

Article

Spatial Silhouette: A Study on the Creation Strategy of Strong Bamboo Architecture with “Negative Space” as the Main Feature—A Case Study of Phu Quoc Island Visitor Centre, Vietnam

Chaoxian Li ^{1,2} , Jiaojiao Ma ¹  and Xiaoming Gao ^{1,2,*} 

¹ School of Architecture and Urban Planning, Shandong Jianzhu University, Jinan 250101, China; 13946@sdjzu.edu.cn (C.L.); 2021055234@stu.sdjzu.edu.cn (J.M.)

² KAM, Kinetic Architecture Modular Research Lab, Shandong Jianzhu University, Jinan 250101, China

* Correspondence: gxm1983@sdjzu.edu.cn

Abstract: The Gestalt theory of mental completeness in architecture gave rise to the ideas of “positive space” and “negative space”. This research digs into the sturdy structural building process of bamboo architecture, which is essentially distinguished by “negative space”. It examines how bamboo is articulated in architectural space, while attempting to establish a balance between form and structure, with the goal of discovering the current value and spiritual position that bamboo in architecture represents. Using the Phu Quoc Island Visitor Center in Vietnam as an example, we introduce the strong structure concept and examine its design process in terms of spatial operation technique and strong structural expression logic. The fundamental strategy for creating bamboo architecture under this concept is to take the lead in negative space design and use the material capabilities of bamboo to build structural space prototypes. This further encourages the use of green building materials and offers architects working with bamboo a reference.

Keywords: negative space; strong structure concept; bamboo architecture; structural prototype; construction strategy



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1. Introduction

Pier Luigi Nervi points out in his book “The Art and Technology of Architecture” that architecture has both artistic and technological qualities. To develop the union of the two, the logical structural language and the vivid architectural design language must be united [1].

The architectural space showcases the ideal marriage of technology and art. In terms of spatial understanding, the concept of “completion” in Gestalt psychology refers to a holistic and organic structure which emphasizes an individual’s knowledge and understanding of the wholeness of things, and is made up of a combination of positive and negative shapes, which can be used by creators to create works with stronger visual effects [2]. The book also introduces the concepts of “positive space” and “negative space” in architecture, which are important aspects of visual literacy and have implications for both perception and creativity. Space in architecture is enclosed by structure. The concept of structure is explored in detail in the book “Words and Architecture”, which describes structure as the support system of a building [3]. Finally, technology and art are representations of architectural structures in connection to space.

Throughout history, the relationship between architectural structure and space has occasionally been different from one another [4]. During a time of rapid technological advancement, certain structural designs descended into rigid Baroque, creating a rift between technology and art. Architects have combined structural design with space shape to create a number of renowned masterpieces. For example, Louis Kahn’s Kimbell Art

Museum created a spiritual space by continually using sixteen arched space units [5]. With advancements in construction technology and building materials, there has been a growing focus on the integration of structure and space in architectural design.

To accomplish organic integration, spatial operation and structural logic must therefore activate one another. Functional requirements and humanistic perception shape space operation concepts and methodologies, drawing attention to the rational design of the spatial organization's order structure. Technical rationality is where structural logic has its roots. Architects need to combine functional needs, humanistic needs, and technical rationality, etc. in architectural design to achieve an organic combination of the two, so as to find a structural form that is more suitable for space realization [6].

Bamboo is one of the ecological building materials for which structural logic and spatial activities are considered in artistic endeavors [7]. Bamboo buildings have a different structural logic because of the disparities in architects' design approaches. When designing structures, some architects concentrate on the structural qualities of bamboo, utilizing it as columns and in combination with other materials to support weights [8].

However, this creative notion limits how materials can be used to shape architectural space. Some architects are passionate about parametric technology and use bamboo's bending qualities to weave non-linear structures and achieve distinctive looks. The internal experience of space shape is disregarded in this design approach. One of the leading practitioners of bamboo architecture is Vo Trong Nghia. He has studied bamboo architecture extensively and paid close attention to how structural elements shape architectural space—especially the Phu Quoc Island Visitor Center in Vietnam, which is one of his best works. The linear arrangement, axis rotation, and other functionalities of bamboo structural units result in a variety of spaces.

This innovative idea aligns with the recently suggested “strong structure” concept in architecture, which examines how to blend art and technology in structural design [9]. “Strong” is one of these concepts; it can indicate several things. Architects design structures that do more than just support weight. This concept not only performs the essential structural tasks, but it also significantly alters the building's design and layout [10]. This concept's emphasis on structural ambiguity can improve the relationship between structure and space in the creation of bamboo architecture, whereas “strong structure” encourages structural innovation based on architectural intentions, both of which are useful in researching bamboo architecture creation methods [11]. Consequently, this was brought into the domain of building design using bamboo.

Bamboo architecture will concentrate on how the structure shapes space under a strong structural concept. Researchers mostly concentrate on bamboo structural construction methods, bamboo building structural node construction, structural construction systems, structural composition methods, and space shape while evaluating the global research trends in this field. Research on the relationship between structure and space in bamboo construction is conspicuously lacking, nevertheless. The majority of the links between the two clearly classify structural systems, but there is a glaring absence of investigation into techniques for manipulating space under structural influence.

Thus, using pertinent research on the idea of strong structure and negative space as a foundation, this article develops a design approach for the strong structural concept of bamboo architecture by utilizing innovative ideas and operational techniques. We observe how bamboo architecture strikes a dynamic balance between its structural logic and its spatial operation, and investigate how bamboo architecture creates its spaces within the framework of strong structure ideas.

Based on the strong structural design thinking about structure and space in this bamboo architecture case, this study uses a case study approach to analyze the spatial manipulation and material construction logic of the Phu Quoc Island Visitor Centre case in Vietnam through illustrations and then refines a design strategy for creating architectural negative space using bamboo structures (Figure 1). This paper focuses on the following issues:

- (1) The connection between the concept of strong structure and bamboo architectural design;
- (2) The creation strategy of the bamboo structure to shape the negative space of the building.

