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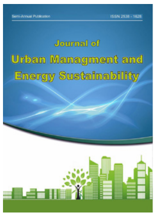

CASE STUDY RESEARCH PAPER

Biomimetic Structural Optimization of High-Rise Buildings Based on Bamboo Culm Structure: Nonlinear Pushover Analysis of Bionic and Conventional Framing Systems

Alireza Meshbaki Isfahani[1*], Mostafa Hadavand Mirzaei[1], Behnam Nateghi Gargari[2], Alireza Attarhai Tehrani[2]

*1 *Department of Art and Architecture, Payame Noor University, Tehran, Iran*
2 Department of Art and Architecture, ST.,C., Islamic Azad University, Tehran, Iran

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ABSTRACT

High-rise buildings are subject to significant lateral forces, including seismic and wind loads, making structural optimization a critical challenge in contemporary architectural and engineering design. While conventional framing systems address stability requirements, they often fall short in simultaneously achieving material efficiency, ductility, and lateral load resistance. This study investigates whether biomimetic structural configurations inspired by the hierarchical structure of bamboo culm, particularly its peripheral vascular bundle distribution and graded fiber density can outperform conventional high-rise framing systems under lateral loading conditions. The primary objective is to identify optimal structural patterns for tall buildings by translating bamboo's biological architecture into steel framing geometries, with particular emphasis on improving stiffness, ductility, and material efficiency. Eight 20-story steel structural models were developed and analyzed, comprising two conventional configurations, four peripheral bionic column arrangements, and two diagrid systems with inclined perimeter members. All models were standardized with identical floor area, story height, steel volume, and loading conditions. Nonlinear pushover analysis was performed using SAP2000 software, applying triangular lateral load distributions, with a 2% inter-story drift ratio defined as the failure threshold. The results showed that modeling the structure of bamboo walls significantly increases stiffness and ductility and reduces material consumption and ultimately reduces construction costs. These findings confirm that peripheral column arrangements inspired by bamboo vascular bundle distribution effectively replicate the plant's mechanical behavior, offering a viable biomimetic framework for optimizing high-rise structural design with reduced material consumption.

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NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
23	14	04

*Corresponding Author:
Email: *a.moshabaki@pnu.ac.ir*
Phone: +982122195303
ORCID: https://orcid.org/0009-0004-2825-5897

INTRODUCTION

The increasing population and the increasing need for urban spaces have increased the need for optimal utilization of urban land. These factors have made vertical construction, especially the creation of tall towers, a common and strategic solution in the process of urban development. These buildings not only help meet the needs of housing, work, and public services, but also have a significant impact on the shape and identity of cities (Chen & Zhang, 2025). One of the main challenges in designing these structures is choosing forms that, in addition to being beautiful, also perform well against lateral forces such as wind and earthquakes. Therefore, paying attention to the aesthetic and safety aspects of these buildings, in addition to responding to urban needs, is of great importance. As a result, optimizing the design of these towers can help improve the quality of urban life and reduce problems caused by population density. (Zivori Afzal & Karimi Consultant, 2014). Nature, as a source of inspiration, has always provided intelligent solutions. These solutions, which have been obtained through billions of years of evolution, can be used as a model for solving engineering problems. Natural structures are designed in such a way that they provide the best response to needs with the least use of materials, and at the same time, their form has the greatest capacity to withstand and distribute forces. To translate these natural structures into architecture, we need a deep understanding of their structure and how they transfer loads, which is possible by conducting numerous experiments (Golabchi & Khorsand Niko, 2013). Nature always offers the simplest and best solutions to its needs. All living and non-living elements in nature are designed in a logical and functional way to achieve a specific goal. Despite their great diversity, they are all formed based on the principle of survival and continuation of life. The basic characteristics of natural organisms include optimal consumption of matter and energy, adaptation of form and function to the environment, the existence of a cycle of balance and unity despite diversity (Qarouni Esfahani & Tirgarian, 2014). The complexity and beauty of biological structures have long been beyond human understanding, but with the advancement of technology and the widespread use of digital technologies, this understanding has gradually deepened. Plants, due to their spatial stability, have experienced the most changes to adapt to the environment. Changes such as the shape and size of the roots, the thickness and height of the stem, and orientation to environmental factors such as wind and sunlight, all indicate their gradual evolution. Bamboo is one of the plants that has always been of interest due to its tubular structure and the presence of diverse vascular pathways in its body that help transport nutrients and water. Bamboo's resistance, flexibility, and adaptability to environmental conditions are characteristics that have made it an ideal model for the design and optimization of high-rise structures. Given the similarity of these features to construction needs, modeling from bamboo can contribute significantly to improving the quality and economic savings in construction (Ma et al., 2008). In this study, after gathering theoretical foundations and reviewing previous works, six models with different structural features are designed and examined using the push-over analysis method inspired by the biological structure of the bamboo trunk. Two models are also evaluated based on conventional structures to measure their resistance and resilience against incremental lateral loading. A careful study and correct analysis of these structures, by keeping conditions such as the weight of materials and the area of the foundation constant, can lead to a better understanding of the performance of each of these models and their comparison with conventional structures. This study also seeks to identify the optimal conditions for a structure modeled on bamboo structures to achieve ideal resistance and structural properties while optimizing material consumption. Based on these, the following hypotheses are proposed in this research:

-Bamboo’s high resistance and flexibility against external forces is due to its biological and morphological structure.

-A structure designed based on a vascular structure can be more stable than typical structures in tall buildings.

