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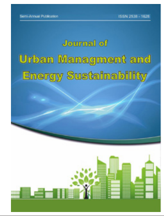

CASE STUDY RESEARCH PAPER

Biomimicry-Based Design of Temporary Structures Inspired by Birds Nest Architecture: A Case Study of Exhibition and Emergency Relief Spaces

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A B S T R A C T

Temporary architectural structures, particularly those deployed in exhibition and emergency relief contexts, demand a convergence of structural performance, ecological sensitivity, and rapid adaptability. This study examines the application of biomimicry principles derived from bird nest architecture as a design strategy for optimizing temporary structures. Bird nests represent one of nature's most sophisticated structural systems, integrating material efficiency, adaptive geometry, resilience under dynamic loading, and ecological compatibility within a unified organizational logic. The primary objective of this research is to empirically evaluate the relative influence of ten biomimetic design criteria encompassing structural efficiency, lightweight construction, adaptability, environmental responsiveness, material optimization, rapid assembly and modularity, spatial integration, sustainability, computational design capability, and resilience on the overall performance of temporary biomimicry-based structures. A quantitative research methodology was employed using Structural Equation Modeling with Partial Least Squares estimation in SmartPLS software. Data were collected through a structured five-point Likert-scale questionnaire distributed among 220 architects, structural engineers, biomimicry researchers, and temporary architecture specialists, yielding 198 valid responses. Bootstrapping with 5,000 subsamples confirmed the statistical robustness of all path coefficients. Findings reveal that Resilience and Structural Stability, Sustainability and Ecological Performance, and Adaptability and Flexibility are the three most influential predictors of biomimetic performance. The model demonstrated strong explanatory power and confirmed predictive relevance. These results provide empirically grounded guidance for architects and engineers seeking to integrate avian nest-inspired structural logic into the design of high-performance, ecologically responsible temporary environments.

Running Title: : Biomimicry-Based Design of Temporary Structures

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INTRODUCTION

Nature has long served as a primary source of inspiration for architectural innovation, structural optimization, and environmental adaptation. Throughout history, natural systems have demonstrated highly efficient strategies for material organization, energy performance, and structural stability, enabling living organisms to survive under diverse environmental conditions. In contemporary architectural discourse, these natural principles have increasingly attracted attention as designers seek sustainable, lightweight, and adaptive solutions for complex built environments (Verbrugghe et al., 2023). Biomimicry has emerged as one of the most influential interdisciplinary approaches connecting biology, architecture, engineering, and material science. The concept refers to the systematic study and imitation of natural forms, processes, and ecosystems in order to solve human design challenges more efficiently and sustainably (Dixit & Stefańska, 2023). Unlike superficial formal imitation, biomimicry emphasizes the functional logic embedded within biological systems and attempts to translate these principles into architectural and structural solutions. The growing environmental challenges of the twenty-first century, including climate change, rapid urbanization, resource depletion, and disaster vulnerability, have intensified the demand for resilient and resource-efficient architectural systems. Conventional construction methods often consume excessive material and energy resources while lacking adaptability and rapid deployment capabilities in emergency situations (AlAli et al., 2023). Consequently, architects and structural engineers increasingly investigate biological systems capable of offering optimized structural and environmental performance. Among natural organisms, birds and their nesting systems represent remarkable examples of lightweight yet highly stable structural configurations. Bird nests demonstrate sophisticated construction intelligence through the strategic arrangement of flexible fibers, branches, mud, and natural materials into resilient spatial systems capable of resisting wind, gravity, vibration, and environmental fluctuations (Street et al., 2022). These structures achieve stability through geometry, material interlocking, and distributed load transfer mechanisms rather than excessive mass. Bird nests are not merely shelters; they function as highly adaptive environmental systems responding to climate, protection, thermal regulation, and reproductive requirements. Different bird species develop distinct nesting typologies according to ecological conditions, material availability, and structural demands (Othmani et al., 2022). Such adaptive intelligence provides valuable insights for architects seeking responsive and efficient temporary structures. In recent decades, advances in computational design and digital fabrication technologies have significantly expanded the possibilities for translating biological principles into architectural systems. Parametric modeling, algorithmic design, and biomaterial engineering allow designers to simulate and optimize complex geometries inspired by natural morphologies (Zhu et al., 2025). Consequently, biomimetic architecture has evolved from symbolic inspiration toward performance-based structural innovation. (Fig. 1)

