

Presentation and Expression of Large-Scale Public Building Structures Based on Data Visualization

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Abstract

With the help of clustering analysis tools in the field of computer science, this paper conducts a visual study on the structure of contemporary large-scale public buildings. It summarizes the expression strategies of large-scale public building structures and provides references for research and practice in the new era. Based on the visualization analysis results of VOS viewer, this paper conducts analysis from three aspects: first, by reflecting on the development of traditional wood structure technology, it reveals the lag in the development of contemporary architectural structures; second, based on the new temporal context, it distinguishes the cognitive paradigm of contemporary architectural structures; third, it clarifies the inherent requirements of architectural structure representation and explores the possible answers to the expression of architectural structures in the new era.

Keywords: Data visualization; VOS viewer; Architectural technology; Architectural art; Structure and materials

1. Introduction

Against the backdrop of China's reform and opening-up, architecture has sprung up like mushrooms after rain [1]. Prominent examples include the Bird's Nest designed by Swiss architect Herzog, the CCTV Headquarters designed by Rem Koolhaas, and the Guangzhou Opera House designed by Zaha Hadid (Figure 1). The presentation of these architectural structures often pursues novel, unique, and visually striking effects. While people willingly pay for this "visual consumption," they often overlook practical issues such as structural rationality, cost-effectiveness, and cultural heritage.

This paper uses computer visualization tools to analyze the research on the structure of contemporary large-scale public buildings and explores the expression of architectural structures in the new era. VOS viewer, developed by Nees Jan van Eck and Ludo Waltman of Leiden University in 2009, is a bibliometric analysis software used to visualize scientific knowledge maps[2, 3]. The software conducts co-occurrence network analysis and visualization in the form of scientific knowledge maps, exploring key information within various knowledge domains through cluster views, density views, and other methods. By applying the technology of VOS viewer in this study, the research hotspots of current large-scale public building structures can be efficiently and scientifically identified. The analysis results (Figure 1) show that the current research hotspots are concentrated in aspects such as structure and form, structural technology, and the nodes and materials of structures. However, there is less focus on creative ideas, technical thinking, and artistic thinking in architectural structural design, which are essential elements for the sustainable development of large-scale architectural structures. In general, the current research focus is on the external representation of structures, and there is insufficient understanding of the objective and rational aspects of architectural structural entities.

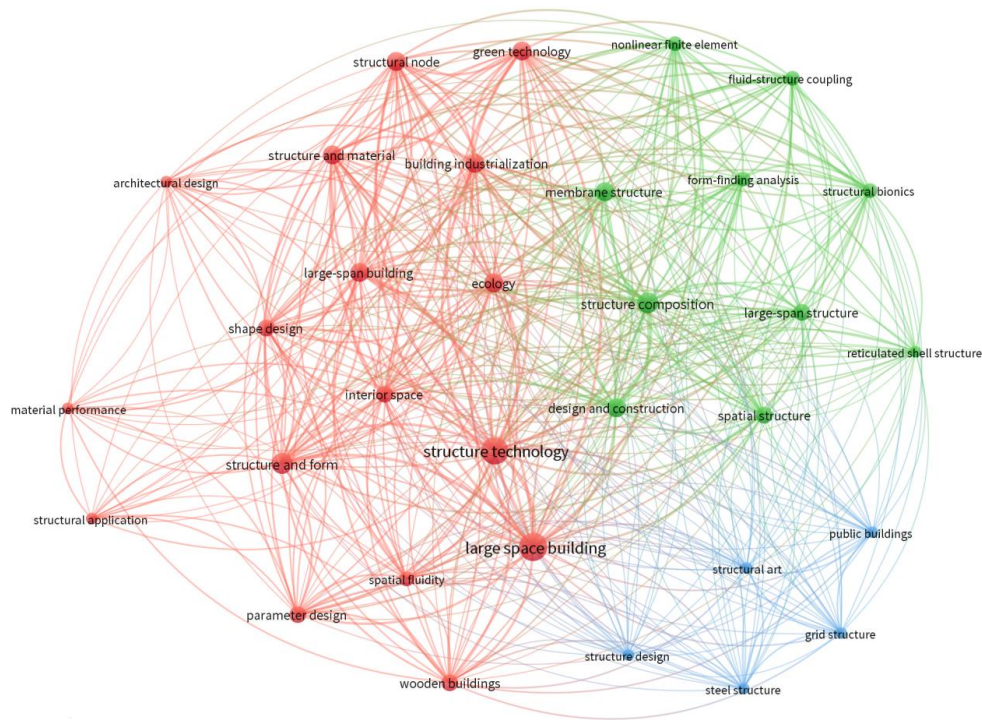
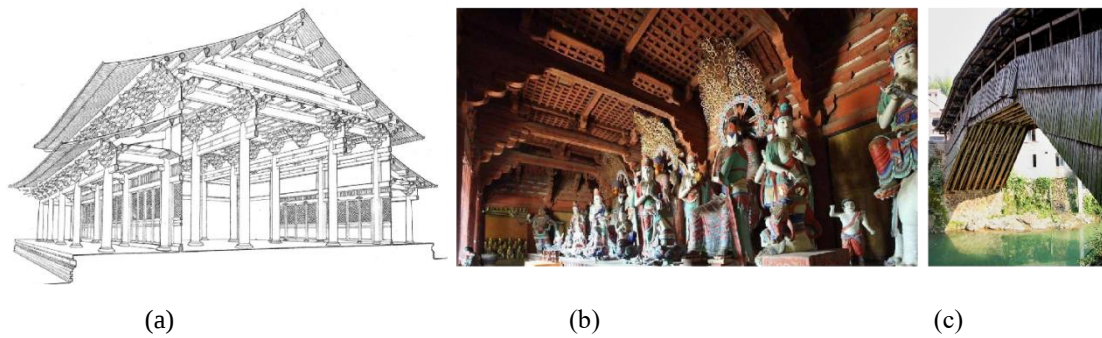


