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Design Strategies of Bamboo Fiber-Based Composites Pavillon Under the Dual-Carbon Background

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ABSTRACT

With China already committed to peak carbon emissions before 2030 and carbon neutrality before 2060, the Central Economic Work Conference urged faster steps to develop an action plan to enable peak emissions in a joint response to global climate change. According to the central government, "Achieving carbon peak and carbon neutrality is a broad and profound economic and social systemic change", and the opening up of the dual carbon strategy will change the way every Chinese lives and works, and reshape our attitudes towards the natural environment. As the construction industry accounts for 33% of global carbon emissions, we as designers should conduct innovative research and try to respond with low carbon design methods. The traditional Chinese timber construction system is prefabricated and takes into account natural ventilation and lighting, achieving low carbon and green from three aspects: material, construction and operation. The problem that prevents the promotion of timber construction on a large scale today is the fire resistance and durability of the material. In the combination of this course and the innovation and entrepreneurship project, the research team was invited to build the Shanghai Urban Space Art Season (SUSAS) with the design of the "Cycling station", and then cooperated with the leading structural bamboo research and development company in China through the joint school-enterprise approach to obtain the innovative material "bamboo steel". The research results were finally presented in Shanghai Lingang with the participation of students, and received wide public response and praise.

Keywords: Dual carbon background, High-performance bamboo-based fiber composites, Bamboo steel, Prefabricated assembly pavilion

THE RESEARCH BACKGROUND AND PURPOSE

With the continuous development of human society, human demand for energy continues to grow, and the massive use of fossil energy has posed serious challenges to the global ecosystem and environmental protection, resulting in climate change, which has become a global issue related to the fate of mankind and a major challenge to sustainable development in the 21st century. In order to prevent global climate change from posing a major threat

to human society, more and more countries have elevated "carbon neutrality" to a national strategy, and 178 parties around the world have signed the Paris Agreement, which is a unified arrangement for global action to address climate change after 2020. China has adopted a dual carbon national strategy since 2020, and the central government pointed out that "achieving carbon peak and carbon neutrality is a broad and profound economic and social systemic change", and the opening of the dual carbon strategy will change the way each Chinese lives and work and transform our attitude towards the natural environment. As the construction industry accounts for 33% of global carbon emissions, we as designers should conduct innovative research and try to respond with low carbon design methods.

In the 2021 Shanghai Urban Space Art Season - Lingang Sample Exhibition, As a design and research institute, A.C.R.E. Atelier was invited to design and build an "Art pavilion". The exhibition organizers hope that the Lingang area will serve as a model for the "community of the future" and promote the creation of a 15-minute community living circle that is more oriented to daily life and the construction of a higher-quality public space. Facing the large-scale new city space in the core area of Lingang New District, we discussed with the curator that the best way to perceive Lingang is to ride through a cycling route, and to link the journey of spatial perception through a cycling route. As architects, we hope to adopt a new green material that echoes the "dual Carbon background", so we conducted research and design of bamboo and wood structure materials.

INVESTIGATION

The craftsmen adopted a standardized and prefabricated approach, taking into account the natural ventilation and lighting of the building, which is low-carbon and green in terms of materials, construction, and operation, and is well in line with the current dual Carbon strategy. In China, it is not possible to promote wood frame buildings and structures in large numbers because of the following three factors: 1. the structural strength of wood is not sufficient for structural materials; 2. the durability does not meet the 50-year life of buildings; 3. the fire resistance of pure natural bamboo wood is poor.

With the emergence of new materials, a bamboo fiber-based composite material has recently emerged. The strategy of fabricating high-performance bamboo steel with green and abundant natural bamboo as raw materials is highly attractive for the sustainable development of structural engineering materials.

The composite material is made of bamboo fiber curtain, which is hot (cold) pressed and glued in the direction of the grain, and is made of bamboo fiber and resin at high temperature and high pressure. The tensile strength of the material is three times that of steel of the same weight, and the life span can be up to 50 years, so it is called "bamboo steel".

Structural Properties of Bamboo Steel

The structural properties of the material are close to those of FRP, and due to the high strength and density of bamboo steel, all indicators have met or

Table 1. Main mechanical properties of reconstituted bamboo for structural use (Self-drawn by the author).