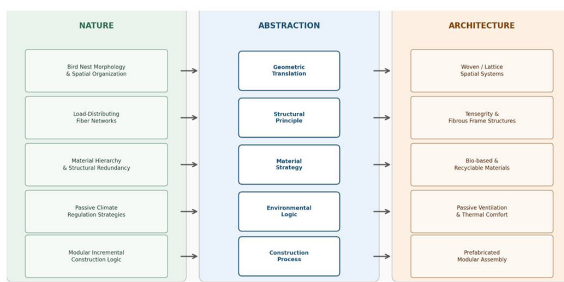

Figure 1: Biomimicry Design Translation Framework: Hierarchical translation of bird nest structural principles into architectural systems (Adapted from: Verbrugghe et al., 2023; Dixit & Stefańska, 2023)

Temporary structures constitute one of the most important fields in which biomimetic principles can be effectively applied. Unlike permanent buildings, temporary structures require rapid assembly, lightweight construction, transportability, adaptability, and efficient material consumption. These requirements closely correspond with the structural logic observed in biological systems, particularly bird nests, which combine minimum material use with maximum spatial and structural efficiency (Phocas et al., 2023). The increasing frequency of natural disasters, humanitarian crises, and forced displacement has highlighted the urgent need for innovative emergency relief structures. Earthquakes, floods, wars, and climate-related catastrophes continuously generate demand for rapidly deployable shelters capable of providing safety, flexibility, and environmental comfort under constrained conditions (Fatima, 2024). Traditional emergency shelters often fail to address long-term social, spatial, and environmental needs. Emergency relief architecture requires structural systems that are lightweight, modular, rapidly deployable, and adaptable to different climatic and geographic contexts. In this regard, biomimetic approaches offer substantial potential by introducing structural principles derived from naturally optimized systems (Fatima, 2024). Bird nest architecture, in particular, provides an important conceptual framework for designing interconnected, flexible, and resilient temporary shelters. Similarly, exhibition spaces represent another category of temporary architecture requiring flexibility, mobility, and rapid spatial transformation. Contemporary exhibitions increasingly demand adaptable structures capable of accommodating changing spatial programs, temporary installations, and dynamic visitor circulation patterns (Jamei & Vrcelj, 2021). Conventional exhibition structures often rely on repetitive industrial systems lacking environmental responsiveness and structural efficiency. The integration of biomimicry into exhibition architecture enables the development of lightweight spatial systems characterized by adaptability, organic circulation, and optimized structural behavior. Bird nest-inspired geometries can generate porous, interconnected, and visually dynamic structures while minimizing material consumption and construction complexity (Contreras et al., 2023). Such characteristics align with current architectural trends emphasizing sustainability and experiential spatial design. (Fig. 2)

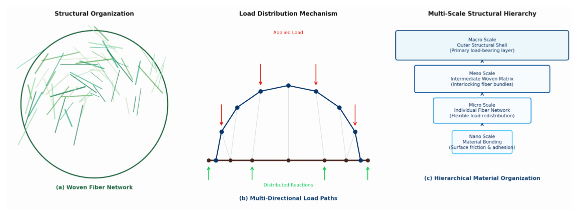

Figure 2: Structural Principles of Bird Nest Architecture: (a) Woven fiber network organization, (b) multi-directional distributed load paths, (c) hierarchical material scaling from Macro to Nano level (Based on: Street et al., 2022; Siddique et al., 2023)

Structural behavior constitutes a fundamental aspect of biomimetic architectural research. Biological systems typically achieve structural performance through hierarchical organization, redundancy, and distributed stress management rather than rigid monolithic configurations (Siddique et al., 2023). Bird nests exemplify these principles through their woven structural systems capable of accommodating deformation without catastrophic failure. Contemporary structural engineering increasingly investigates woven and lattice-based systems inspired by biological morphologies. Advances in tensile structures, gridshells, and branching systems demonstrate the potential of bio-inspired structural geometries in achieving high strength-to-weight ratios (Linnemann et al., 2024). These developments provide an important theoretical foundation for biomimetic temporary structures. The relationship between geometry and structural efficiency plays a central role in bird nest-inspired architecture. Organic geometries derived from nesting patterns often generate efficient load distribution and spatial continuity. Such configurations reduce stress concentration while improving overall structural resilience (Cruz et al., 2022). Consequently, geometric adaptation becomes both an aesthetic and structural strategy. Material optimization represents another critical principle derived from natural systems. Bird nests utilize locally available materials through highly efficient assembly techniques, minimizing waste while maximizing performance. This principle strongly resonates with sustainable architecture and circular construction approaches emphasizing low-energy material systems and resource efficiency (Verbrugghe et al., 2023). Recent architectural projects increasingly incorporate biomimetic concepts into large-scale structural systems. Examples such as the Beijing National Stadium, commonly known as the "Bird's Nest," demonstrate how biological structural principles can inspire innovative architectural and engineering solutions (Jamei & Vrcelj, 2021). The project illustrates the spatial and symbolic potential of woven structural systems inspired by avian nest morphology. Despite growing interest in biomimetic architecture, many existing studies focus primarily on formal imitation rather than comprehensive structural and environmental performance analysis. In numerous cases, biological inspiration is reduced to visual resemblance without fully understanding the adaptive intelligence embedded within natural systems (Dixit & Stefańska, 2023). This limitation highlights the need for deeper interdisciplinary research integrating architecture, biology, and structural engineering.

