the auspicious numbers and religious attributes of the measuring poles in northeastern Fujian, all embed regional cultural connotations into tool making, making construction craftsmanship not only a construction technique but also a carrier of regional cultural inheritance. Although the bridge contracts in northeastern Fujian and the ink-marker inscriptions in western Hunan contain no theoretical records of core structures, they focus on the regulation of practical details, forming an implicit standardization system for traditional craftsmanship through practice.

This inheritance model, centered on physical tools and carried by on-site practice, represents the dual adaptation of craftsmen in both regions to their own cultural context and technological demands. It avoids the cultural limitation of craftsmen being illiterate, ensures the continuation of traditional covered bridge construction techniques through deep integration with regions, culture and communities, and further verifies the complexity of China’s traditional timber bridge technical lineage. Rather than relying on standardized written theories, the inheritance of such skills depends on a composite system of tools, practice and culture, enabling technologies to achieve innovation and inheritance in dynamic practical processes.

4.3. Contemporary Insights of Local Artisans Adapting to Local Conditions

The philosophy of adapting to local conditions in the construction techniques of Fengyu Bridges (Wind-and-Rain Bridges) represents a deep integration of traditional building wisdom and regional practice. Its core lies in achieving an organic unity of the natural environment, cultural heritage, construction techniques, and practical needs based on regional characteristics. This provides significant intellectual resources and practical paradigms for contemporary architectural design, cultural heritage revitalization, and sustainable development.

From the perspective of ecological sustainability, the material practices documented in Section 3.1.1 and the construction techniques described in Section 3.1.2 both embody the craftsmen's practical principle of "using local materials and adapting to nature", providing a vivid model for the low-carbon transformation of contemporary architecture. Craftsmen in northeastern Fujian skillfully utilize local resources such as timber, stone, and clay, while Dong ethnic craftsmen in western Hunan use native fir wood to construct the main body of their structures. This not only reduces the energy consumption and environmental impact associated with material transportation but also allows the buildings to naturally integrate into the surrounding ecosystem. In response to humid and rainy climatic conditions, Dong Fengyu Bridges employ techniques like tung oil coating and painted decorations to resist moisture and pests, whereas Fengyu Bridges in northeastern Fujian use stone reinforcements for piers to withstand erosion. This reflects a precise adaptive logic: responding to environmental challenges by leveraging material properties and selecting appropriate techniques. This insight urges contemporary architecture to move away from high-consumption, high-emission extensive models and instead prioritize ecological principles. By favoring local low-carbon materials, optimizing structural designs based on regional climate and terrain, and integrating traditional "passive protection" wisdom with modern environmental technologies and traditional protective experiences, the environmental impact throughout a building's life cycle can be reduced. This approach supports the development of sustainable architecture in alignment with the "dual carbon" goals.

In the expression of cultural locality, craftsmen integrate regional cultural genes and community needs into the entire construction process, offering crucial insights for contemporary architecture to uphold cultural identity. Craftsmen in northeastern Fujian translate concepts of yin-yang and the five elements, folk legends, and religious consciousness into auspicious motifs in wood carvings and painted decorations. Dong ethnic craftsmen, on the other hand, build a decorative system centered around "dragon culture," elevating Fengyu Bridges beyond their transportation function to become cultural symbols that embody community beliefs, aesthetic paradigms, and collective memory. Simultaneously, craftsmen incorporate the needs of local production and daily life, endowing Fengyu Bridges with diverse functions such as rest, meetings, and rituals, achieving a deep integration of architecture with community life. This suggests that contemporary architectural creation, in the context of globalization, should abandon the impetuous mindset of blindly replicating foreign styles and instead delve deeply into regional cultural connotations and genuine community needs. Through concrete means such as material selection, technical application, and spatial layout, folk traditions and spiritual beliefs should be transformed into perceptible architectural language. Moreover, it is essential to respect the cultural interpretive authority and skill transmission status of folk craftsmen, promoting their involvement in contemporary regional architectural design. This approach ensures that architecture becomes a vital medium for sustaining cultural identity and preserving collective memory.