Serial number	Technical specifications		Unit	Detection value	Standard value
1	Flexural modulus of elasticity		MPa	30.9x103	28.0x103
2	Flexural strength		MPa	215.9	165
3	Parallel tensile strength		MPa	234.2	130.0
4	Compressive strength with smooth grain		MPa	153.6	85.0
5	Parallel grain shear strength		MPa	20.8	15.5
6	Transverse compressive ultimate proportional strength	All	MPa	19.7	18.5
		Partial	MPa	41.5	20.5

exceeded the performance index requirements of the blade base material and outdoor panels (Table 1).

Comparing the strength of bamboo steel with several of bamboo and wood material indicators in the Chinese code "Wood Structure Design Standard" GB50005-2017 (Table 2), it can be seen that the design indicators of this new material are significantly advanced compared to traditional wood-based structural materials.

Table 2. Comparison of design values for structural reconstituted bamboo and typical wood structural lumber (Self-drawn by the author).

	Strength design value(N/mm2)					
Tree species	flexural	Compressio n resistance with smooth grain	Along-grain tensile	Smooth grain shear resistance	Cross grain compressio n resistance	Modulus of Elasticity (N/mm2)
	fm	fc	fr	fv	fc,90	
Recombinan t bamboo for cichlid structures	56.91	32.88	43.16	5.15	6.89	27730
Reconstitut ed bamboo for moso bamboo structures	46.36	27.46	37.43	5.1	5.1	18360
Glued laminated wood TCT40	27.9	23.2	17.9	-	-	12500
Square wood TC17	17	16	10	1.7	4.6	10000
Structural materials imported from Europe	26.5	15	12.9	1.9	5.5	14000
New Zealand imported structural lumber	23.6	23.4	9.3	1.8	6	15200

Fire Resistance of Bamboo Steel

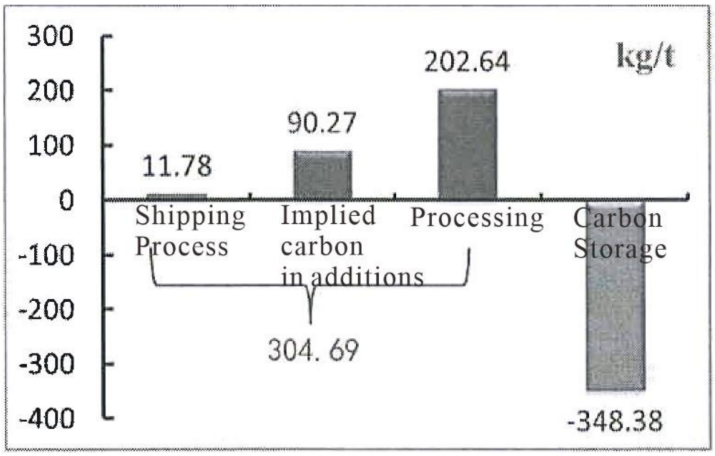
"Bamboo steel" is tested to be organic material class B1 (non-combustible), which retains a certain strength for a certain period after burning and carbonization, and has no smoke or toxic gas. The fire resistance level reaches the B1 level of Chinese material fire rating, that is, "difficult to burn", which exceeds the B2 or C burning level of wood, making "bamboo steel" a more widely used scenario.

Green Properties of Bamboo Steel

The main raw material of bamboo steel is Chinese bamboo, because of its small diameter and thin wall, the value of industrial use of bamboo is low, except for bamboo weaving and paper making, there is no other industrial use, resulting in a large number of idle resources. However, "bamboo steel" can be degraded after use, so the pollution to the environment is low.

The most important thing is that "bamboo steel" is a "carbon-negative" material in the whole production process (Table 3).

Table 3. Carbon emission properties of recombinant bamboo for structural use (Self-drawn by author).



DESIGN STRATEGIES

Reducing Carbon Emissions - a Low-Carbon System Led by Bamboo and Steel

As a cycling shelter station and one of the nodes of the urban furniture service system, the structural system of the cycling station is made of steel and wood structure from the beginning to reduce carbon emissions. Low carbon green construction is considered from the production and processing of main materials, transportation of materials and equipment, construction process, and building operation.

In the face of the completed site, the building foundation of the riding station adopts the smallest way to the ground pavement to intervene in the site, using 200MM I-beam as the foundation, which is fixed on the ground by 20MM anchor bolts. Abandoning the traditional need to pour concrete slabs on site to make the foundation. The construction process uses efficient assembly construction, with a site construction cycle of nearly 60 hours(see Figure 1), reducing the carbon emissions generated during construction and material production. The construction process also has a good dust reduction effect, saving water, electricity and other energy, while achieving the original purpose of energy-saving and environmental protection of the building (see Figure 2).

Figure 1: On-site installation of factory prefabricated assembled components (Author's own photos).