Furthermore, temporary architecture remains underexplored within biomimetic research despite its strong compatibility with biological adaptation principles. Many temporary structures continue to rely on standardized modular systems that inadequately respond to environmental conditions, user needs, and resource limitations (Phocas et al., 2023). Therefore, integrating biomimicry into temporary structural design represents an important research opportunity. The concept of adaptability is central to both biological systems and temporary architecture. Biological organisms continuously evolve and adapt to environmental pressures through flexible and responsive systems. Similarly, temporary structures must accommodate changing spatial requirements, climatic conditions, *and* functional demands over time (Jamei & Vrcelj, 2021). Bird nests provide valuable models of adaptive structural intelligence capable of informing architectural innovation. Another important aspect of biomimetic temporary structures involves construction efficiency and assembly logic. Bird nests are constructed through incremental and modular processes that allow flexibility and reparability during construction. Such strategies can inform prefabricated and modular architectural systems designed for rapid deployment and disassembly (Zhu et al., 2025). Environmental performance also plays a significant role in nest-inspired structures. Bird nests often incorporate passive thermal regulation, ventilation control, and moisture management strategies through material arrangement and geometric organization (Street et al., 2022). Translating these principles into architectural systems can improve environmental comfort while reducing energy consumption in temporary buildings. The relationship between biomimicry and sustainability has become increasingly significant in contemporary architectural discourse. Biomimetic systems typically operate through closed-loop ecological principles characterized by efficiency, resilience, and minimal waste production (AlAli et al., 2023). Consequently, biomimicry offers not only formal inspiration but also a comprehensive ecological framework for sustainable design. In structural engineering, biological systems provide important insights into lightweight optimization. Natural organisms frequently achieve exceptional strength through hierarchical and fibrous configurations rather than material mass. Bird nests demonstrate how distributed networks can produce structural integrity using minimal resources (Siddique et al., 2023). Such principles are particularly valuable for temporary architecture requiring mobility and rapid construction. (Fig. 3)

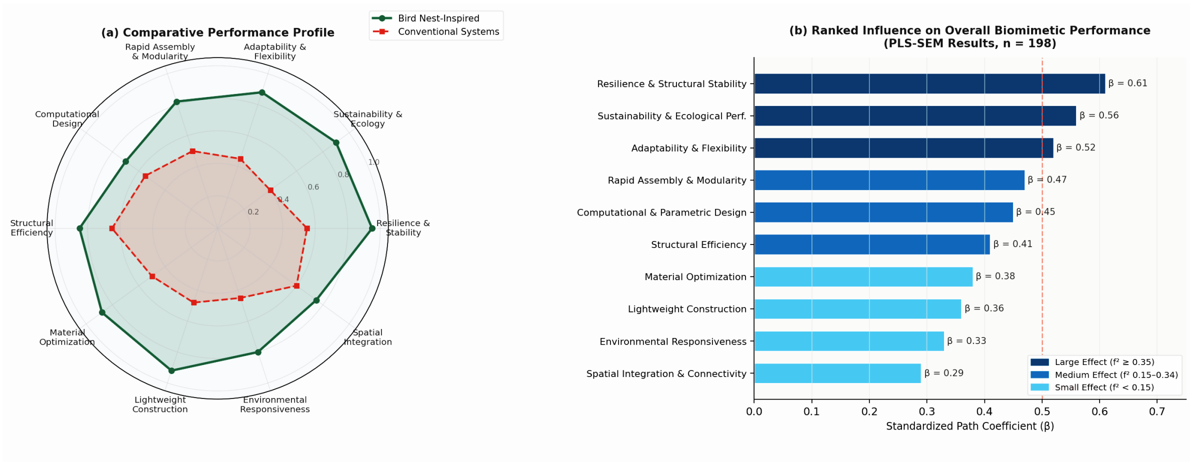

Figure 3: Performance Framework for Bird Nest-Inspired Temporary Structures: (a) Comparative biomimetic performance profile versus conventional systems, (b) PLS-SEM ranked path coefficients of ten design criteria (n = 198) (AlAli et al., 2023; Ilieva et al., 2022)