Figure 1 Cluster visualization view of keywords based on VOS viewer
(Self-drawn by the author.)

2. Reflection on the History of Structural Technology

The traditional timber construction in China offered a solution to the span problem by not only increasing the size of the beam but also employing cantilevering. In terms of structural thinking, it can be summarized as the positive or negative "overlapping". For example, in the architectural terminology of the Song Dynasty, the "raising beam style" can also be referred to as "overlapping" [4]. It is a primitive method of "replication and addition," where different-sized roof frames are stacked on top of each other, presenting a progressive or regressive arrangement. This method solves the problem of roof slope height and inclined surfaces, but the span problem still depends on the bottommost beam. From a mechanical perspective, this design does not undergo force decomposition, and its main function is to transmit vertical forces. Take the tangential hand of the Tang Dynasty as an example, the designer at that time simply continued a certain form, perhaps considering it stable, but certainly not considering it as a more reasonable force distribution [5]. Finally, in the Ming and Qing Dynasties, it was simplified to the Shu column.

In addition, the most relevant component to cantilevering is the dougong, which supports the beams layer by layer or extends far to support the overhanging eaves. The raised beam roof of official-style architecture, with horizontally receding beam frames, is like an inverted dougong. By progressively shortening the columns, the load is distributed to both ends of the beam to reduce the bending moment within the beam (Figure 2a). In terms of structure, although in the Tang and Song Dynasties, the inner circle of the jinxiang dou groove had protruding column tops and dou arches, attempting to minimize the distance between the two supports of the beam (Figure 2b), which improved to some extent the contradiction between the small size of the timber and large spans. However, the span created by dougong was still severely limited. The exception to this is the woven timber arch (Figure 2c). This structure intertwines straight wooden elements, forming a mutually supportive and interlocking relationship between components, creating a larger span arch structure (Figure 3).



Figures 2 Structural Analysis of arch of wooden architecture

(a)The restored structure of the Song Dynasty official-style architecture based on the "Yingzao Fashi"; (b)The protruding inner circle column top dou arch of the jinxiang dou groove; (c)The Min-Zhe wooden arch bridge supported by woven timber arches

(Image 2 is from Liang Sicheng's book "A History of Chinese Architecture" . Tianjin: Baihua Wenyi Publishing House, 1998.02. Images 3 and 4 are self-drawn by the author.)



Figure 3 The structural demonstration of the Min-Zhe wooden arch bridge

(Self-drawn by the author.)

Translation: Just as Mr. Liang Sicheng lamented in "A History of Chinese Architecture": "The ancient ruling class advocated frugality and virtue...thus architecture became a burden on the people and harmed agriculture...historical records may not depict it in a favorable light...resulting in architectural activities being seen as solely focused on economy and simplicity...the progress of craftsmanship was influenced by these factors" [6]. Ancient imperial and divine authority overshadowed the wooden structures of palaces, and the form of traditional architectural structures was determined by a higher level of ideology. Under strict architectural systems and cultural customs, craftsmen did not have the power to explore the possibilities of structural systems. Today's concept of "structural rationality" had limited room to develop [7]. Meanwhile, during the same period, in the West, architectural types represented by stone construction had already begun to explore the perfect integration of structural art and architectural art, starting from the development of arches and vaults. This division is rooted in the foundation of two architectural civilizations.