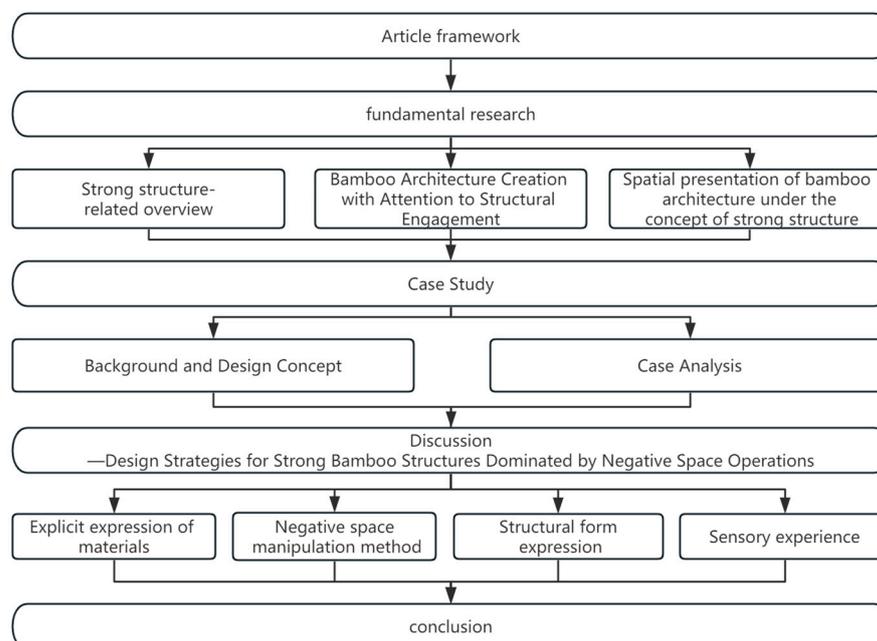


Figure 1. Research framework diagram.

This research is divided into five parts: the first part is the introduction; the second part is an overview of the theories related to strong structure and bamboo architecture; the third part is a case study; the fourth part is a discussion that proposes a strong structure of bamboo architecture dominated by a “negative space” strategy; and the fifth part is the conclusion.

2. Synopsis of Strong Structure Ideas and Associated Theories in Bamboo Building

2.1. Background and Related Overview of Strong Structure Ideas

The way that architecture and structure are related is always changing. During the early Renaissance, architects were all-rounders who worked on building projects from start to finish. During the Gothic era and up until modernism, architectural design was intimately related to the craftsmanship of construction. Following modernism, rapid advancements in computer-aided technology led to the separation of structural calculation work from the architectural profession and its delegation to structural engineers. “Architecture should look like a structure” is something Alberti stated in “On Architecture” [12]. Stated differently, the structure ought to convey a greater significance than merely supporting weight. Architects and structural engineers, both domestically and internationally, have come to the realization in the 21st century that this unbalanced situation is temporary. In order to illustrate the function and importance of structure in architecture, the Architectural Institute of Japan organized a related travelling exhibition in 2008. The 2014 Sino-Japanese Structural Architecture (Archi-Neering) Academic Symposium fostered discipline integration by examining the connection between structural and architectural design [13,14]. With the current speed at which digital technology is developing, structural design has progressively become more rigidly Baroque. Some architectural works of art which emphasize pure structural expression and are separated from structure are the result of structural engineers’ artistic studies. But there are also extreme examples, such as separating technology from art and concentrating solely on formal expression or structural form. There are also real-world examples which show how architectural structures can be both technically

sound and artistically pleasing. Thus, architects ought to strive for a balance between art and technology, which also leads to the development of strong structure ideas (Figure 2).

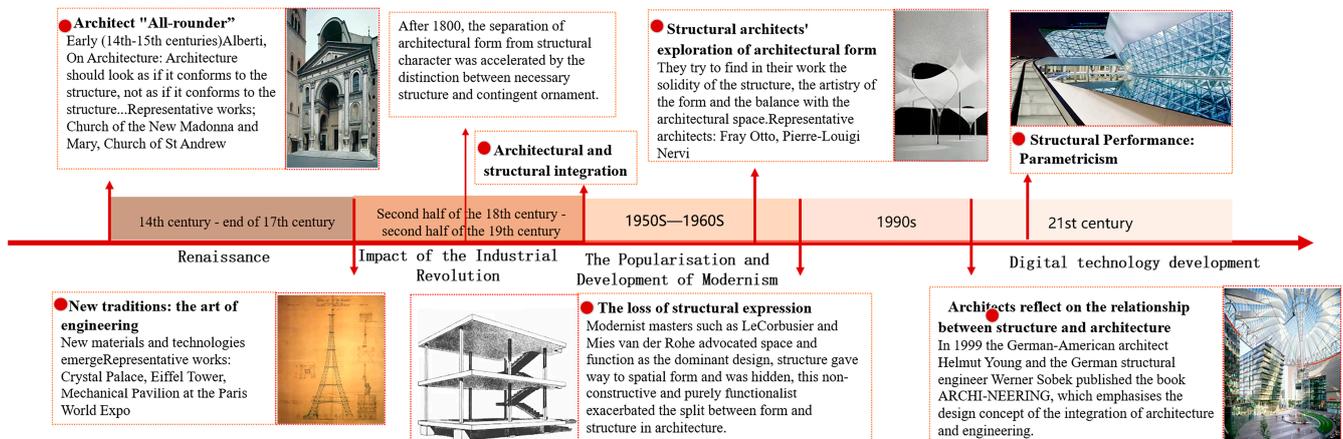


Figure 2. Development of the relationship between structure and architecture.

In order to identify the traits of this kind of construction, Arthur Rugg originally put up the idea of “Starke Strukturen” (strong structure) in the fifth issue of the Swiss journal “Werk, Bauen + Wohnen” in 2009 [15]. The criticism of the adoration of technology gave rise to the term “strong structure”. More attention is paid to the interaction between people and the structure, as well as how it affects space, than to the load-bearing efficiency and optimization techniques of the building.

The architectural design offers an entwined interpretation of space and structure in a variety of materials under the idea of strong structure. Using the architect Toyo Ito as an example, he constructed thirteen frame columns out of steel. Every plane displays a free plane’s form [16]. The structural column frame spans the floors and curves along the diameter, irrespective of the facade. He created a continuous arch structure out of concrete for the Tama Art University Library which divided the inside of the structure into several quadrangular and triangular areas [17]. Shigeru Ban can also be used for illustration. He built the Nine Bridges Golf Club, where wood is artfully woven into umbrella-like columns that organically reach the roof. In the discipline of bamboo architecture design, designers skillfully combine structure and open space with bamboo. This summary indicates that, due to the distinct material properties, different materials give rise to unique spatial atmospheres (Table 1).