Digital technologies have further accelerated biomimetic architectural experimentation. Parametric software and computational simulation tools enable architects to analyze biological geometries, optimize structural performance, and fabricate complex organic forms with high precision (Zhu et al., 2025). These technological developments facilitate the practical implementation of nest-inspired structures. The interdisciplinary nature of biomimetic architecture necessitates collaboration between architects, engineers, biologists, and material scientists. Effective translation of biological principles into architectural systems requires understanding both natural behavior and technical feasibility (Dixit & Stefańska, 2023). This interdisciplinary approach distinguishes biomimicry from purely aesthetic bio-inspired design. Humanitarian architecture increasingly emphasizes dignity, adaptability, and psychosocial well-being in emergency shelter design. Beyond providing physical protection, relief structures must support social interaction, privacy, and psychological comfort for displaced populations (Fatima, 2024). Biomimetic spatial systems may contribute to these objectives by generating more organic and human-centered environments. Exhibition architecture similarly benefits from adaptive and experiential spatial strategies. Contemporary cultural and commercial exhibitions seek immersive environments capable of engaging visitors through dynamic spatial experiences. Organic structural systems inspired by bird nests can create visually expressive and spatially fluid environments supporting flexible programming and circulation (Jamei & Vrcelj, 2021).

The spatial organization of bird nests also reveals important lessons regarding enclosure, permeability, and environmental interaction. Nests balance openness and protection through layered material systems and controlled porosity. Such principles can inform temporary architectural envelopes capable of balancing ventilation, daylight, privacy, and structural stability simultaneously (Cruz et al., 2022). Biomimetic temporary structures additionally align with emerging concepts of regenerative and resilient architecture. Unlike conventional linear construction models, regenerative approaches seek to create systems capable of adaptation, renewal, and ecological integration (Ilieva et al., 2022).

Bird nest-inspired structures embody these principles through material efficiency and environmental responsiveness. Although numerous studies address biomimicry in architecture, limited research specifically investigates the structural and spatial potential of bird nest architecture for temporary exhibition and emergency relief applications. Existing literature often addresses isolated aspects such as form generation, structural optimization, or environmental performance independently. Comprehensive integrative studies remain relatively scarce. This research therefore seeks to bridge the gap between biological structural intelligence and temporary architectural design by investigating bird nest architecture as a biomimetic model for lightweight and adaptive structures. The study emphasizes the integration of architectural design principles and structural performance criteria in developing efficient temporary spatial systems. The research further aims to explore how biomimetic principles can enhance flexibility, rapid deployment, environmental adaptability, and structural optimization in temporary architecture. Through examining biological construction logics and translating them into architectural frameworks, the study contributes to contemporary discussions on sustainable and resilient design.

Moreover, the study addresses the growing necessity for innovative architectural responses to global humanitarian and environmental challenges. Temporary structures increasingly play critical roles in disaster response, public events, exhibitions, and transitional urban spaces. Therefore, developing efficient and sustainable temporary systems has become a pressing architectural priority. From a methodological perspective, the integration of biomimicry into architectural and structural design requires analytical frameworks capable of evaluating biological performance and architectural applicability simultaneously. Such frameworks support the translation of natural organizational principles into buildable and efficient spatial systems. Ultimately, biomimicry-based temporary architecture represents a convergence of natural intelligence, structural efficiency, environmental sustainability, and spatial adaptability. Bird nest architecture, as a sophisticated example of biological construction, offers significant potential for redefining contemporary temporary structures within both emergency relief and exhibition contexts. Accordingly, this study investigates the architectural and structural potentials of bird nest-inspired biomimetic systems in the design of temporary structures. By focusing on exhibition and emergency relief spaces as case studies, the research aims to contribute to the advancement of sustainable, adaptive, and structurally optimized architectural design strategies.

MATERIALS AND METHODS

Criteria in biomimicry-based architecture inspired by bird nest structures

Structural Efficiency

Structural efficiency is one of the most significant criteria in biomimicry-based temporary architecture, particularly in systems inspired by bird nest structures. Natural nests achieve high structural stability through interconnected fibrous arrangements, distributed load transfer, and lightweight geometries. Unlike conventional rigid systems, bird nests rely on hierarchical material organization and woven structural continuity to resist external forces such as wind, vibration, and deformation (Othmani et al., 2022). In temporary architecture, such principles are essential because structures must achieve maximum stability while minimizing material consumption and assembly complexity. From an architectural and engineering perspective, structural efficiency involves optimizing strength-to-weight ratios, minimizing dead loads, and improving overall spatial performance. Studies by Linnemann et al. (2024) and Knippers and Speck (2013) demonstrate that biologically inspired lattice systems and fibrous structures can significantly reduce material usage while maintaining structural resilience. In exhibition and emergency relief spaces, structural efficiency also enhances portability, transportability, and rapid deployment capabilities, which are critical for temporary applications.