MATERIALS AND METHODS

Inspiration from natural structures and their use in architectural design is possible with a deep understanding of natural forms and mechanisms. To translate pristine natural structures into architecture, it is necessary to have complete knowledge of how these structures function and how they transfer loads. (Wang et al., 2014). This can only be achieved by conducting numerous and accurate experiments. Nature always tries to prevent bending and wasting materials by using axial forces, because bending means inefficiency in the use of materials, which contradicts the principle of efficiency and productivity in nature (Zhao et al., 2025). Using natural principles in the design of structures optimizes the flow of force and prevents energy waste, and also reduces the dimensions of structural members, which ultimately helps protect the environment. Flexibility and deformation of components are other principles that natural structures use to cope with environmental forces and ensure survival. These principles are not only applicable to modern designs, but can also lead to sustainable innovations in construction. (Golabchi & Khorsand Niko, 2013)

Research Background

Several studies have been conducted in the field of analyzing the morphological structure of bamboo and finding solutions to exploit this knowledge in various industries. A brief description of these studies and their results is given below. In 2010, Zhao and his colleagues focused on the design of lightweight structures in order to develop a standard method for creating bionic mechanical structures. The main goal of this research was to reduce the dead load of the structure and improve its overall performance. In this study, finite element methods were used along with rapid prototyping using casting and machining, as well as practical experiments. The results obtained showed that the bamboo-inspired samples performed better than the original samples, while at the same time the weight of the parts was reduced. These advances can help optimize the use of bamboo in various industries and indicate the high capabilities of this material in modern designs. (zhao et al., 2010).

Palombini et al. (2020) studied the thin-walled structure and vascular network geometry of a particular plant. Using finite element methods as well as numerical and laboratory techniques, this study designed an optimal model that can withstand high axial, lateral, and bending forces. The main goal of this research is to achieve a product with an optimal weight-to-strength ratio. Due to its special characteristics, this product can be used in various industries such as automotive, aerospace, and military industries. This research shows that by applying engineering and materials science principles, it is possible to achieve products that have high performance in different conditions, and for this reason, it has attracted the attention of many industrialists (Fig. 1) (Palombini et al., 2020).

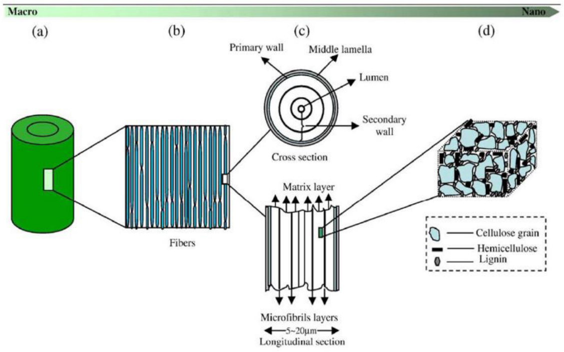


Figure 1: Fibril structure and cellular tissue of bamboo plant bark (zhao et al., 2010)

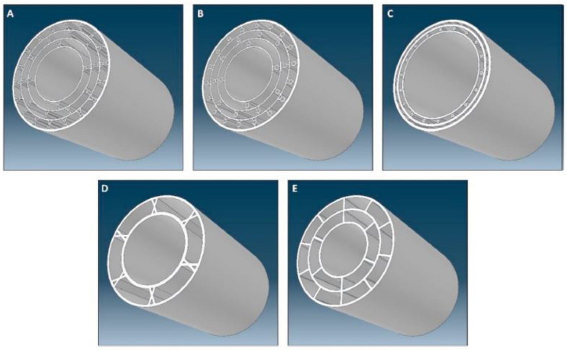


Figure 2: Modeled specimens for finite element analysis (Palombini et al., 2020)

The results obtained from Palombini's research show that:

1-The shape of bamboo vascular bundles contributes significantly to the way the plant manages its mechanical behavior.

2-The design of the reinforcing cores alone has a large impact on the performance of thin-walled structures and can significantly increase their efficiency.

3-The use of X-pattern connections at four specific points not only improves the performance of the model, but can also increase the load-bearing capacity by up to 17% compared to conventional specimens.

4-The use of gradient distributions in vascular bundles in the arrangement of reinforcing cores can have a profound effect on the ultimate strength of the structure and significantly increase its quality.

5-The analysis results show that the thickness of the cylindrical shells increases clearly from the inside to the outside. These changes in thickness can indicate an improvement in the overall performance of the structures and are especially important in engineering applications.

In the research of Fu et al. (2019), various models of structural tubes that have been studied with LS-DYNA software have been optimized. These models are designed as nested cylindrical shells with X-shaped joints, which have shown the best performance in the analyses. (Fig. 3)

Furthermore, this research has investigated the form of X-shaped joints and their number in the buckling process of the layers and has reached the following results:

1-The two-layer bionic tubular structure with X-shaped joints has better performance than simple and conventional tubes.

2-The number of X-shaped joints is one of the key factors that significantly affects the buckling process. The distribution of six of these connections around the cross section has the greatest effect on the energy absorption by the structure.

3-The thickness of the X-shaped connections, the angle between its two sides, and the distance between the layers are also effective factors in the amount of energy absorbed by the connections.

4-By repeating the analysis of different types, it is possible to achieve the optimal parameters including the thickness, angle, distance, and number of connections, as well as the thickness and distance of the shell walls that provide the best performance. This process helps designers create structures with higher efficiency and greater resistance to stresses and buckling. (Fu et al., 2019) .

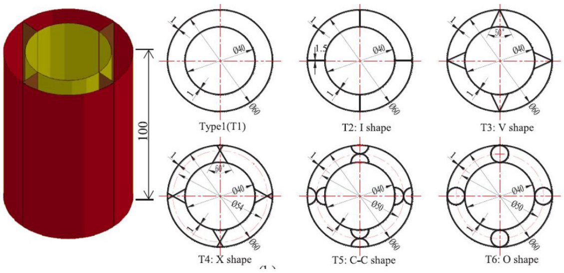


Figure 3: Sections designed for finite element analysis (Fu et al., 2019)

Feng Ma et al. (2008) also achieved a 124% increase in buckling strength by modeling the distribution of fiber bundles and vessels and designing a bionic cylinder. The main goal of this study is to achieve a lightweight cross-section with high load-bearing capacity in various industries. To evaluate the performance of this bionic section, alternating axial loadings were performed on it using ANSYS software. The designed model consists of three walls with unequal distances and X-shaped connections in different numbers.

In this research, changes in wall thickness, distance between cylindrical shells, as well as dimensions and number of X-shaped connections are considered. Nonlinear buckling analysis with incremental loading until reaching the point of instability is the method used in this study. This method has many advantages, including the ability to model geometric defects, materials, and loading, which can help improve designs and reduce costs. The ultimate goal of this research is to improve the efficiency and safety of structures using bionic principles and intelligent design (Huang et al., 2024). (Figs. 4 and 5).