Figure 2: 60 hours to complete the cycling station (Author's own photos).

Light intervention of assembled bamboo and wood structures

A.C.R.E. Atelier has been thinking about how to make the building adaptable to cities that need micro-renewal, integrating with the site with the lightest intervention within the constraints of the site conditions. The cycling station is assembled and built with a bamboo and wood structure, and the material utilization rate is improved through downstream optimization and reuse of components(see Figures 3 and 4).

Figure 3: The light and shadow formed by the rotating spokes (structural members), the wooden spokes that stand out in the air, forming a smooth surface. (Author's own photo).

Figure 4: 2021 Urban Space Art Season - Cycling Event (Author's own photo).

Morphogenesis and Structural Efficiency

The morphogenesis is inspired by the trajectory of the wheel, the mechanical movement of the bicycle in four-dimensional space-time constitutes a solid structure in three-dimensional space, providing a place for cyclists to rest and shelter (see Figure 5).

In the way the timbers are assembled, the architects staggered the timbers and laminated them together so that the load-bearing and maintenance systems of the timber structure are integrated into one, "weaving" them into a stable triangular structure, thus eliminating diagonal bracing. This straightforward construction gives the building structure visual certainty and unity (see Figure 6).

Figure 5: Triangular structure of the post (Author's own photo).

Figure 6: The wooden spokes rotate around the bearings while translating, solidifying the trajectory of the bicycle wheel. (Author's own photo).

Different Ways to Park Bicycles

The design site will host road cycling events like the Tour de France in the future. Based on the problem that professional bicycles cannot be parked independently, the station structure system is adapted to combine bicycle parking methods. The two methods can meet the needs of professional and recreational bicycle parking to the maximum extent, and have little impact on the structure of the station.

Interspersed Parking

The spacing of the structural uprights is set to accommodate the bicycle wheels, which can be easily inserted for parking, and children can easily park their bicycles into them, which can also meet the parking needs of nearby residents when there is no demand for professional events in general (see Figure 7).

Suspension Parking

Suspended bicycle parking method, suitable for professional road cycling events, professional bicycles can not be independently parked and the weight of small, can be suspended on the crossbar to achieve a certain number of bicycle storage and parking (see Figures 8 and 9).

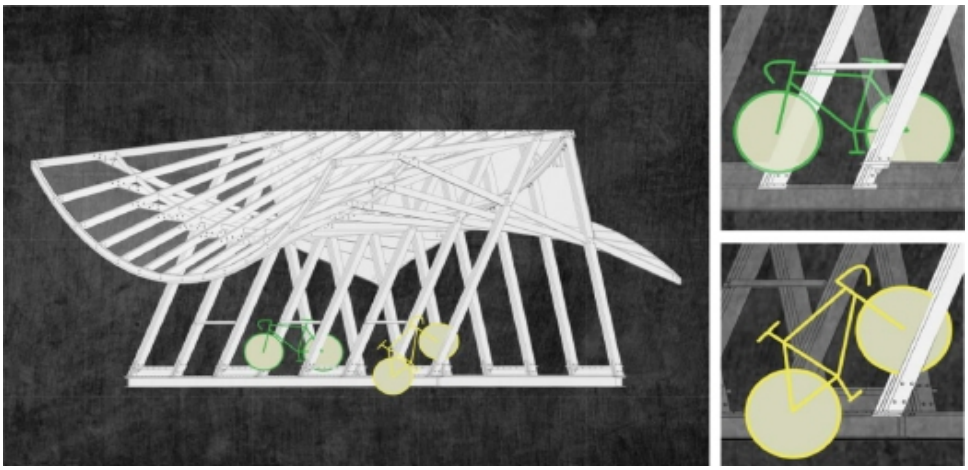


Figure 7: Two types of stops (Self-drawn by the author).

Figure 8: Interspersed bicycle parking (left) and Suspended parking for bicycles (right).

Figure 9: Hanging crossbar rotates through a combination of bolts and powerful magnets, allowing storage during weekdays when events are not held. (Self-drawn by the author).

CONCLUSIONS

The design of the cycling station is based on the needs of urban public space living, to provide a possibility of public communication while solving the demands of public life in small and micro spaces. More importantly, this is the first time in China that "bamboo steel" is used as a structural material for an outdoor station. Through design research and construction experiments on new materials, the project expands the use of new low-carbon and environmentally friendly materials, providing reference for the construction of green cities with a low-carbon system in the future and making exploration and efforts for the development of China's design industry towards the "dual Carbon" goal.

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