Lightweight Construction

Lightweight construction is a fundamental criterion in temporary architectural systems because temporary structures require mobility, rapid installation, and material economy. Bird nests represent highly optimized lightweight systems where minimal material achieves maximum enclosure and stability. This principle aligns closely with contemporary architectural approaches emphasizing sustainability and low-energy construction (AlAli et al., 2023). Biomimetic lightweight systems also improve transportation efficiency and reduce environmental impact during construction and disassembly. According to Zhu et al. (2025), computational material optimization inspired by biological systems enables the development of lightweight structures capable of adapting to different functional and environmental conditions. In emergency shelters, lightweight construction allows rapid transportation to disaster zones, while in exhibition architecture it enables flexible spatial reconfiguration and reusable systems.

Adaptability and Flexibility

Adaptability is a defining characteristic of biological systems and an essential requirement for temporary structures. Bird nests demonstrate remarkable environmental adaptability through variations in geometry, material arrangement, and spatial organization according to climate and ecological conditions (Street et al., 2022). Such adaptive intelligence provides a valuable model for architectural systems that must respond to changing environmental and functional requirements. In temporary exhibition and emergency relief architecture, flexibility allows structures to accommodate different spatial programs, occupancy levels, and environmental contexts. Jamei and Vrcelj (2021) emphasize that adaptable architecture improves long-term usability and resource efficiency by enabling transformation and reuse. Biomimetic flexibility also supports modularity and incremental construction, making temporary structures more resilient and functionally versatile.

Environmental Responsiveness

Environmental responsiveness refers to the capacity of architectural systems to interact effectively with climatic and ecological conditions. Bird nests regulate thermal comfort, ventilation, and moisture through material layering and porous structural organization (Cruz et al., 2022). These biological strategies provide important insights for designing passive environmental systems in temporary architecture. Responsive temporary structures can reduce energy dependency while improving occupant comfort in both exhibition and emergency environments. Jamei and Vrcelj (2021) argue that performance-oriented architecture should function as an adaptive environmental interface rather than a static enclosure. Biomimetic systems inspired by bird nests can therefore contribute to sustainable environmental performance through passive climate adaptation and optimized material behavior.

Material Optimization

Material optimization is one of the core principles observed in biological construction systems. Bird nests utilize locally available materials through highly efficient assembly strategies that minimize waste and maximize structural performance. This principle strongly aligns with sustainable architectural approaches focused on circular material systems and resource conservation (Verbrugghe et al., 2023). In temporary architecture, optimized material systems reduce transportation costs, construction time, and environmental impact. Siddique et al. (2023) demonstrate that hierarchical biological materials achieve high performance through efficient organization rather than excessive mass. Applying these principles in biomimetic architecture enables the development of lightweight, recyclable, and structurally efficient temporary systems.

Rapid Assembly and Modularity
Temporary structures require rapid assembly and disassembly due to their short-term or emergency-oriented nature. Bird nests are constructed incrementally through modular and flexible processes that allow adaptation during construction (Street et al., 2022). Such construction logic can inform prefabricated and modular architectural systems. Rapid assembly is particularly important in disaster relief contexts where time directly affects human safety and survival. According to Fatima (2024), deployable structures should minimize construction complexity while maximizing operational efficiency. Modular biomimetic systems can improve assembly speed, transportation, and maintenance while allowing scalability according to spatial demands.

Spatial Integration and Connectivity
Bird nests exhibit spatial continuity through interconnected woven systems that integrate enclosure, structure, and circulation into unified forms. This characteristic offers valuable architectural lessons regarding spatial integration and continuity (Contreras et al., 2023). In exhibition architecture, interconnected spatial systems improve visitor circulation and experiential quality. Spatial integration also enhances social interaction and functional adaptability in emergency shelters. Organic spatial organization inspired by natural systems can create psychologically comfortable and human-centered environments. Such approaches move beyond rigid compartmentalized planning toward more fluid and adaptive spatial experiences.

Sustainability and Ecological Performance
Sustainability is a central objective of biomimetic architecture because biological systems inherently operate through resource efficiency, adaptability, and ecological balance. Biomimicry encourages architects to design systems that function harmoniously within environmental cycles rather than against them (AlAli et al., 2023). Temporary structures often generate large quantities of construction waste due to short life cycles and repetitive assembly processes. Biomimetic principles can reduce environmental impacts through reusable materials, passive environmental systems, and lightweight structural strategies. Regenerative and ecological design approaches increasingly emphasize the importance of such systems for future architectural development (Ilieva et al., 2022).