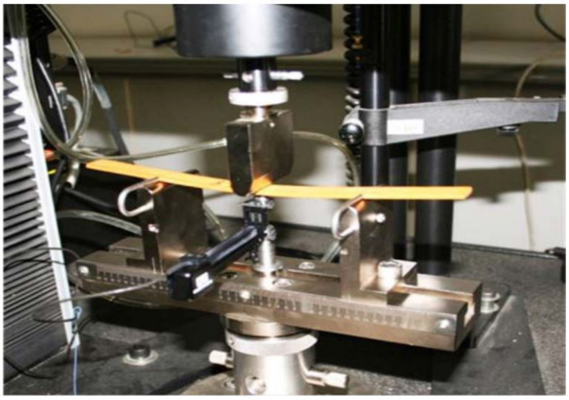


Figure 4: Experimental setup for testing bamboo samples (Huang et al., 2024)

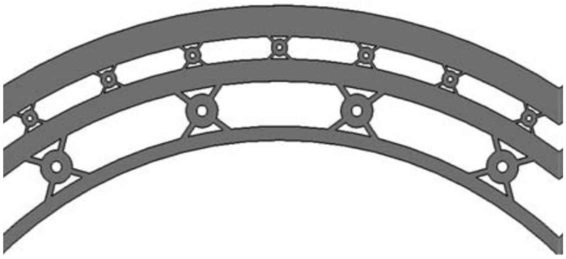


Figure 5: Designed cross section based on finite element analysis (Huang et al., 2024)

Methodology

This study employs a quantitative-comparative research design grounded in biomimetic structural engineering, following a three-phase framework: biological analog identification, parametric translation of bamboo morphological features into steel structural configurations, and computational performance evaluation. The biomimetic translation operates at the structural-organ level, focusing on form imitation and load-transfer mechanism replication, consistent with the classification proposed by Qiyabglu (2013). The primary biological reference is the bamboo culm, whose peripheral vascular bundle distribution, hollow tubular geometry with nodal reinforcement, and graded fiber density were systematically translated into three categories of 20-story steel structural models: two conventional reference configurations (orthogonal and circular plans), four bionic peripheral column arrangements inspired by bamboo's peripherally concentrated vascular bundles, and two diagrid systems replicating the anisotropic fiber orientation of bamboo's outer shell. To ensure controlled comparison, all eight models were standardized with identical plan area, story height, total steel volume, material grade, gravity loading, rigid diaphragms, fully rigid connections, and fixed-base supports. A 20% progressive reduction in member cross-sectional hardware was applied per every five stories to replicate the natural tapering of bamboo culm along its longitudinal axis. Structural performance was assessed through nonlinear static pushover analysis using SAP2000 software, selected for its capacity to capture progressive yielding, post-elastic response, and the interaction of vertical and lateral loads. Gravity loads were applied in a single initial stage, followed by incremental triangular lateral loading, replicating the first-mode-dominant seismic force profile, applied simultaneously to all story levels. Plastic hinge formation was monitored continuously throughout loading, with analysis terminating upon the first member reaching the defined failure threshold of 2% inter-story drift ratio relative to total building height. The resulting base shear–displacement curves for all eight models were then comparatively evaluated to quantify and rank structural strength, stiffness, and ductility performance across conventional, bionic peripheral, and diagrid configurations. (Tab. 1)

Table 1: Example of a biomimetic application framework (Qiyabglu, 2013).

Level of Imitation	Method of Imitation	Example of a Building that Imitates a Termite Mound
Structure and Organs	Form	A building that resembles a termite mound.
	Material	A building constructed from materials similar to the termite's body parts, such as its skin or skeleton.
	Construction Method	A building that, like a termite mound, has different growth periods.
	Process	A building that, like a termite mound, continuously has access to sufficient water by combining atmospheric oxygen with hydrogen (e.g., recycling waste into biogas and treating wastewater on-site).
	Function	A building constructed from recycled materials, similar to the termite's function (which converts cellulosic waste into soil).
Individual Behavior	Form	A building that appears to have been built by termites and resembles a termite nest.
	Material	A building whose materials are similar to those of a termite nest.
	Construction Method	A building constructed using termite nest-building techniques (excavating the ground and constructing chambers).
	Process	A building that, like a termite nest, has the most suitable orientation, shape, and materials.
	Function	A building whose internal conditions, in terms of thermal comfort, are always maintained at an optimal temperature.
Ecosystem and Behaviorism	Form	A building that resembles the ecosystem in which termites live.
	Material	A building constructed from natural resources available in the ecosystem where termites live.
	Construction Method	A building that, like the termite ecosystem, benefits from principles of succession and complexity over time.
	Process	A building that, like the termite ecosystem, receives energy from the sun and stores water.
	Function	A building that, like the termite ecosystem, exploits the interconnections between the water, carbon, and nitrogen cycles.

Application of bamboo in the construction industry:

In the bamboo plant, the mechanical and physical properties and characteristics are directly affected by the distribution of vascular bundles and the density of vascular sheaths of the vascular tissue (Yang et al., 2024). The mechanical properties of bamboo are unique among the woods of other plants, and bamboo fibers have significant tensile and compressive strength, and its use is very common in various construction fields in the world (Liu et al., 2023). Concrete with the presence of bamboo has a strength equivalent to 4 times that of unreinforced concrete. Various studies have been conducted on the mechanical properties of bamboo in different directions, including fatigue, shear, torsion, abrasion and hardness (Qarouni Esfahani, 2015).

The use of bamboo in the construction industry is in two direct and indirect ways, which are:

1-Use as a building material directly as beams, columns, roofs, walls, etc. in local buildings

2-Use of bamboo form and structure in the design of structures and forms of buildings.

3-Specific uses, for example, using bamboo instead of rebar in concrete parts in local buildings and constructing structures and arch forms that are covered and used with concrete.