In summary, the philosophy of adapting to local conditions embodied in the construction techniques of Fengyu Bridges provides systematic insights for contemporary development from three dimensions: ecological adaptation, cultural translation, and technical revitalization. Its core value lies in establishing a synergistic and symbiotic relationship among nature, culture, and craftsmanship. This traditional wisdom is not only a precious asset in the field of architecture but also offers valuable lessons for sustainable design, cultural heritage preservation, and rural development. It supports contemporary society in maintaining its local roots amid rapid development, achieving a harmonious coexistence between humanity and nature.

5. Conclusions

There are distinct differences in material selection, large wood structure systems and construction processes between the Dong people's wind-rain bridges in northeastern Fujian and western Hunan, and craftsman factors are the core reason for these differences. The impact of geographical environment and resource endowments is ultimately reflected through the technical inheritance, construction concepts and practical choices of craftsmen in the two regions: craftsmen in northeastern Fujian rely on family-based craftsman gang inheritance, take the "wooden arch weaving" technique as the core, and highlight the characteristics of pragmatism and craftsman-led; while Dong craftsmen in western Hunan adhere to the concept of collective construction, adopt the combined method of "cantilever beams and stacked beams", reflecting the construction tradition of community collaboration.

In summary, the core differences in the construction techniques of wind-rain bridges in the two regions are mainly attributed to the craftsmen's inheritance models, construction concepts and technical preferences, which are examples of the in-depth integration of craftsmen's skills with the regional environment and culture. The core significance of protecting such cultural heritage lies in maintaining community cultural identity, safeguarding the living technical genes centered on craftsmen, inheriting the "harmony between man and nature" construction wisdom, and protecting the diversity of excellent traditional Chinese culture.

Based on the fact that the core cause of the differences is the craftsman factor, the protection work should adopt a differentiated approach: northeastern Fujian focuses on supporting the inheritance of family-based craftsman gangs and the digital archiving of craftsmen's skills; western Hunan needs to respect the core status of the master craftsmen, protect traditional techniques, rituals, and encourage community participation. At the same time, both regions should conduct rescue records of surviving senior craftsmen,

promote the systematic inheritance of skills, take into account the original functions of the bridges, avoid excessive commercial erosion, and realize the living continuation of the techniques.

Funding: This research did not receive external funding.

Conflicts of Interest: The author declares no conflict of interest.

Data Availability Statement: The data of this study are available from the corresponding author upon reasonable request.

References

1. Cheng, F., & Xiao, D. (2017). A comparative study of timber arch covered bridges in Fujian-Zhejiang and wind and rain bridges in Hunan-Guangxi. *Traditional Chinese Architecture and Gardens*, (2), 22–27.
2. Liang, S. (2023). *History of Chinese architecture*. Beijing, China: Taiwan Strait Press.
3. Liang, Y. (2024). *Research on construction techniques of Dong wind and rain bridges in the Pingtuan River Basin*, Master's thesis. Guangzhou, China: Guangzhou University.
4. Li, X., Xiao, D., Smith, K., et al. (2018). Carpenter's pole, ritual and the bridge of life: Construction and cultural connotation of Dong wind and rain bridges. *Architectural Journal*, (201), 105–108.
5. Shen, C. (2020). Building a bridge is building a temple: Construction and application of timber arch covered bridges in Fujian and Zhejiang. *Journal of Henan Institute of Education (Philosophy and Social Sciences Edition)*, 39(1), 17–20.
6. Traditional construction techniques of Chinese timber arch bridges. (2025). *Teacher's Review*, (14), 98.
7. Wu, H. (2008). *Treasures of Chinese Dong architecture: Drum towers · wind and rain bridges*. Nanning, China: Guangxi Nationalities Publishing House.
8. Yao, H., & Gong, D. (2007). Construction techniques of Fujian timber arch bridges. *Traditional Chinese Architecture and Gardens*, (4), 11–14, 66–67.

Publisher's Note: IJKII remains neutral with regard to claims in published maps and institutional affiliations.



© 2026 The Author(s). Published with license by IJKII, Taiwan. This is an Open Access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/) (CC BY), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.