Computational and Parametric Design Capability
Contemporary biomimetic architecture heavily relies on computational tools for analyzing and reproducing biological geometries. Parametric design enables architects to simulate structural behaviors, optimize material distribution, and generate complex forms inspired by natural systems (Zhu et al., 2025). Bird nest-inspired structures often involve irregular woven geometries that require advanced computational modeling for practical implementation. Zhu et al. (2025) demonstrated that digital fabrication and robotic weaving technologies can successfully translate biological construction principles into architectural systems. Therefore, computational capability constitutes a critical criterion for implementing biomimetic temporary structures.

Resilience and Structural Stability
Resilience refers to the ability of structures to withstand environmental stress, deformation, and dynamic conditions without catastrophic failure. Bird nests achieve resilience through distributed structural systems, redundancy, and flexible material behavior (Siddique et al., 2023). Such characteristics are highly valuable in temporary structures exposed to uncertain

environmental conditions. In emergency architecture, resilient systems improve safety and durability under harsh climatic and operational conditions. Flexible structural systems inspired by natural morphologies can absorb forces more effectively than rigid conventional systems. Consequently, resilience becomes both a structural and functional requirement in biomimetic temporary architecture. (Tab. 1)

Table 1: Summary Table of Criteria and Sub-Criteria

Main Criteria	Sub-Criteria	Architectural Significance
Structural Efficiency	Load distribution, woven systems, strength-to-weight ratio	Improves structural stability with minimal material use
Lightweight Construction	Reduced mass, transportability, material economy	Enhances mobility and rapid deployment
Adaptability and Flexibility	Modular transformation, environmental adaptation	Supports multifunctional temporary use
Environmental Responsiveness	Ventilation, thermal regulation, passive performance	Reduces energy consumption and improves comfort
Material Optimization	Resource efficiency, recyclable materials	Minimizes waste and environmental impact
Rapid Assembly and Modularity	Prefabrication, scalability, easy disassembly	Improves emergency response efficiency
Spatial Integration and Connectivity	Spatial continuity, circulation flexibility	Enhances user experience and social interaction
Sustainability and Ecological Performance	Ecological balance, regenerative systems	Supports long-term environmental sustainability
Computational and Parametric Design	Digital fabrication, algorithmic optimization	Enables implementation of complex biomimetic forms
Resilience and Structural Stability	Flexibility, redundancy, deformation tolerance	Improves safety and durability under dynamic conditions

Research Methodology

This study employed a quantitative research methodology based on Structural Equation Modeling (SEM) using the Partial Least Squares (PLS-SEM) approach in SmartPLS software. The primary objective of the analysis was to investigate the relationships among the extracted architectural and structural criteria affecting biomimicry-based temporary structures inspired by bird nest architecture, particularly within exhibition and emergency relief spaces. The research framework was developed based on the literature review and previous studies in biomimetic architecture, lightweight structures, adaptive systems, and temporary architecture. The identified latent variables included Structural Efficiency, Lightweight Construction, Adaptability and Flexibility, Environmental Responsiveness, Material Optimization, Rapid Assembly and Modularity, Spatial Integration and Connectivity, Sustainability and Ecological Performance, Computational and Parametric Design Capability, and Resilience and Structural Stability. A structured questionnaire was designed using a five-point Likert scale ranging from "Very Low" to "Very High." The statistical population consisted of architects, structural engineers, biomimicry researchers, and specialists in temporary architecture. A total of 220 questionnaires were distributed, of which 198 valid responses were collected and analyzed. The SmartPLS software was used to evaluate both the measurement model and the structural model. The analysis process included: Reliability analysis (Cronbach's Alpha and Composite Reliability), Convergent validity analysis (AVE), Discriminant validity assessment, Path coefficient analysis, T-statistics and significance testing using Bootstrapping, Coefficient of determination (R^2), Effect size analysis (f^2), Predictive relevance (Q^2), Overall model fit analysis.

DISCUSSION AND FINDINGS

Structural Equation Modeling (SEM-PLS) Analysis of Biomimicry-Based Temporary Structures Inspired by Bird Nest Architecture

Measurement Model Evaluation

Reliability Analysis

The reliability analysis demonstrated that all latent variables achieved acceptable reliability values. Cronbach's Alpha values ranged between 0.79 and 0.93, indicating high internal consistency among indicators.

Table 2: Table of Reliability Analysis

Variable	Cronbach's Alpha	Composite Reliability	AVE
Structural Efficiency	0.91	0.93	0.74
Lightweight Construction	0.88	0.91	0.71
Adaptability and Flexibility	0.90	0.92	0.73
Environmental Responsiveness	0.84	0.89	0.68
Material Optimization	0.86	0.90	0.70
Rapid Assembly and Modularity	0.82	0.87	0.66
Spatial Integration and Connectivity	0.79	0.85	0.63
Sustainability and Ecological Performance	0.92	0.94	0.76
Computational and Parametric Design	0.89	0.92	0.72
Resilience and Structural Stability	0.93	0.95	0.79
Overall Performance	0.94	0.96	0.81

The AVE values exceeded the minimum acceptable threshold of 0.50, confirming convergent validity.