4-Inspiration from the geometry and biological behavior of the bamboo plant in the design of optimal building sections, with the aim of improving the mechanical behavior of the section and optimizing and reducing the consumption of materials (Titilayo et al., 2017)

- Extensive research has been conducted in the field of using bamboo in the construction industry, which can be divided into five main categories:

1) Material use:

The use of bamboo as a natural building material has been investigated directly in the construction of beams, columns, ceilings and walls. In these studies, various parameters such as lifespan, strength and behavior of these materials have been tested and analyzed (Trujillo & López, 2016).(Fig. 6)

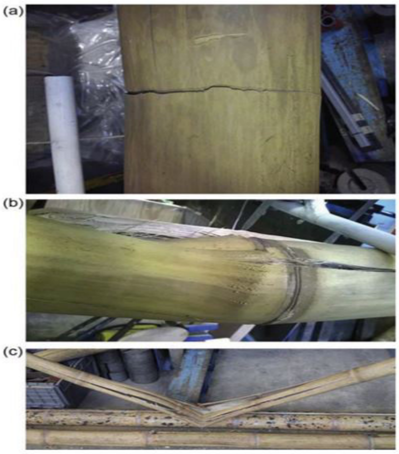


Figure 6: Flexural failure modes in bamboo: (a) fiber crushing in compression, (b) fiber collapse and buckling in compression, and (c) stem collapse (Trujillo & López, 2016).

2) Mechanical structure:

The analysis and investigation of the mechanical structure of bamboo includes flexural, compressive, shear strength as well as its creep and ductility properties. This research is mainly conducted in the laboratory and using modeling software to identify the behavioral advantages of bamboo compared to other materials and to investigate the possibility of replacing it with similar materials in various applications (Zhou et al., 2023).

3) Specific application:

In this section, the use of bamboo in some specific applications is investigated. For example, the investigation of the use of bamboo as a replacement for rebar in concrete parts in vernacular buildings as well as in the construction of structures and arch forms that are covered with concrete is one of the important topics in this field. These types of applications demonstrate the unique capabilities of bamboo in construction projects and can help optimize construction (Chen et al., 2024).

4) Optimization:

Drawing inspiration from the geometric principles and natural behaviors of the bamboo plant in the design of building sections allows for the creation of optimal sections that not only perform better mechanically, but also reduce material consumption. Bamboo, with its special structure, shows high efficiency in load-bearing and flexibility (Han et al., 2024). These features can be used in the design of structures and help us to minimize the weight and cost of materials by using appropriate geometric forms. In this way, by inspiring the nature and structure of the bamboo plant, solutions can be achieved that are both effective in preserving natural resources and help improve the performance of structures. This approach not only contributes to environmental sustainability, but also leads to the creation of structures with long lifespan and high safety. (Fig. 7 to 9)

Figure 7: Bamboo rods instead of concrete reinforcement in columns (Hildayanti and Wasilah, 2023)

Figure 8: Bamboo that is woven and placed horizontally is then concreted. b) Bamboo rods are used instead of concrete reinforcement for columns (Hildayanti and Wasilah, 2023)

Figure 9: Construction of bamboo truss (Hildayanti and Wasilah, 2023).

Modeling

Modeling the biological structure of bamboo is introduced as a new approach in the design of tall buildings. This method is used to increase the load-bearing capacity and optimize the use of materials. Examining this modeling requires the use of practical experiments and software analyses. In these studies, the strength and weight of the structure are usually considered as two main factors and are compared while maintaining other parameters such as the number of floors, the height of each floor, building dimensions, type of materials, and analysis conditions. These comparisons can help to better understand the efficiency and stability of structures and lead to the optimization of designs in construction projects. Therefore, inspired by the natural structure of bamboo, innovative solutions can be achieved in building engineering that, in addition to increasing strength, also help reduce resource consumption (Kim et al., 2023).

MATERIALS AND METHODS

In this study, an attempt has been made to achieve an optimal design for the skeleton of tall buildings, inspired by the structure and mechanical properties of the bamboo plant. This optimization is carried out in order to increase the load-bearing capacity, improve the mechanical properties and reduce the consumption of materials. In this regard, six different geometric patterns of bamboo cross-sections along with two types of tall and conventional buildings have been selected as a basis for comparison in terms of structural behavior. All samples have been designed in the form of a 20-story steel building. The key variable examined in this study is the maximum lateral force that is applied to the building before reaching the failure limit. The failure limit here is related to a deformation of 2% of the building height. For all samples, parameters such as floor area, floor height, number of floors, and volume of steel consumption are considered constant. Also, internal connections and supports are designed as rigid. In order to better match the analyzed patterns with the conditions of conventional buildings in terms of height, the volume of floor beams and columns hardware has been reduced by 20% in every five floors. (Fig. 10)

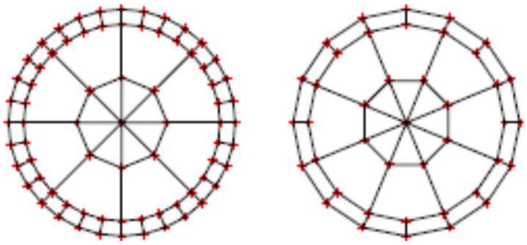


Figure 10: Column and beam plans of a structure modeled on bamboo

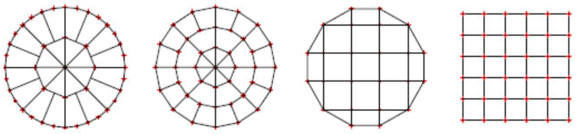


Figure 11: Plan of conventional structures for behavioral analysis and comparison with modeled samples

Selection of Design Variables: In this study, in order to comprehensively examine the results, different types of structures were examined. The variables considered in this analysis include the number and arrangement of floor columns and beams. All connections are designed as rigid and supports are considered as fixed. The type of steel used is ST-37, which has a yield stress of 2400 kg/cm2. The dead and live loads for each floor are considered to be 500 and 200 kg/m2, respectively, which are determined based on residential use. The roof and floor surfaces are also considered as rigid diaphragms. Due to the symmetry of the plan, the loading due to eccentricity is also ignored. (Fig. 12)