Furthermore, since the Western Industrial Revolution, the forceful entry of Western powers opened the doors of China, and Chinese architectural culture was forced to be included in the international perspective. The birth of modern Chinese architectural culture was primarily characterized by the rigid transplantation of industrial civilization [8]. During this period, there were a few instances of understanding traditional Chinese architectural structures, but it was mostly an interpretation of Western structural science. One could say it was an interpretation of Chinese wooden traditional architectural structures based on Western structural thinking. This kind of mutual translation was prevalent at the time and had become a prevailing trend. Although scholars like Chen Deng'ao and Mei Jikui actively explored domestic architectural structures during this time, both in theory, as seen in publications like "Conceptualization and Structural Selection of Large-span Structures" [9], and in practice, such as the exhibition hall featuring new structures like the hyperbolic paraboloid roof of Beijing Railway Station, which became an excellent representative of the "Top Ten Buildings." However, due to the

nationalist sentiment of the era, Chinese people were forced to accept industrial civilization on the one hand while being burdened by a deep sense of national identity on the other. The mentality of enduring humiliation and carrying a heavy load made it difficult to provide enough tolerance and openness to foreign structural forms. Additionally, the unstable national situation and turbulent social environment of the time greatly affected the dissemination of industrial civilization, thereby diminishing the depth and breadth of research on foreign structural forms.

Therefore, during this period, Chinese architecture experienced shocks, constraints, and introspection, and its lagging nature was hard to erase [10]. Profound introspection of its own origins is the necessary path to complete the transformation of architectural structural design today.

3. The Cognitive Paradigm of Structural Expression in Architecture

The questioning of "structural expression in architecture" in contemporary China coincides with the transition period from comprehensive market-oriented reforms to a moderately prosperous society [11]. It reflects the contradiction between higher demands for architectural expressive quality and the crude reality presented by architectural structures. In the face of this contradiction, contemporary Chinese architects need to stand on the timeline, clarify the fundamental meaning of architectural structural expression, continuously update their theoretical research and understanding, and ultimately find the correct answer. Therefore, there are two important tasks to be completed: 1) Returning to the essence of architectural structure and objectively and rationally understanding how this form is presented; 2) Sorting out its inherent requirements and exploring the expressive characteristics of architectural structures in the new era.

3.1 The fusion of technical and artistic thinking in structural expression

In the process of disciplinary development, people gradually realize that there should be no boundaries between disciplines, and the discipline of design has achieved continuous integration between technology and art [12]. The combination of individual creativity and the scientific application of materials and structural principles has become the path to successful expression in modern large-span architectural structures. As Stanford Anderson said, "Designers who have made breakthroughs in both technology and aesthetics can successfully grasp the final solution in architectural design" [13]. Mr. Feng Jizhong also pointed out, "Structure teaches you how to select sections rationally, economically, precisely, and comprehensively, while art teaches you exaggeration and expressive power. They should not contradict each other but complement each other. Balancing the two is the essence of design" [14]. Design is the medium that connects art and technology, and the two merge, coexist, dialogue, and intersect through design[15]. As the philosopher marco-diani pointed out, "Design becomes an indispensable intermediary that combines various one-sided aspects of science, technology, and humanities" . Therefore, whether it is "from art to technology," "from technology to art," or the "integration of art and technology," truly excellent structural expression is an organic fusion of technical and artistic thinking.

3.2 A rational attitude as the foundation of structural expression

Although the attainment of expressive structural forms relies on the designer's creative thinking, the foundation of structural expression should be rational. Successful construction must adhere to a rational spirit, which includes the logic of construction, structure, materials, and detailed joints. For structural forms, adherence to mechanical logic is the most fundamental and important point. As Heinrich Wölfflin said, "The opposition between material and formal forces becomes the theme of architecture," and what we experience is "the gravity that opposes the material" [16]. Structural design should follow the basic laws imposed by the materials and construction processes in resisting gravity. Rational mechanical principles serve as both the framework that constrains design and the source of innovative inspiration. Examples such as the Tao Yuan wooden bridge museum (Figure 4) and the Tama Art University Library (Figure 5) become exemplars of the integration of architectural art and scientific thinking.