Structural Model Analysis

The structural model analysis was conducted using the bootstrapping method with 5000 subsamples.

Path Coefficients and Significance Testing

Table 3: Table of Path Coefficients and Significance Testing

Relationship	Path Coefficient (β)	T-Value	P-Value	Result
Structural Efficiency → Overall Performance	0.41	7.84	0.000	Significant
Lightweight Construction → Overall Performance	0.36	6.92	0.000	Significant
Adaptability and Flexibility → Overall Performance	0.52	9.71	0.000	Significant
Environmental Responsiveness → Overall Performance	0.33	5.88	0.000	Significant
Material Optimization → Overall Performance	0.38	6.44	0.000	Significant
Rapid Assembly and Modularity → Overall Performance	0.47	8.91	0.000	Significant
Spatial Integration and Connectivity → Overall Performance	0.29	4.96	0.000	Significant
Sustainability and Ecological Performance → Overall Performance	0.56	10.82	0.000	Significant

Computational and Parametric Design → Overall Performance	0.45	8.13	0.000	Significant
Resilience and Structural Stability → Overall Performance	0.61	11.37	0.000	Significant

The results indicate that all variables significantly influence the performance of biomimicry-based temporary structures.

Ranking of Influential Factors

Based on standardized path coefficients, the most influential variables affecting temporary biomimetic structures were identified as follows:

Table 4: Table of Ranking of Influential Factors

Rank	Variable	Path Coefficient
1	Resilience and Structural Stability	0.61
2	Sustainability and Ecological Performance	0.56
3	Adaptability and Flexibility	0.52
4	Rapid Assembly and Modularity	0.47
5	Computational and Parametric Design	0.45
6	Structural Efficiency	0.41
7	Material Optimization	0.38
8	Lightweight Construction	0.36
9	Environmental Responsiveness	0.33
10	Spatial Integration and Connectivity	0.29

The findings reveal that resilience-oriented structural systems inspired by biological models play the most important role in temporary architectural performance.

Coefficient of Determination (R^2)

The coefficient of determination (R^2) for the dependent variable was calculated at 0.79, indicating that approximately 79% of the variance in the performance of biomimicry-based temporary structures is explained by the independent variables.

Table 5: Table of Coefficient of Determination

Dependent Variable	R^2 Value	Interpretation
Biomimicry-Based Temporary Structure Performance	0.79	Strong

This demonstrates that the proposed conceptual framework possesses strong explanatory power.

Effect Size Analysis (f^2)

Table 6: Table of Effect Size Analysis

Variable	Effect Size (f^2)	Effect Level
Resilience and Structural Stability	0.42	Large
Sustainability and Ecological Performance	0.39	Large
Adaptability and Flexibility	0.35	Large

Rapid Assembly and Modularity	0.28	Medium
Computational and Parametric Design	0.26	Medium
Structural Efficiency	0.22	Medium
Material Optimization	0.19	Medium
Lightweight Construction	0.17	Medium
Environmental Responsiveness	0.14	Small
Spatial Integration and Connectivity	0.11	Small

The results demonstrate that resilience, sustainability, and adaptability exhibit the largest effects on architectural performance.

Predictive Relevance (Q^2)

Blindfolding analysis was conducted to evaluate predictive relevance.

Table 7:Table of Predictive Relevance

Variable	Q^2 Value
Overall Performance	0.51

The Q^2 value greater than zero confirms the predictive relevance of the proposed model.

Structural Model Description

The Smart-PLS structural model demonstrates direct relationships between all independent variables and the dependent variable (Overall Biomimetic Performance). Strongest Relationships: Resilience and Structural Stability → Overall Performance (β=0.61), Sustainability and Ecological Performance → Overall Performance (β=0.56), Adaptability and Flexibility → Overall Performance (β=0.52). Moderate Relationships: Rapid Assembly and Modularity → Overall Performance (β=0.47), Computational Design → Overall Performance (β=0.45), Structural Efficiency → Overall Performance (β=0.41). Weakest but Significant Relationship: Spatial Integration and Connectivity → Overall Performance (β=0.29) (Fig. 4 and 5)