Table 1. Strong structural presentation with different building materials [18–21].

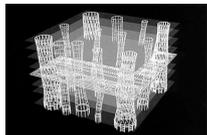
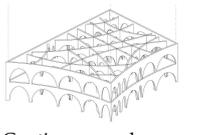
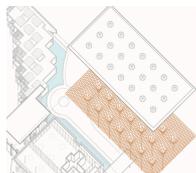
Building Materials	Material Characteristics	Design Standard	Maximum Span of Structure	Representative Cases	Structural Features
Steel	High strength, good plastic toughness, excellent weldability and assemblability, and poor fire and corrosion resistance.	Specification for Structural Steel Buildings (ANSI/AISC 360-22)	No fixed limits, subject to overall structural design	 a. Sendai Mediatheque	 Special-shaped structural columns dominate the space
Concrete	High strength, durability, cost-effectiveness and malleability	American Concrete Institute. (2017). ACI 318-2017: Building Code Requirements for Structural Concrete and Commentary. Farmington Hills, MI: American Concrete Institute.	No fixed limits, subject to overall structural design	 b. Tama Art University Library	 Continuous arch structure under a floating grid system.

Table 1. Cont.

Building Materials	Material Characteristics	Design Standard	Maximum Span of Structure	Representative Cases	Structural Features
timber	Natural, environmentally friendly, renewable, lightweight and with excellent thermal insulation properties, as well as good visual and tactile effects.	ANSI/AWC NDS National Design Specification for Wood Structures	Wooden houses: approx. 12–18 m Large span glued laminated timber structures: approx. 40 m CLT cross-laminated timber frame: up to 60 m	 c. Nine Bridges Country Club	 Hexagonal mesh roof structure
bamboo	Fast-growing, highly renewable, environmentally friendly, low-carbon and with a high strength-to-weight ratio, it excels especially in earthquake resistance and energy efficiency, but requires high weather resistance and fire treatment.	ISO22156:2021—Bamboo structures—Bamboo culms—Structural [21]	Bamboo buildings: around 20–30 m	 d. Roc Von Restaurant	 Bamboo woven into 12 giant structural columns

2.2. Overview of Bamboo Architecture Creation with a Focus on Structural Engagement

Bamboo’s exceptional mechanical qualities and structure have drawn the interest of numerous scientists [22]. Their interest is first and foremost about the study of bamboo’s structural characteristics, with researchers conducting experiments to gather data and conduct a comparative analysis of bamboo’s structural characteristics (Figure 3). After comparing bamboo to steel and spruce wood, it was determined that bamboo is a green building material with a short growth cycle, a tensile strength greater than three times that of wood, and a reputation for being plant-reinforcing steel [23]. But bamboo also has certain disadvantages, such as a low weather resilience and a susceptibility for damage during severe weather. Consequently, a lot of material scientists have worked to improve bamboo’s mechanical qualities and weather resistance through pre-treatment, chemical, and physical methods, which will increase its service life.

Comparison of selected mechanical properties of spruce wood, steel, and bamboo



Figure 3. Comparison of selected mechanical properties of spruce wood, steel, and bamboo. Source: own elaboration based on the work presented in ref. [23].

Other studies have analyzed and examined the environmental effect of bamboo construction materials throughout their life cycle, which operate as carbon sinks, reducing global warming and providing a more pleasant atmosphere [24].

While developing the relevant codes, the International Network for Bamboo and Rattan (INBAR) convened experts from all over the world to prepare ISO 22156, which focuses on the design of round bamboo structures and applies to bamboo structures with round bamboo as the main load-bearing member or shear wall structures made of round bamboo and is limited to residential, small commercial, or public buildings with less than two floors and a height of no more than 7 m, as well as light industrial buildings [21].

In this context, the architects use bamboo in their ongoing creations. Markus Heinsdorff, a German architect, constructs contemporary bamboo structures with distinctive structural forms using prefabricated building techniques. In his publications “Mechanical Properties of Bamboo” and “Jules J.A. Janssen”, the Dutch architect compiled a comprehensive list of bamboo construction techniques and examined the material’s mechanical and physical characteristics [25]. In his book “Building with Bamboo”, he provides numerous real-world examples and particular bamboo operating techniques for reference [26]. Numerous scholars are now looking into the computerized construction of bamboo structures [27]. These establish the framework for the practice of bamboo architecture.

The consideration of bamboo structures has always been evident in the planning and construction of bamboo buildings. The majority of the designs generate architectural spaces with specific organizational techniques using bamboo structural parts. Rich forms are displayed in bamboo buildings in various structural configurations. We use German architect Heino Engel’s classification scheme for building structural systems as a model for categorizing the structural systems of bamboo buildings. Bamboo building structures are classified into two categories: surface-acting structural systems and vector-acting structures, based on elements including the structure’s shape and stress characteristics. The system comprises the following: structure, function, and form [28] (Table 2).

Table 2. Spatial presentation of bamboo buildings under different structural systems.

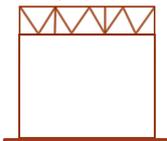
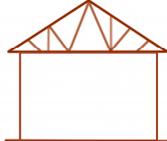
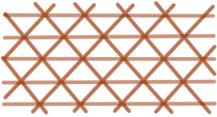
Structural System	Mechanical Characteristic	Structure Type	Representative Case	Space Features
Structural system of vector action	A vector-acting structural system is a structural system in which forces are decomposed and transmitted in different space vector directions by means of linear structural members.	Rectangular trusses 	 JiuFeng Village Hall	A large space without columns, separated by the ambiguous bamboo pole interface.
		triangle truss 	 The Nomadic Museum	The linear display of the bamboo structural units is an enhancement of the interior space.
		arch truss 	 Panyaden International School Gymnasium	The establishment of the arch truss structure creates a large interior domed space.

Table 2. Cont.