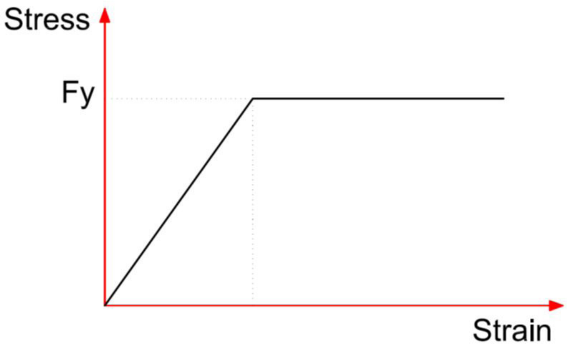
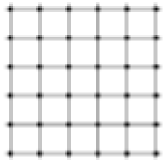
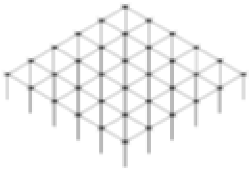
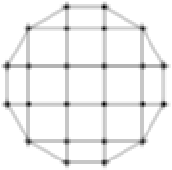
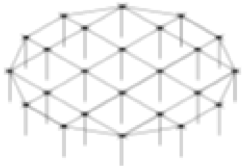
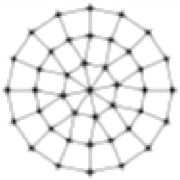
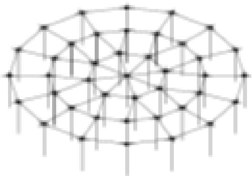


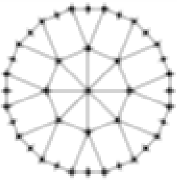
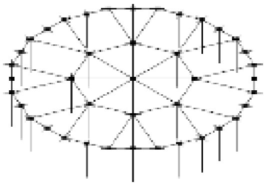
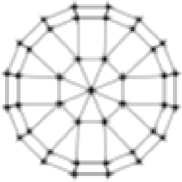
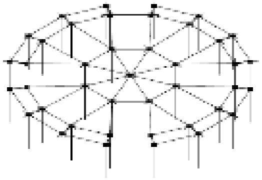
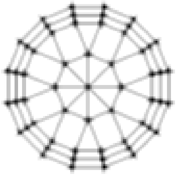
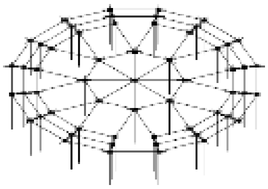
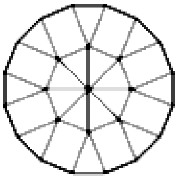
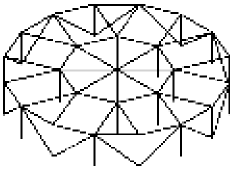
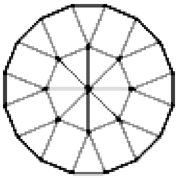
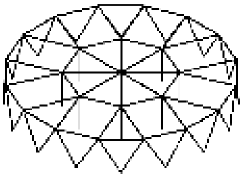
Figure 12: Steel stress-strain variation diagram

Structural models of the design

In this study, different types of steel structures with similar specifications and parameters and different structures have been investigated. Common features of these structures include area, height, number of floors, type and amount of materials and hardware used, as well as loading conditions. The detailed specifications of these buildings are presented in Table 2. (Tab. 2)

Table 2: Column and beam specifications of the models

Row	Column and Beam Framing Plan	One-Story Isometric View
Model No. (1)		
Model No. (2)		
Model No. (3)		

Model No. (4)		
Model No. (5)		
Model No. (6)		
Model No. (7)		
Model No. (8)		

Models (1) and (2) are considered as representative of common structures of tall buildings. These structures have regular column arrangement in both transverse and longitudinal directions with square and circular plans. Model (3), with polar column arrangement, is considered as the first model modeled on bamboo. This model with regular column arrangement in plan can be considered an intermediate model compared to the peripheral arrangement (modeled on bamboo) and model (2). Models (4), (5), and (6) are models modeled with peripheral arrangement of columns in plan. Models (7) and (8) are diagrid structures with inclined peripheral columns, which have been selected with the aim of considering the integrated mechanical characteristics and rigidity of the outer shell of bamboo.

Analysis and Loading

For the analysis of these structures, the nonlinear pushover analysis method (increasing load) has been used using SAP2000 software. In this method, gravity loading, including dead and live loads, is applied to the structure in one stage and then, lateral loading is applied to the structure gradually and step by step. In this study, the triangular lateral loading pattern (Figure 15) has been applied to each structure and examined. With the increase in the amount of lateral load and the interaction of vertical loads on the structural members (P-Δ), plastic joints are gradually formed and the plastic behavior of the structure begins. With the increase in the number of plastic joints, the shear of the building base gradually enters the nonlinear stage and progresses until one of the members reaches the failure stage. (Fig. 13)

Failure is the first end member of the analysis. The final base shear rate and the behavior of the structure in the nonlinear stage indicate the strength and flexibility of the structure before failure, respectively. These indices are shown in the form of force-displacement diagrams for all structures after analysis. (Tab. 3)