Figure 4 Tawaraya Wooden Bridge Museum

(The left and middle images are from <https://www.archdaily.cn/>. The right image is redrawn by the author.)

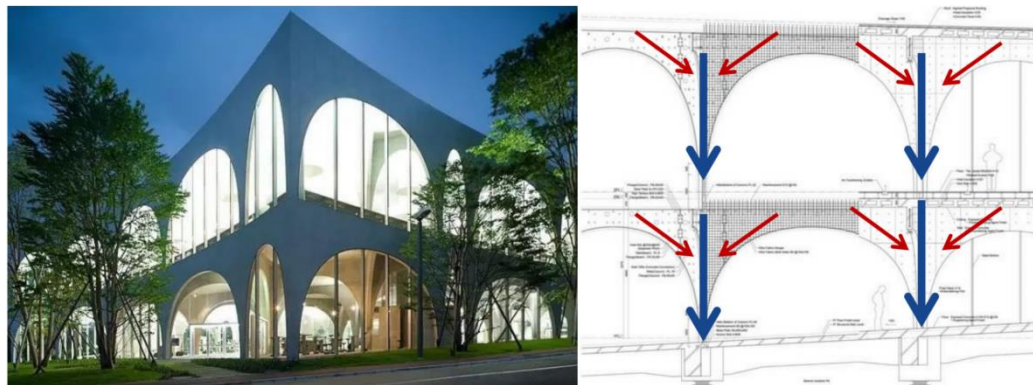


Figure 5 Tama Art University Library

(The left is from <https://www.archdaily.cn/>. The right image is redrawn by the author.)

3.3 The expression of architectural structure is a manifestation of creative thinking.

The aesthetic form of a structure is an important aspect of structural expression research, but form cannot exist in isolation from the artistic intent of architectural creation. While focusing on structural expression, it is crucial to pay attention to the underlying design ideas, contextual environment, generation process, and even specific construction methods. The Karato Seafood Market in Shimokitazawa City, Japan (Figure 6), is a representative case of a suspension structure. Architect Yoshiro Ikehara embodies the concept of "visualizing the transmission of forces" in his design. Through the structural design by Professor Masao Saitoh, a structural expert, a composite structural system consisting of a steel cable-stayed beam and diagonal cables was selected, providing a column-free space with a span of 44.8 meters for the market. Similarly, in the HSBC Headquarters designed by Norman Foster (Figure 7), the design achieves a spectacular column-free floor structure, clearly expressing the logical transmission of forces in the structure system constructed by steel and the direct correspondence between the architectural structural form and the flow of forces. Its structural form is highly integrated with the creative thinking.

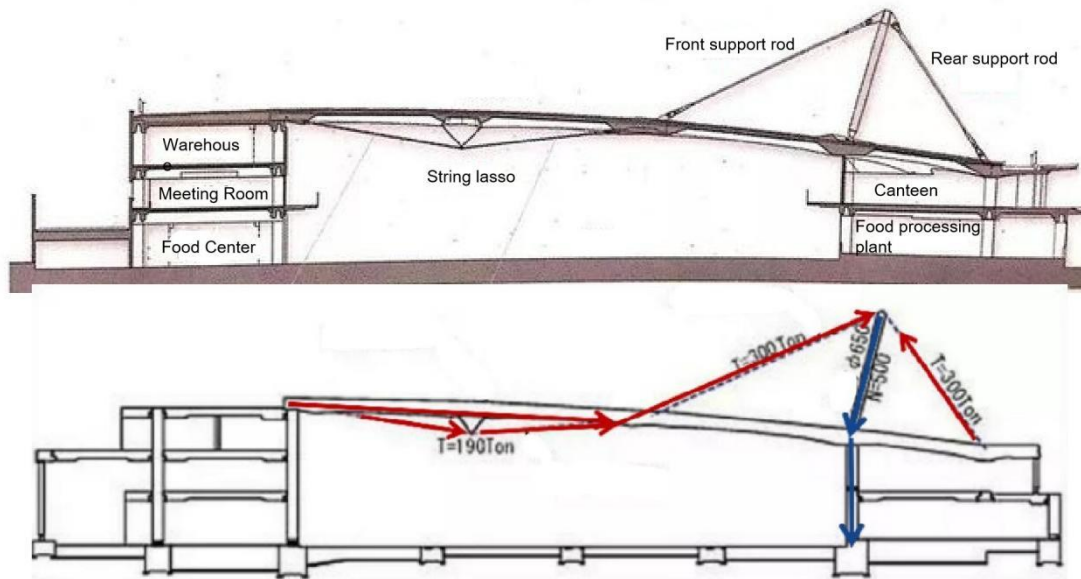


Figure 6 Karato Seafood Market in Shimokitazawa City, Japan

(The image above is from <https://www.archdaily.cn/>. The image below is redrawn by the author.)