Structural System	Mechanical Characteristic	Structure Type	Representative Case	Space Features
Structural systems under morphological action	Single stress structural systems, where the members of the structure are subjected to only one single stress, such as pressure and tension.	Bamboo Arch Structure 	 International Bamboo and Rattan Pavilion at the Beijing World Expo	Large span column-free space.
		Bamboo cantilever structure 	 Wings of Bamboo	Feathery structures create distinctive gable spaces.
		bamboo pillar arch 	 Naman Retreat Conference Hall	A linear array of repeating bamboo arch structures creates two different sized spaces, the main use space and the colonnade space.
Structural systems under surface action	The members of a structural system under surface action are mainly subjected to film stresses, and the members of the structure are wrapped around each other to resist the tensile and thrust forces in the structure.	Gabion net structure 	 Yangshuo Bamboo Pavilion	Forming flowing spatial forms through gabion weaving.
		Bamboo pole woven mesh shell structure 	 ZCB Bamboo Pavilion, Hong Kong	The arched mesh structure forms a public event space.

(1) Vector action structural system:

Via linear structural members, the vector action structural system breaks down and transfers forces in various spatial vector directions. Bamboo can be used to create arched, triangular, and rectangular trusses in architectural designs. For instance, the Jiu Feng Village Living Room's fuzzy bamboo pole interface separation produces a rich interweaving of light and shadow in the room, while the room's rectangular truss structure provides a huge area free of columns.

(2) Morphological structure system:

The constituents of the morphological action structural system, such as pressure and tension, are subject to only one stress. This is a single-stress structural system. The Naman Retreat conference hall, for instance, uses a bamboo arch style of construction. The linear array of repeating bamboo arch constructions creates two different spaces: the major usage area and the colonnade.

(3) Structural system of surface interaction:

Film stress primarily affects the structural system's constituent parts under surface action. After becoming entangled with one another, the parts of the structure work together

to resist strain and push. Bamboo pole woven mesh shell structure and bamboo strip woven mesh shell structure make up the structural system under surface action. For instance, structural engineers are needed for the ZCB Bamboo Pavilion in Hong Kong during the form-finding phase. The arching grid layout of the building delineates a public activity space.

We can conclude that bamboo has rich architectural forms under the structural system of morphological action; a truss structure forms and a large-span column-free space is created under the structural system of surface action; and architectural space and structure are integrated under the structural system of vector action. Generally, after being weaved, bamboo, whether it is in the shape of sheets or rods, develops a specific structural system. The overall shape of the structure is shaped by the structural system selection. In addition to providing mechanical support, the bamboo architectural framework is essential to the overall visual presentation and place creation.

2.3. Spatial Presentation of Bamboo Architecture under the Concept of Strong Structure

Based on an overview of the strong structure idea and a survey of the literature on bamboo structures, the relationship between bamboo architectural design and the strong structure concept is investigated. Finally, we summarize the relationship between the structure and space of bamboo architecture under the concept of strong structure.

- (1) Analysis of the correlation between bamboo architectural design and the strong structure concept (Figure 4).

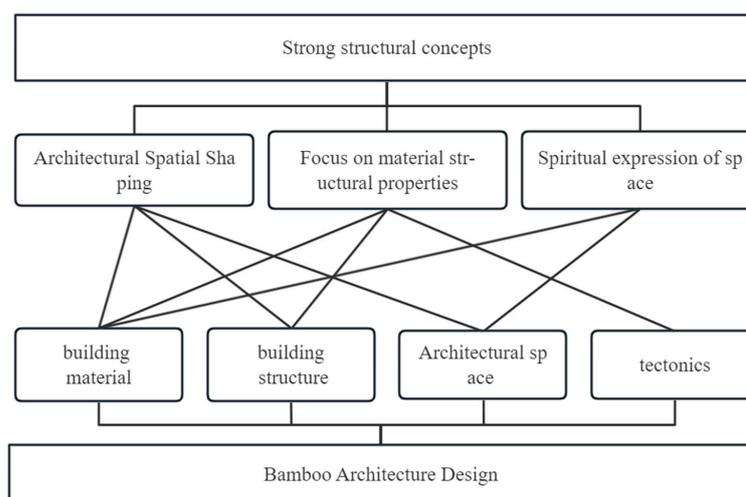


Figure 4. Association of bamboo architecture with the strong structure concepts.

To compare and evaluate the distinctive features of the two and to identify the links between the two in order to investigate whether the design of bamboo buildings can benefit from the strong structural concept, it is essential to perform the following:

- Pay attention to the visual expression of the structure; this is where the primary focus of the strong structure concept. Bamboo architecture is a unique form of building. A building's texture, shape, and joining method can give it a unique visual identity made of bamboo materials.
- Be mindful of how structure affects space; the idea of strong structure explores people's perceptions of space and centers on how structure shapes space. The architectural style of bamboo buildings also reflects it. Architects intentionally convey the rich features of the bamboo building structure by actively taking on the function of the structure rather than passively adjusting to its strength.
- Be mindful of how structure expresses itself spiritually; the idea of strong structure explores how structural ambiguity is expressed and influences how people perceive rich spaces through structural design [29]. Bamboo architectural design is in line with

the idea of “strong structure”, since it places a high emphasis on spatial experience. It also aims to create a unique spatial environment by closely integrating structure, space, and concept [30].

- (2) Bamboo architectural design, where structure and space work together under the concept of strong structure.

According to the correlation between the strong structure concept and bamboo architecture, it is concluded that there is a consensus between the two in terms of the shaping of the structure in the space. Therefore, under the concept of strong structure, we explore the creation method of bamboo architecture and summarize the method of intervening in the spatial operation of bamboo architecture with structural elements so that the spatial operation can be triggered using the structural logic. Firstly, according to the performance of bamboo material, the form of its participation in architectural design is classified as linear and curvilinear. On this basis, bamboo architecture is classified according to the form of bamboo structural elements involved in architectural design: linear, surface, and block. Therefore, the presentation of the bamboo structure in space is summarized as the intervention of bamboo as a straight element, the intervention of bamboo as a curved element, and the joint participation of straight and curved forms of bamboo (Tables 3–5).

Table 3. Summary of case studies on the way linear bamboo structures intervene in architectural space.

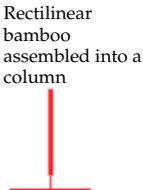
Curved Bamboo Intervenes as a Structural Element					
Rectilinear Bamboo Intervenes as a Structural Element	Structural Intervention Modus Operandi	Representative Case	Case Location	Architectural Style	Structure Type
① Linear elements (columns) 		 Sanlo Restaurant	Vietnam	Regionalism	Building systems under vector action
		 He louxuan	Shanghai, China	Modern regionalism	Building systems under vector action
		 Catuçaba Art Gallery	Brazilian	Portuguese style colonial farmhouse style buildings	Building systems under vector action
		 Handmade School	Bangladesh (formerly East Pakistan)	Traditional regionalism	Building systems under vector action

Table 3. Cont.