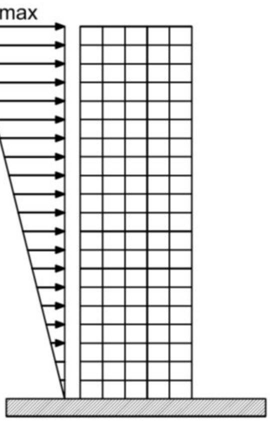
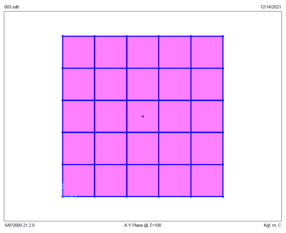
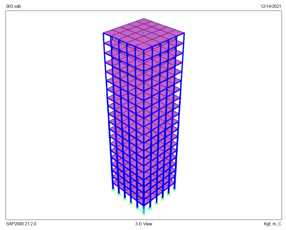
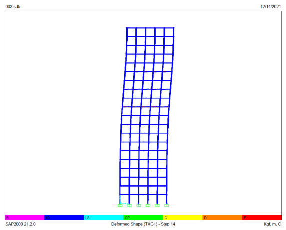
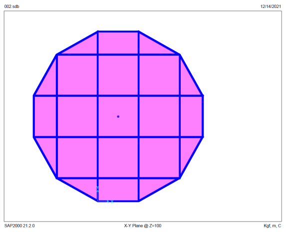
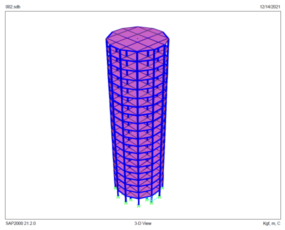
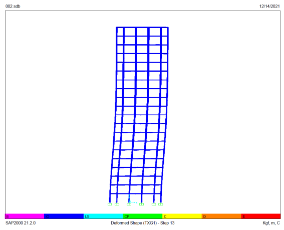
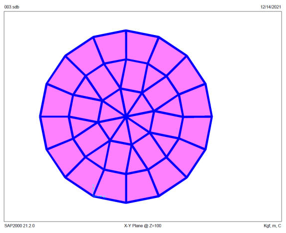
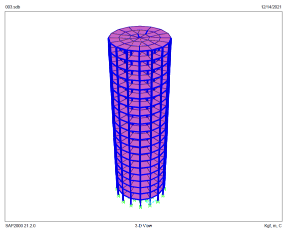
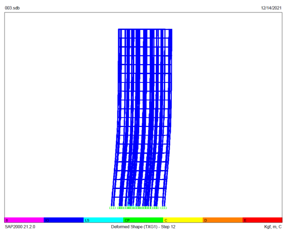
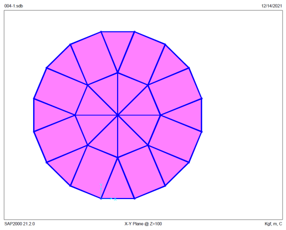
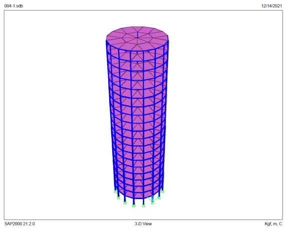
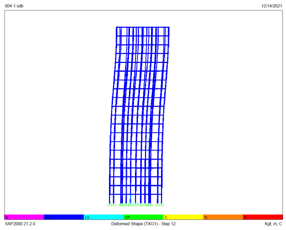
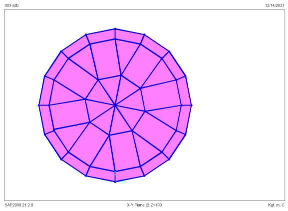
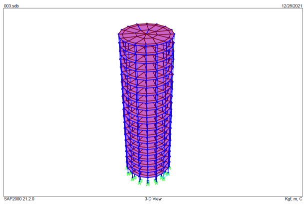
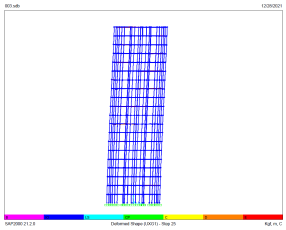
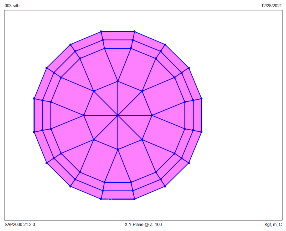
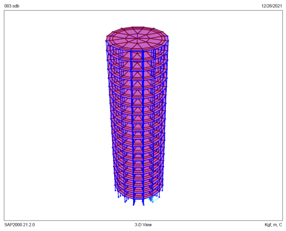
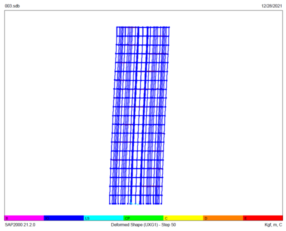
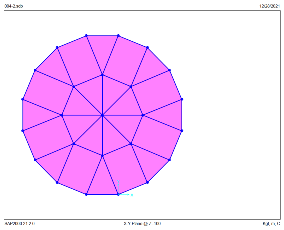
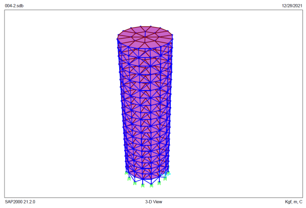
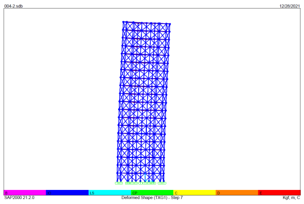
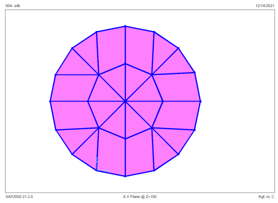
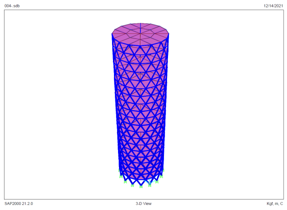
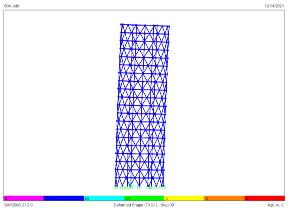