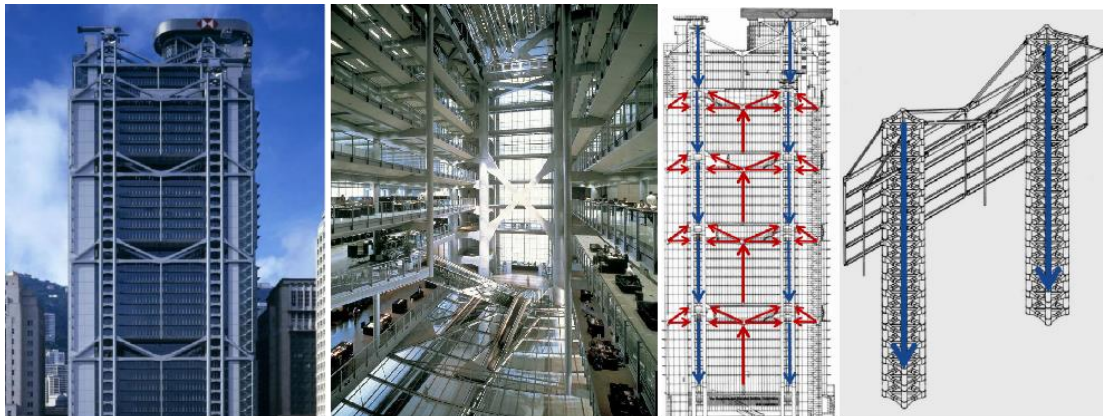


Figure 7 HSBC Headquarters Building in Hong Kong

(The left is from <https://www.archdaily.cn/>. The right image is redrawn by the author.)

4. Inherent Requirements of Architectural Structural Expression

The task of structural expression is to integrate social, economic, technological, and humanistic factors, applying structural logic and imaginative thinking to endow large-span buildings with emotional order and artistic attributes, imbuing them with profound connotations, distinct personalities, and graceful forms. The expression paradigm of architectural structure in the new era cannot be separated from an analysis of its inherent logic.

4.1 Architectural structure and structural expression

4.1.1 Establishing clear logic

The logic of architectural structural expression refers to providing visual clues associated with the structure, which can support the perception and understanding of the structure. Therefore, establishing clear logic is inseparable from the clear orderliness of architectural structure, which is characterized by rational organization and rigorous form. In terms of visual presentation, it exhibits clear coherence; in terms of structural expression, it endows the architectural work with its own integrity. Taking the Renault automobile company's product distribution center as an example (Figure 8), the overall structure is composed of standard module units

measuring 24 meters by 24 meters. Each unit is supported by four 16-meter-high columns. The arch-shaped steel beams are supported between two columns. To prevent the tall columns from becoming unstable, four steel cables exerting tension are added to the columns, forming a mast-like shape. The structural form has a distinct structural logic.