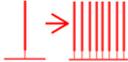
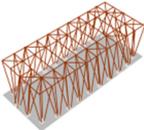
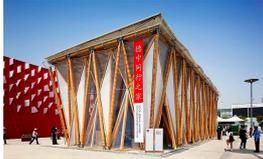
Curved Bamboo Intervenes as a Structural Element					
Rectilinear Bamboo Intervenes as a Structural Element	Structural Intervention Modus Operandi	Representative Case	Case Location	Architectural Style	Structure Type
		 bamboo house	Beijing, China	Naturalism (philosophy)	Decorative structures
② Faceted elements	Linear bamboo repeatedly constructed in a 2D plane 	 Soe Ker Tie House	Thailand	Regionalism, low-technology	Decorative structures
		 Mason Lane Farm	Goshen, KY, United States	Low-technology	Decorative structures
③ Block elements	Additive-linear repetitive construction of bamboo components in a 3D space 	 German-Chinese Peer House	Hangzhou, China (current location)	Modernism	Vector building structural systems

Table 4. Summary of case studies on the ways in which curvilinear bamboo structures intervene in an architectural space.

Curved Bamboo Intervenes as a Structural Element	Curvilinear Structure Intervenes in the Way of Operation	Representative Case	Case Location	Architectural Style	Structure Type
① Linear elements (columns)	Curve-shaped woven bamboo columns limit space 	 Kontum Indochina Café	Vietnam	Regionalism	Structural systems under morphological action
		 Bathroom Pavillion Flor de Babmú	Mexico	Structural geometrics (physics)	Structural systems under morphological action

Table 4. Cont.

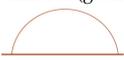
Curved Bamboo Intervenes as a Structural Element	Curvilinear Structure Intervenes in the Way of Operation	Representative Case	Case Location	Architectural Style	Structure Type
		 THE ARC	Indonesia	Low-technology	hyperbolic parabolic structure
② Faceted elements	Curves woven into overall spatial form (Geometric/Biological)	 Pavilion Of Clouds	Beijing, China	Green low technology	Structural systems under surface action
		 LUUM temple	Mexico	Naturalism (philosophy)	Structural systems under surface action
③ Block elements	Addition (geometric) 	 Xiamen Vocano Island_Nhà hang	Xiamen, China	Structuralism	Structural systems under morphological action
		 Sen Village Community Center	Vietnam	Naturalism (Philosophy)	Structural systems under morphological action

Table 5. Bamboo straight and curved forms of the combination of the constructive tables.

Operating Method	Representative Case	Case Location	Architectural Style	Structure Type
Combination of straight and curved lines	Subtraction (negative space)  Phu Quoc Island Visitor Centre, Vietnam	Vietnam	Regionalism	Structure combination

Table 5. Cont.

Operating Method	Representative Case	Case Location	Architectural Style	Structure Type
Interspersed nesting		Japan	Naturalism (philosophy)	
	Bamboo Forest			

- Intervention of bamboo in a linear shape

In this scenario, bamboo is mostly impacted by axial stress, and the design is based on the entire culm. When bamboo is introduced in the shape of a straight line, it is mostly displayed in the building with linear structural components, surface structural elements, and block structural elements. For example, in Vietnam's San Lo Restaurant, linear bamboo is utilized to make columns to construct a structure with regional features, while Kengo Kuma's Bamboo House in Beijing, China, employs continuous bamboo poles to form the walls of the interior decorations, which are natural.

- Bamboo in a curved shape.

When bamboo is used in a spatial building with curved shapes, it demonstrates the dynamic bending nature of bamboo. Similar to the classification of components used in linear forms, when bamboo is included in linear elements, it is mostly curved bamboo that is joined to make a certain type of column, as seen in Kontum Indochina. For example, Kontum Indochina Café features an umbrella-shaped bamboo structure. Some buildings, such as the Lum temple, are made entirely of bamboo.

- Participation of Straight and Curved Bamboo Materials

When the curvature and straightness of bamboo are combined to construct a building, the negative space and space nesting methods are primarily used, as seen in the Phu Quoc Island Visitor Centre, which employs both positive and negative space methods to highlight the bamboo structure's unique material characteristics.

From the analysis of the drawn table, we know that the architects have insisted on the creation of a bamboo structure space, which is mainly embodied in public buildings, residential buildings, landscape buildings, and temporary buildings. For example, The Arc, a public building designed by IBUKU, is used as a sports building to create a large space for people to play sports; He Gu Xuan, designed by Chinese architect Feng Jizhong, is used as a landscape building, echoing traditional culture while reflecting the pursuit of modern architecture.

And, due to the different regions, there are differences in the acceptance of bamboo. Summarizing the representative works of bamboo architecture in different regions and their stylistic features and contrasting the strong structural concepts in different regions of bamboo architectural design, this paper focuses on bamboo architectural design around Southeast Asia, exploring the method of interweaving structure and space in bamboo architectural design.

3. Case Overview and Analysis of Creative Methods

By examining the creative practice of bamboo architecture through the lens of the strong structure concept, we can gain an understanding of the fact that bamboo architectural constructions are typically displayed in public areas. However, bamboo-structured spaces show distinct forms because of the architects' varied design conceptions and techniques of space operation. Since 2008, Vo Trong Nghia has been utilizing bamboo materials in her artwork, and her concepts for bamboo architecture are comparatively developed. The

architecture of the Phu Quoc Island Visitor Centre in Vietnam not only embodies the characteristics of structure shaping space, which is in line with the architectural creation characteristics of the concept of “Strong Architecture”, but the design also embodies the cultural characteristics of Vietnam, with unique spatial treatments. Therefore, we chose this case to analyze and study its creation process.

3.1. Synopsis of the Case

(1) Creative background

The structure is situated on Phu Quoc Island, Vietnam, a tourist area. In order to portray Vietnamese traditional symbols and culture, Vu Trong Ngai merged images of lotuses and bronze drums in 2021 to create a massive edifice made entirely of bamboo which had 42,000 bamboo poles. The spatial form is richer, and the architectural structure system is more intricate than in Vo Trong Nghia’s earlier bamboo architectural works.