Figure 13: Triangular lateral loading pattern diagram

Table 3: Analysis of indices in the form of force-displacement diagrams

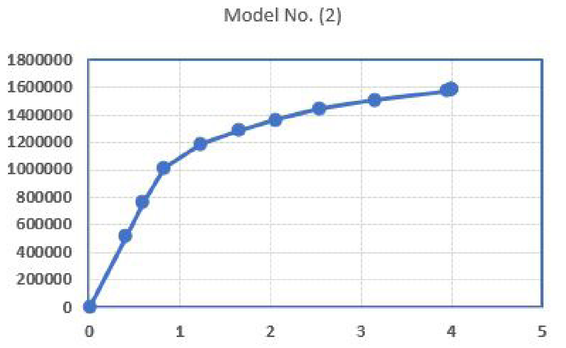
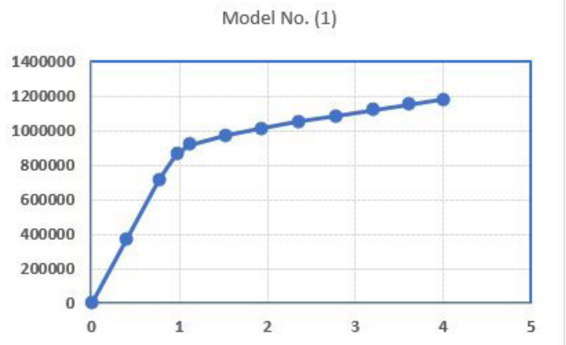
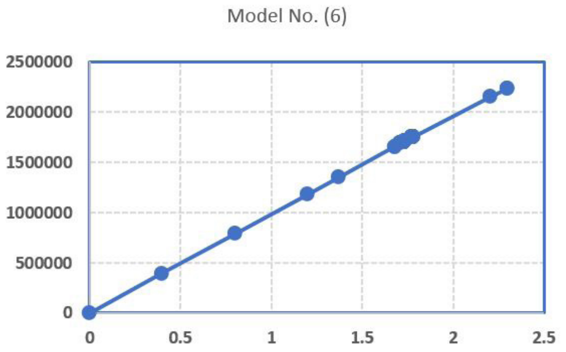
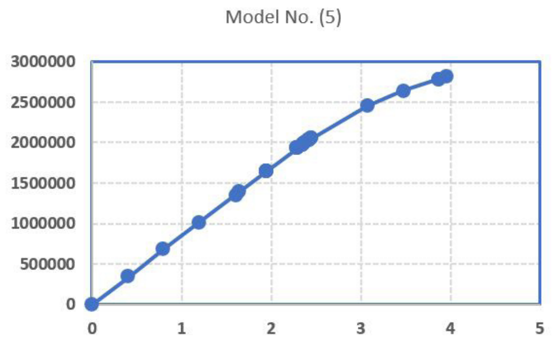
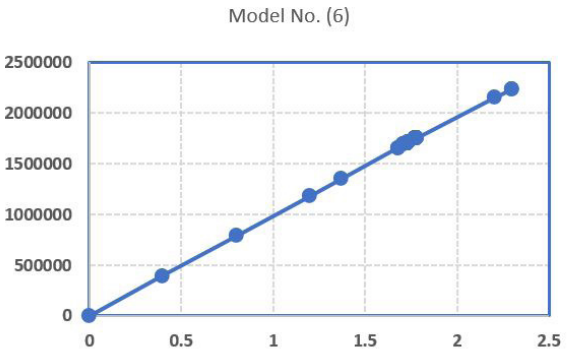
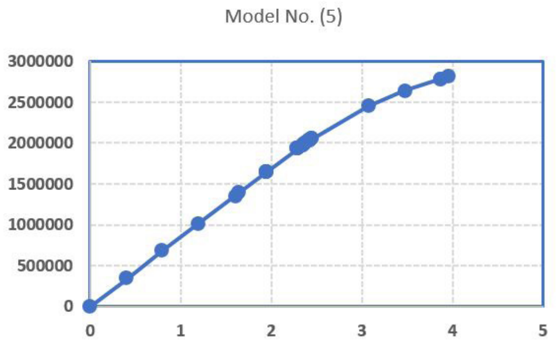
	Column Layout Plan	Structural Isometric View	Deformed Configuration View
Model No. (1)			
Model No. (2)			
Model No. (3)			

Model No. (4)			
Model No. (5)			
Model No. (6)			
Model No. (7)			
Model No. (8)			

Data analysis

After analyzing each model, the base shear diagram and displacement of each one have been obtained as shown in Table 4. Examination of the diagrams shows that models 1 and 2 (conventional buildings) have completely nonlinear behavior with increasing force and have progressed to the limit of the final deformation of the structure without creating an instability mechanism. Among these two models, the circular cross-section has resulted in a higher base shear due to the higher moment of inertia of the building cross-section. Model 3, as the first modeled sample, has shown higher stiffness and strength compared to the first two models, while being ductile up to the limit of the maximum deformation of the structure. Models 4, 5, and 6 are samples with structural perimeter columns. All three models show better strength and ductility compared to models 1 and 2. In addition, these three samples show a special feature, which is lower stiffness than models 1, 2, and 3, while the base shear is higher and the plastic behavior is presented with a higher slope, and this graph shows the success of the modeled samples in presenting a behavior similar to the bamboo plant, in terms of flexibility and strength. Models 7 and 8, due to the bracing of the outer shell, have very high stiffness and very low ductility. (Tab. 4)

Table 4: Base shear diagrams of displacement analysis of modeled buildings under lateral loading

 Model No. (2)	 Model No. (1)
 Model No. (6)	 Model No. (5)
 Model No. (6)	 Model No. (5)

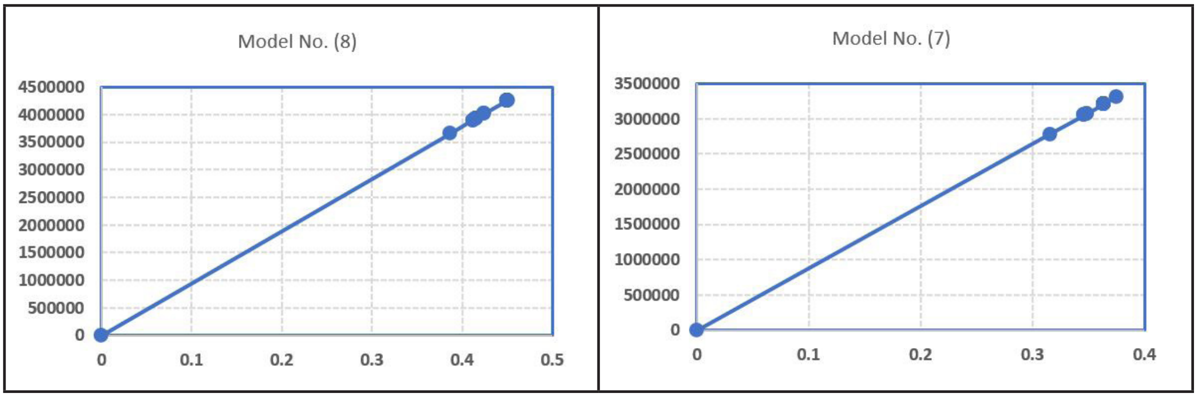


Figure 20 simultaneously shows the base shear-displacement diagrams for all models. As mentioned, the behavior of bamboo with low stiffness and flexible and reversible deformations along with high resistance and resilience before failure against lateral forces has always been of interest to researchers in this field. Structural models 4, 5, and 6 have been able to simulate this behavior to a significant extent by increasing the number of columns and their peripheral arrangement. Of course, the effect of fiber cells among the vessels (load-bearing elements) that perform the function of wall tissue integrity cannot be ignored, and if the role of these cells is affected in the analytical model, better results will be obtained. (Fig. 14)