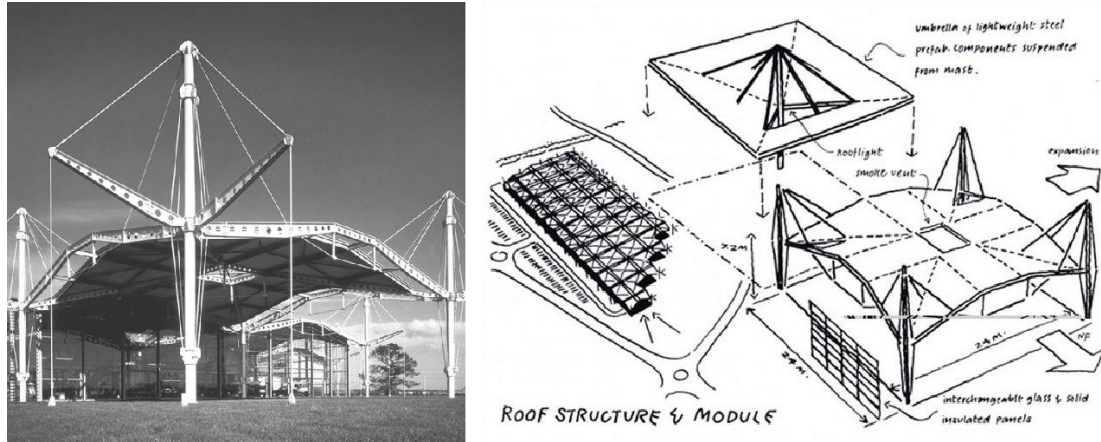


Figure 8 Renault Motor Company Product Distribution Center in the UK
(The image above is from <https://divisare.com/search/advanced/projects>)

4.1.2 Balancing Visual Experience and Cultural Value

Visual considerations are one of the key concerns for architects. Architects should explore the potential of architectural structural expression with a poetic and constructive attitude. They should not only respect the intrinsic logic of the structure but also enhance its visual experience to express the cultural values it embodies. Philip Cox (Figure 9) advocates that buildings should blend into the surrounding natural landscape, embody local cultural traditions, and possess a sense of contemporary spirit and vitality. [17] The design of the Sydney Convention Centre, for example, follows this principle in terms of its form, layout, and material selection. Domestically, buildings such as the Long Museum (Figure 10) actively explore the harmonious visual correspondence, where the large-scale protruding arch-shaped surface of the building is made of finely textured exposed concrete, forming a visual harmony with the "coal funnel" transformed fashionable space called "Doulang" from the original Beipiao Wharf structure.



Figure 9 Sydney Convention and Exhibition Center
(<https://divisare.com/search/advanced/projects>)



Figure 10 Dragon Art Museum
(Self-drawn by the author.)

4.2 Building materials and architectural structural expression

4.2.1 Respecting the will of materials and harnessing mechanical performance

For architectural structures, the structural form of a building is determined by aligning with the nature of the materials. Unearthing the essence of materials, harnessing their properties, and preserving their authenticity are indispensable aspects of the architectural design process. The structure and materials of a building are interdependent. The emergence of new materials inevitably leads to the appearance of new structural forms, and these new structural forms, in turn, fully exploit the mechanical properties of the materials, forming a unified entity of mutual reciprocity and symbiosis. As mentioned earlier, the Min-Zhe Timber Arch Bridge, which relies on wooden supports, is a result of continuous exploration by ancient Chinese people. Based on the characteristics of bamboo (Table 1, 2), the arch structure made of assembled timber fully harnesses its mechanical performance, achieving an exceptional span of 30-40 meters [18]. This breakthrough span also demonstrates the mechanical properties of bamboo.

Table 1 Comparison of Various Properties between Bamboo and Traditional Building Materials

Building materials	Compressive strength (N/mm ²)	Density	Ratio
Concrete	12.6-126	2400	0.053-1.575
Steels	250-350	7800	0.032-0.045
Wood	43	600	0.072
Bamboo	64-110	600	0.011-0.183

Table 2 Mechanical Properties of Bamboo (Strength Unit: N/mm²)

Project	Strength	
Grain direction	Tensile strength	150
	Compressive strength	65
	Compression	59
	Radial compression	11.5
	Splitting	2.3
Cross grain	Radial compression	10.6
	Tangential compression	20
	Flexural strength	1157
Transverse grain compression	Tangential	22.6
	Radial inward edge	154
	Radial outward edge	22.8

4.2.2 Upholding the Principles of Suitability and Ecology

In a speech, Perret once said, "Modern architects' works do not need to be astonishing as long as they do not violate functional requirements and the performance of modern materials... Such buildings may seem ordinary but can withstand the test of time... The true goal of art is to continuously lead us towards satisfaction through dialectical processes, surpassing novelty and reaching the pleasure of pure form" [19]. Perret's speech

highlighted the core principle of material selection in architectural structure. Upholding suitability and ecological considerations represents the purest form of interpreting the harmony between humans and nature. In recent years, China has also begun to consider the comprehensive principles of natural ecology in structural design. For example, in an exhibition building design project in which I participated (Figure 11, 12), the design criteria explicitly required the selection of building materials based on ecological factors. Even in the early stages of exploration, where we are "feeling the stones while crossing the river," surprises will always emerge in the process, particularly in the context of the domestic architectural environment.