According to the specification requirements of the ISO 22156:2021 Design of round bamboo structures, architects will first select bamboo species that are suitable for building purposes, easily available locally, fast-growing, and strong, such as moso bamboo or jatropha bamboo, and treat the material with a drying treatment, anti-corrosion and anti-insect treatment, charring treatment, and other means of material pre-treatment. In addition to the construction procedure, the craftsmen utilized rope to bind the poles together into modular components, which they then assembled for installation. Because the Visitor Centre is a combination of several structural systems, the craftsmen first built the internal dome structure and the copper drum structure, and then on top of that structure, they used the square mesh structure to provide lateral thrusts from different directions, increasing the structure’s stability while also constructing the overall form. The overall shape of the structure was established.

(2) Architectural design concept

The Phu Quoc Island Visitor Center in Vietnam showcases the architectural concept of bamboo design, as thought through by VTN Architects. The example illustrates several design ideas, including the use of natural materials to create a space that blends in with the surrounding scenery, being near nature in its design, and integrating the building into its surroundings. The architecture affects the experience area; the design incorporates traditional culture; the lightness of bamboo allows the architectural structure to provide a light and translucent look; and Vietnamese culture is exhibited in the form of architecture and has some inherent meaning. VTN Architects skillfully crafted the bamboo structure to produce a building with a bright and beautiful interior.

In order to guarantee that architectural projects have internal consistency and purpose at all levels, the design concept of a building serves as both the source of inspiration and the guiding principle for architectural development. The Phu Quoc Island Visitor Center in Vietnam’s design concept places a great emphasis on experience space structure shaping, which aligns with the concept of strong structure, which supports structural ambiguity.

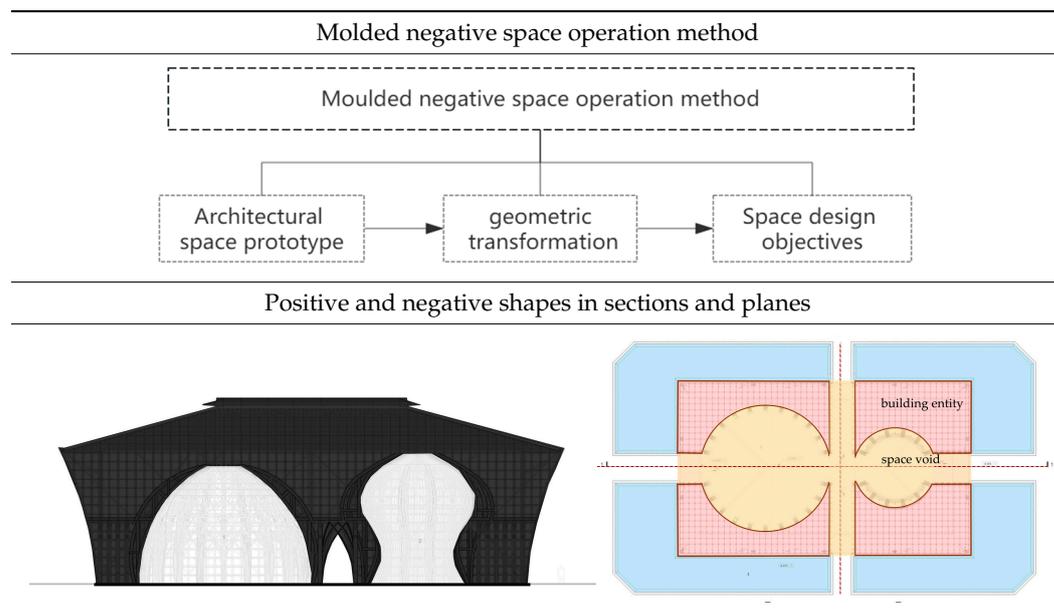
The objectives of this notion are typically met by controlling the way structural elements combine in a way that modifies the building’s overall shape.

3.2. Case Analysis

(1) Analysis of space operation methods

- Architectural negative space prototype: molded negative space

Poster design is another area where “negative space” is used as inspiration. The “picture-ground relationship” refers to the overall image that is created by the prominent graphics and the blank bottom [31]. In Art and Visual Perception, Rudolf Arnheim stated that space is a “container”, which has the capacity to keep objects indefinitely or finitely [32] (Table 6).

Table 6. Analysis of space operation methods.

- Space and the source of space form

The relationship between the building's solid and virtual items operates under the molded negative space operating method in a manner similar to that of the picture's bottom and bottom. A molded negative space prototype must be established before a virtual body experience area can be created. Further investigation leads to the conclusion that the case is predicated on Vietnamese cultural symbols, taking prototypes and converting them into spatial forms that are geometric. The external shape interprets Vietnam's rich culture by echoing the pitched roofs around it (Figure 5). There are three categories of internal space forms:

- a. A lotus-shaped area. The lotus, the national flower of Vietnam, served as the model for the building's shape. It is incorporated into the structure as a domed area that is covered in bamboo. The overall spatial form is similar to Paris's Pantheon. People are profoundly affected by the interplay of light and shadow, despite variations in spatial scale.
- b. A bronze chamber was formed like a drum. The National Museum of Vietnam History currently houses the Ngoc Lou Bronze Drum, a national asset of Vietnam classified under the Dong Son Culture. Its shape is inward-shrinking in the middle, with a huge top and little bottom. This picture served as the inspiration for the building's spatial form. The lower chamber retracts, while the top is also shaped like a dome. People interpret space and visual sensations differently because of the distinct overall shape of the place.
- c. A pointed area, shaped like a coupon. This area assumes the form of a sharp arch. At first, it was thought that the pointed arch found in Western classical architecture served as the inspiration. It is not at all like the latter in terms of its mechanical load-bearing or building techniques, yet people are drawn to it because of the pointed arch's continuous design.

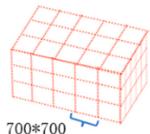
	Literary Echoes: Spatial Archetypes Extracted	Specific operations: spatial prototype translation	Results: architectural space presentation
external form			
interior space			

Figure 5. Diagram analyzing the process of translating spatial forms.