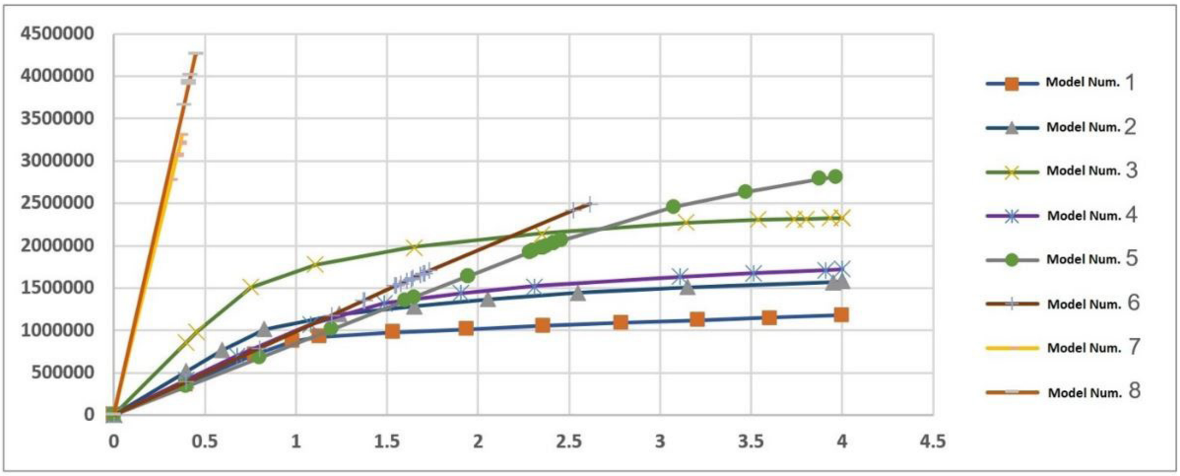


Figure 14: Base section diagram - displacement of all models in a frame (Source: Authors)

Regarding the results obtained for the braced diagrid models, it is observed that the deformation behavior of these structures is completely bending, in accordance with the deformations of the bamboo plant. However, the high stiffness of the diagonal column elements, due to the type of materials and the cross-sectional dimensions of the elements, has caused the inflexible behavior of these models until they reach the rupture limit. Therefore, it seems that if a more flexible texture is used simultaneously for the diagrid elements and the geometry of models 4, 5, and 6 is used, better results can be achieved in terms of resistance and flexibility.

CONCLUSION AND RESULTS

This study set out to examine whether biomimetic structural configurations inspired by the hierarchical morphology of bamboo culm could demonstrate measurable superiority over conventional high-rise framing systems in terms of lateral load resistance, stiffness, and ductility. By developing and analyzing eight 20-story steel structural models through nonlinear pushover analysis in SAP2000, the research provides quantitative evidence that the spatial translation of bamboo's peripheral vascular bundle distribution into structural column arrangements yields significant performance advantages. The findings collectively confirm that biomimetic form-finding, when rigorously grounded in the mechanical principles of the biological analog, represents a viable and effective strategy for optimizing tall building structural systems. The purpose of this research is to analyze and compare the behavior of structures in different conditions and to investigate the effect of the aforementioned variables on their overall performance. Given the importance of selecting materials and appropriate design, this study can help improve the quality of construction and increase safety in construction projects. Among the three model categories examined, bionic peripheral configurations (Models 4, 5, and 6) demonstrated the most balanced and favorable structural behavior, achieving base shear forces substantially exceeding those of conventional reference models while maintaining full ductile capacity up to the defined 2% inter-story drift failure threshold. This behavior closely replicates the mechanical signature of bamboo culm-characterized by simultaneous high resistance and flexible, reversible deformation under lateral loading-confirming the first research hypothesis that bamboo's structural superiority is directly attributable to its biological and morphological organization. Model 3, featuring a polar column arrangement as a transitional configuration, exhibited intermediate performance combining elevated stiffness with complete ductility, suggesting that progressive peripheral column redistribution incrementally enhances both strength and deformation capacity. Conventional models (1 and 2), while exhibiting stable nonlinear behavior throughout loading, were consistently outperformed across all performance indices, underscoring the limitations of orthogonal and standard circular framing systems in replicating nature-optimized load paths. The following results have been obtained from the study conducted on selected structural models based on three functional groups including conventional, patterned and diagrid structures:

1-Patterned structures that are modeled by increasing the number of building perimeter columns in rows 1, 2 and 3 have higher strength and flexibility than conventional structures, and this model can be used for better efficiency of tall building structures.

2-Diagrid models with high stiffness, despite achieving higher base shear, are not a suitable model of bamboo plant performance due to very low flexibility. However, by changing the material specifications and geometry of the bracing elements, a more ideal behavior of these models can be observed.

3-Considering the lack of effect of the fiber retaining tissue performance between the bamboo load-bearing elements in patterned models 4, 5 and 6, it seems that applying this function can improve the performance of the models in terms of mechanical behavior.

The results of this research carry meaningful implications for the broader field of biomimetic structural design in high-rise architecture. The demonstrated effectiveness of peripheral column arrangements in replicating bamboo's vascular bundle mechanics suggests that nature-derived spatial organization principles can be directly and practically implemented within conventional steel construction frameworks without requiring exotic materials or fabrication methods. Furthermore, the standardized equal-volume comparison methodology employed in this study confirms that biomimetic configurations achieve superior structural performance without increased material consumption, supporting their potential contribution to sustainable and resource-efficient construction. Future research should extend this framework by incorporating the mechanical role of bamboo's inter-bundle fiber matrix analogous to infill wall or facade systems in buildings into analytical models, as well as by applying dynamic time-history analysis to evaluate biomimetic structural performance under real seismic ground motion records.

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