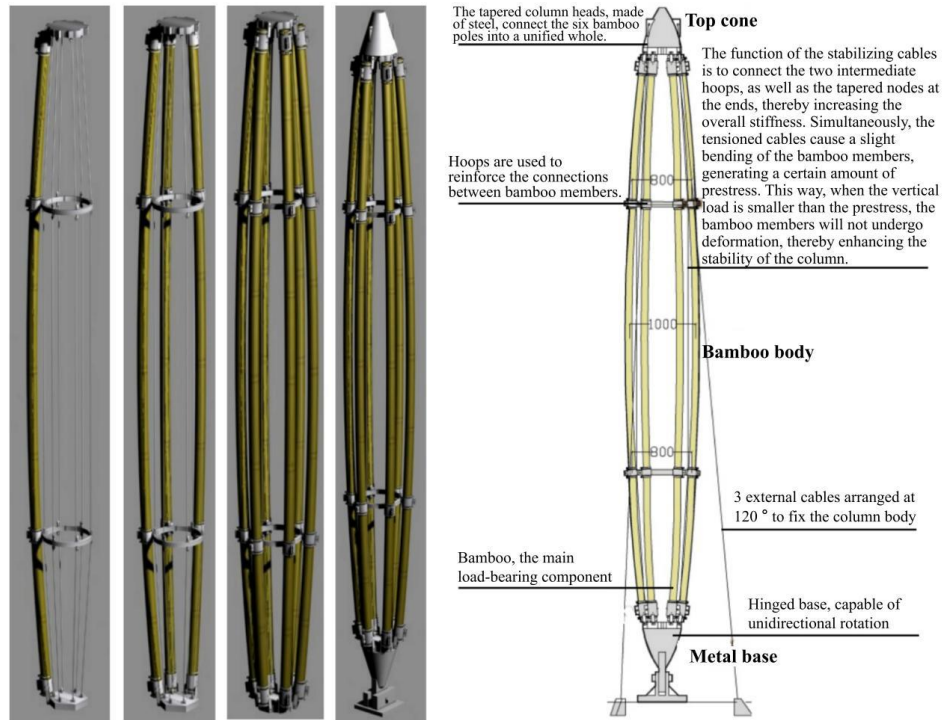


Figure 11 Bamboo as the main material for shuttle components
(Self-drawn by the author.)

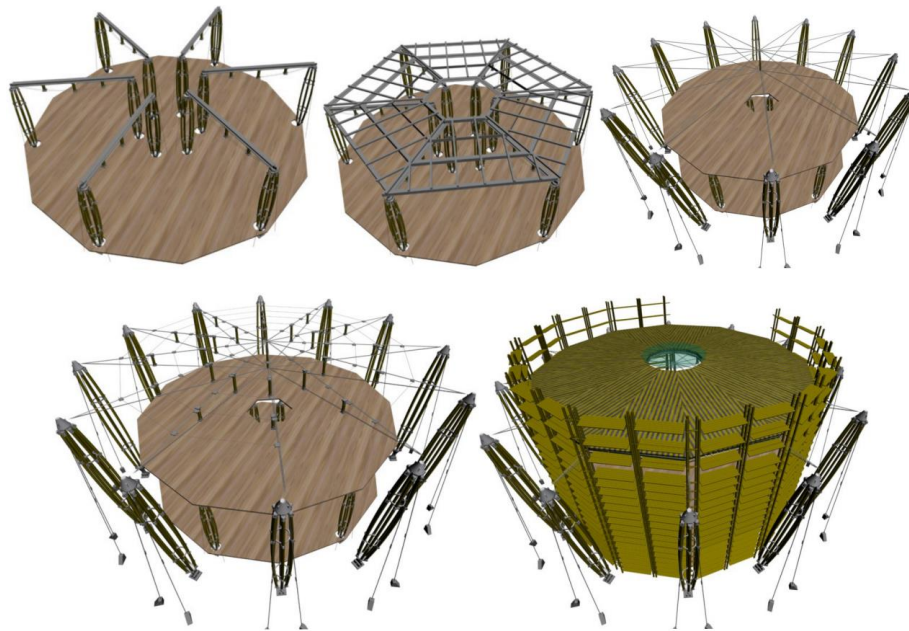


Figure 12 Architectural design of exhibition hall with bamboo structure
(Self-drawn by the author.)