(2) Logical analysis of material construction

Materials are arranged and built to build a structural system based on the spatial goals. The correlation logic of structure and space in architectural development is investigated through an analysis of the building’s structural type and construction logic and an examination of how the building’s structural type, structural units, and construction nodes were used to create the architecture. From the fundamental structural unit to the entire structural system, and finally to the architecture and surroundings, the building’s form is progressively completed through the repetition of structural components (Table 7).

Table 7. Table analyzing the logic of bamboo constructs (source: self-drawing).

Constructive Logic Analysis				
Type of structural system	structural unit	combinatorial approach	final form	structural span (m)
① Network structure system 		Linear array 		33 m
② Dome structure system 		Rotating array 		14 m
③ Space structure system 		Rotating array 		8.5 m

- Structural Types and Structural Units

- a. Grid structure

The term “grid structure” describes a frame system made up of bamboo columns and beams that work together to support both vertical and horizontal loads when in operation. Linear bamboo is utilized to generate structural units and to form the exterior layer of the

building in the form of a grid structure system. Two bamboos grow at each latitude in the three-dimensional space, and six bamboos are intertwined to form a unit, with a linear array forming the outside of the grid system of organization.

b. Ribbed ring dome structure under the spatial structure system

Ribbed ring dome structures are the primary building blocks of the rib-ring dome structure, which primarily produces axial pressure along the arc. Bamboo’s bending resistance can be fully utilized under this structural system to produce a longer, more stable space.

First, the dome-shaped area. The inner dome’s bottom pillars are woven into the dome and have the shape of umbrella branches. Presumably, the external dome-shaped support structure is a crescent-shaped truss. The array is rotated to generate the structural units. The second space form is a translation of the dome-shaped space form, which is taken from the bronze drum shape. Since the structural components are curved overall, a special spatial form of “folding down and placing up” is created when they are rotated in an array.

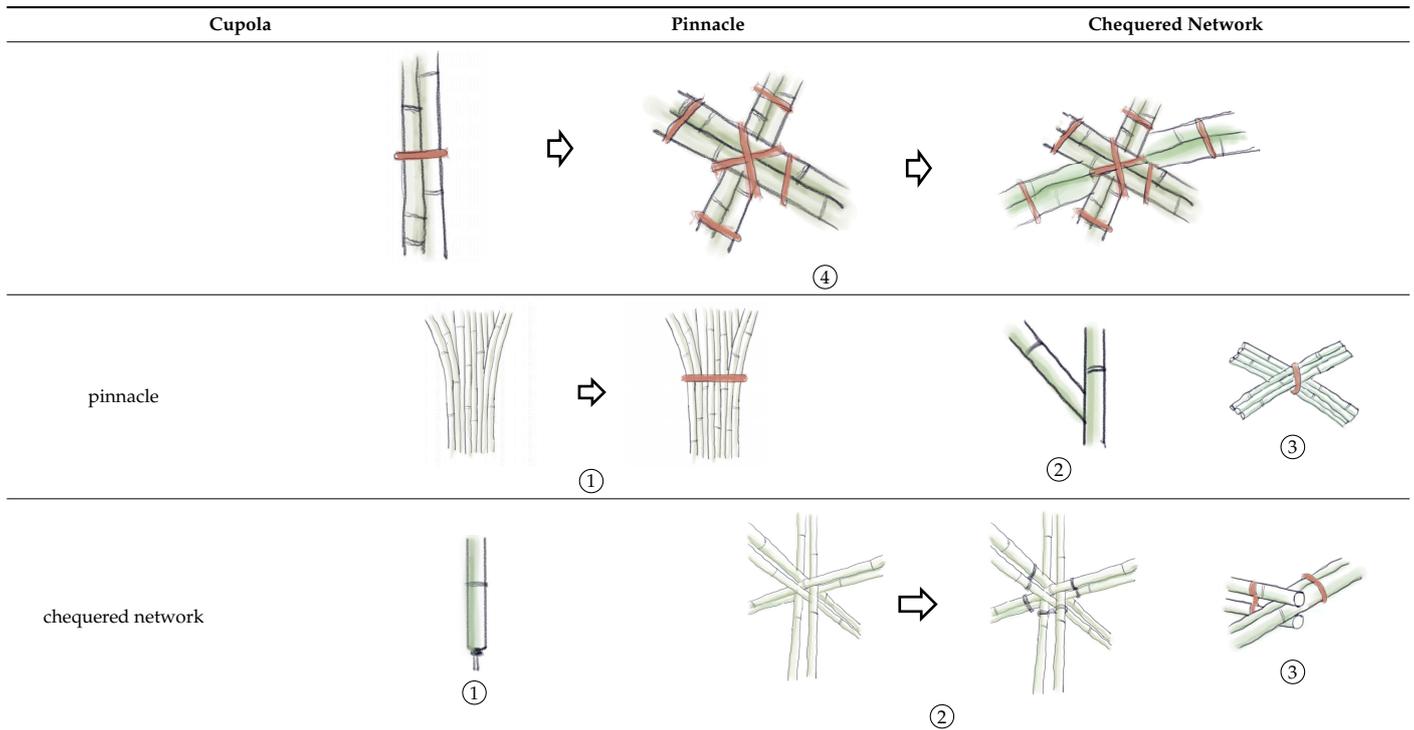
- Construct nodes

Tying, the oldest and most widely used connection technique, is mostly effective in resolving connection issues with bamboo materials [33]. In order to establish attachment, the connected bamboo materials typically cross either vertically or diagonally and are wrapped at the junction places. To create a structural stress unit for specific strength needs, a number of bamboo components are bundled and fastened together. Different structural types’ nodes are categorized and illustrated [34] (Table 8).

Table 8. Analysis table of bamboo structure nodes (source: self-drawing).

Cupola	Pinnacle	Chequered Network	
nodal			
cupola			

Table 8. Cont.



In summary, the design concept of this case is consistent with the concept of strong structure. According to the logic of structure shaping space, in the concept of strong structure, the spatial goal is established by the operation method of negative space, and the bamboo structural units are used to construct a molded space and finally establish the overall shape. This design method is referred to as the “space silhouette”.

The strong structure bamboo architectural design method, dominated by negative space, was extracted from the analysis of the research on the theories pertaining to strong structure and bamboo architectural structure, together with the particular instance of the Phu Quoc Island Visitor Center in Vietnam.