4.3 Building nodes and structural expression

Modern architecture often employs the technique of exposing structural elements to showcase technological beauty, and the design of structural nodes is often endowed with special significance. As expressive structural components are often exposed, the exposed nodes naturally become an integral part of the architectural image. As Vittorio Gregotti pointed out, "The entire constructive potential of architecture lies in transforming the building itself into a poetic and cognitively capable construction ability." [20]

4.3.1 The expression of nodes should incorporate aesthetic principles

The expression of architectural structures at a micro level lies in the exquisite beauty of details and nodes. As Mies van der Rohe said, "God is in the details." Nodes are both the focal points of structural forces and visual attention. They serve as the transformation of structural forces and carriers of visual forms. Therefore, the expression of architectural nodes needs to have a clear dual meaning, respecting both internal rationality and external form (Figure 13).

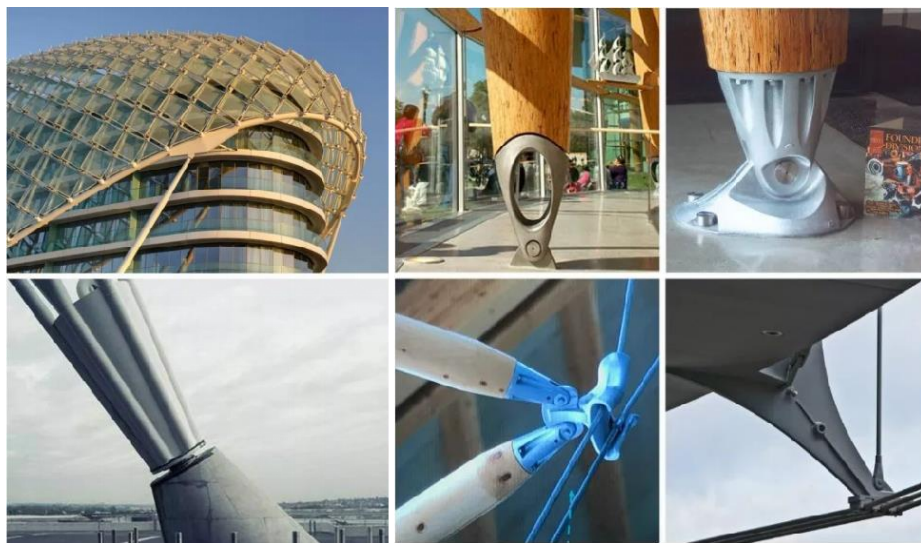


Figure 13 Exquisite treatment of building nodes
(<https://divisare.com/search/advanced/projects>)

4.3.2 The expression of nodes should follow construction logic and overall concept

Component manufacturing in factories and on-site assembly are the most prominent characteristics of architectural production after industrialization. Therefore, the design of architectural nodes should comply with the construction process while presenting a certain aesthetic appeal. Additionally, the node design in the expression of architectural structures should serve as a "strengthening" or "reflection" of the overall structural concept, emphasizing its coherence. In buildings with a coherent design, some nodes need to be emphasized while others require a more subtle approach. Otherwise, the overall architecture may be overwhelmed by exaggerated details and chaos. Washington Dulles International Airport (Figure 14), with its new structure, created a highly concrete avian architectural image. Eero Saarinen described his work as follows: "All these details, from the lines, spaces, and elements to the display screens and boarding gates, are designed to harmonize with nature... Every part here resonates with other designs, making one feel immersed in a complete little world." [21]



Figure 14 Washington Dulles Airport
(<https://divisare.com/search/advanced/projects>)

5. Conclusion

By using the VOS viewer tool in the field of computation, a visual analysis of the structure of large-scale public buildings is conducted, and based on this analysis, further elaboration is made. Overall, this paper, in tracing the history of structural technology, reveals significant differences in the development paths of structures between the East and the West. This historical background inevitably dilutes the purity of the current architectural structural efforts in our country. Therefore, standing on the long axis of time, it is necessary to start with reflection and analysis, clarify the objectives of public building structural design, conduct continuous and updated theoretical research and reevaluation, until finding a correct answer for today's architectural structural design.

Furthermore, it is worth noting that there have been significant differences in speculative thinking between the East and the West for a long time. Relatively speaking, traditional Chinese philosophy places more emphasis on developing a pure conceptual philosophical system and pursuing the "artistic conception," "temperament," and "spiritual charm" of architecture. In the face of the rational culture impact of Western architecture today, its unique artistic and theoretical values should not be lost in the torrent of development. Therefore, there is still much work to be done in translating traditional timber structures into modern architectural structural design, and the pace of establishing a confident architectural culture for the new era should not come to a halt.

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