Initially, architects should consider the importance of a strong structure and how it shapes space while creating their designs. Secondly, they should locate spatial prototypes. Geometric techniques can be applied to change spatial prototypes that are abstracted from nature, culture, biology, etc. and transformed into a tangible spatial form; ultimately, the design is built using the mechanical and material qualities of bamboo in order to achieve its spatial goals (Figure 6).

Architects turn their ideas for abstract spatial configurations into real architectural environments through this method. The significance of architecture develops gradually, moving from mechanics to space to symbolic levels, whether it is in classical or modern design [35]. Structure is a symbol used to express a culture’s spiritual meaning. This is in line with the idea of a solid framework. In order to convey its distinct personality, emotion, and expression, the structure actively contributes to the construction of form and space.

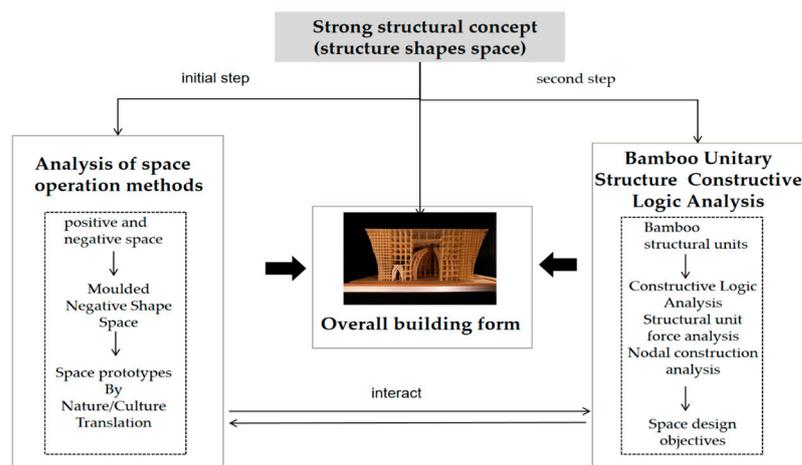


Figure 6. Design flow analysis diagram.

4. Discussion: Architectural Design Strategies for Shaping Negative Space with Bamboo Structural Participation

First, based on the discussion above, we can confirm the relationship between bamboo architectural design and the strong structure concept by examining the unique features of the Phu Quoc Island Visitor Centre in Vietnam. We discovered that the center pays attention to the structure to form the space. Second, a distinct design strategy—that is, the strong structural design strategy of bamboo structures dominated by negative space—was developed by researching its spatial operation methodology and discovering that it is consistent with the negative space operation method.

A strong structural design strategy for bamboo structures, based on negative space analysis was put forth from four perspectives: material expression, structural types, negative space operating techniques, and sensory experience. The following is the strategy:

- First strategy: a poetic account of bamboo which fully emphasizes its artistic and technical beauty.

Bamboo offers various options for bamboo architecture because of its specific structural qualities and distinctive outward form. The creation reflects the structural fit and matching of the materials and available space.

- Second strategy: Geometric techniques are used to translate and express the real and virtual spaces as they coexist.

In order to sculpt the interior space of the structure, the design focuses on negative space operation techniques. Geometric techniques were employed early in the design process to shape the area in accordance with the features of the building's location. The structure offers users an immersive interior environment while blending in with the surroundings.

- Third strategy: make use of distinctive structural forms and look to nature and tradition for inspiration.

The bamboo structure chooses the right kind of structure to build the overall form while combining the properties of geometric space [36]. Traditional culture, the natural world, and biological forms are the sources of structural forms.

- Fourth strategy: Create a rich sensory experience and use space to convey a spiritual message.

People are given a perceivable space through the artistic expression of the mix of bamboo architectural structure and space [37]. It enhances the variations in space by coordinating spatial size and combining spatial sequences. People are moved by their senses throughout the room, from the outside to the inside, conscious of psychological perception, and looking to architecture for ways to communicate one's spirituality [38].

In conclusion, visitors experience a visual feast and psychological ease when bamboo materials, space, and structure are seamlessly woven together. It has been discovered that the secret to the negative space-led bamboo architectural design strategy is the appearance of materials, the harmony between structural expression and spatial function, and the development of a distinct perceptual environment for humans.

5. Conclusions

The idea of a strong structure serves as a foundation for architectural design, guiding the presentation of the structure within the architectural space and drawing attention to the underlying logic of the building. We concentrate on resolving the issues of single space and the lack of integration of structure and architecture in bamboo architecture by summarizing the powerful structural expression of bamboo architecture and offering more workable design techniques.

The strong structural concept and negative space operation approaches are the subjects of this work. It covers the design strategy and the spatial operation procedures of bamboo architecture under the strong structural idea through an actual study of the Phu Quoc Island Visitor Center in Vietnam. This structure-led spatial manipulation method is primarily focused on the building itself, and it can be used in cultural buildings and landscape design to demonstrate cultural and sustainable practices while also providing visitors with richer sensory experiences. Furthermore, in locations where bamboo is abundant, bamboo architects would employ this method to create more symbolic environments.

However, neither the theory nor the actual examples are ideal. According to the theoretical study, the strong structure notion is influenced by the design concepts of individual architects, resulting in some degree of ambiguity, subjectivity, and unpredictability in operation. Furthermore, when presenting a summary of the robust construction of bamboo buildings, the range of cases used was insufficient to include all important cases. This will be expanded into a story in a future study, which will seek to investigate a more thorough approach to the spatial operation of bamboo architecture using the strong structural notion.

Utilizing all of its material qualities, bamboo is used to produce sustainable green buildings by constructing bamboo structures. In order to achieve the unity of function and aesthetics, the design process for bamboo structures should not only concentrate on material selection and creative structural system design; it should also combine structural analysis software with design software, such as parametric design, by writing programs or using parametric design software (such as Rhino 7.0, Grasshopper for Rhino 7.0, etc.) to realize the automation of bamboo structure design.

In short, bamboo architecture design will continue to evolve. With advances in technology, bamboo architecture can now optimize the design process and integrate bamboo architectural technologies to create more dynamic experience zones. These technologies include digital assembly, robotic engineering, augmented reality assembly interfaces, and 3D printing. However, to realize the full potential of bamboo architecture, more research into the structural and physical properties of bamboo materials is needed to improve the design standards and construction methods.

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