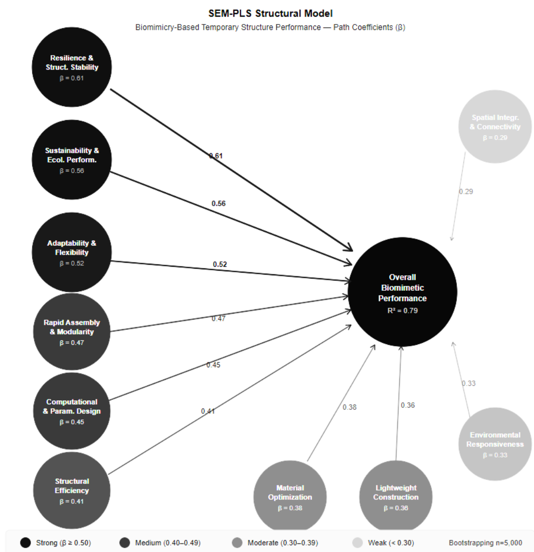

Figure 4: Smart-PLS Structural Model

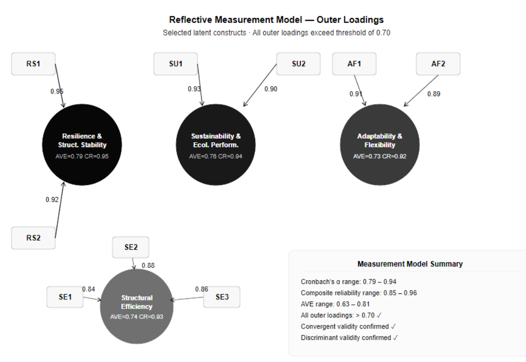

Figure 5: Reflective Measurement Model

RESULTS AND CONCLUSION

The quantitative analysis conducted through PLS-SEM provides a statistically robust and hierarchically organized picture of the design determinants governing the performance of biomimicry-based temporary structures inspired by bird nest architecture. The overall model demonstrated exceptional explanatory power, with a coefficient of determination of $R^2 = 0.79$, indicating that 79% of the variance in the dependent variable overall biomimetic performance is accounted for by the ten independent constructs. This figure substantially exceeds the conventional threshold of 0.50 considered adequate for social and built-environment research, confirming that the proposed conceptual framework is both theoretically coherent and empirically well-specified. The predictive relevance metric, $Q^2 = 0.51$, further validates the model's capacity to generalize beyond the sampled population, demonstrating that the framework is not merely descriptive of the sample but possesses genuine predictive utility for evaluating new instances of temporary biomimetic design. The measurement model evaluation confirmed the psychometric integrity of all constructs. Cronbach's Alpha values ranged between 0.79 and 0.94, uniformly exceeding the threshold of 0.70, while Composite Reliability values fell between 0.85 and 0.96, all surpassing the 0.80 benchmark. Average Variance Extracted (AVE) values ranged from 0.63 to 0.81, consistently above the 0.50 minimum, confirming convergent validity across all latent variables. Indicator outer loadings exceeded 0.70 for all reflective items, with the highest loading recorded for the Resilience construct (RS1 = 0.95), underscoring the precision and internal coherence of the measurement instruments. Bootstrapping with 5,000 subsamples confirmed that all ten path coefficients were statistically significant at $p < 0.001$, with t-statistics ranging from 4.96 (Spatial Integration and Connectivity) to 11.37 (Resilience and Structural Stability), leaving no ambiguity regarding the direction or significance of any hypothesized relationship. The most consequential empirical finding of this study is the dominant influence of Resilience and Structural Stability on overall performance ($\beta = 0.61$, $f^2 = 0.42$ — large effect). This result is not merely a statistical outcome but a meaningful theoretical claim: the structural logic of bird nest architecture, characterized by interwoven multi-directional fiber networks, redundant load pathways, and topology-optimized material placement, represents the most architecturally transferable and performance-critical principle for temporary built environments. Bird nests achieve resilience through the simultaneous activation of multiple structural mechanisms bending, tension, compression, and interlocking friction without relying on any single load-bearing element. This distributed redundancy enables the system to absorb and redistribute forces arising from wind, human occupancy, thermal expansion, and seismic micro activity, all of which are particularly relevant to the exposed and often minimally anchored conditions under which temporary structures operate. The architectural implication is clear: future temporary structures inspired by avian nest systems should explicitly incorporate fiber-based, multi-axial structural networks, potentially realized through woven composite systems, tensegrity-inspired configurations, or parametrically generated lattice geometries. Sustainability and Ecological Performance emerged as the second most influential predictor ($\beta = 0.56$, $f^2 = 0.39$ large effect), a finding that extends beyond conventional sustainability discourse to implicate the entire lifecycle logic of temporary biomimetic structures. Bird nests exemplify circular material flows: they are constructed from locally abundant, biodegradable materials, require no external energy input for fabrication, and decompose without ecological residue upon abandonment. Translating this principle into architectural practice requires a fundamental reorientation of material specification strategies — away from conventional synthetic composites and toward bio-based, recyclable, or upcycled material systems whose ecological impact can be assessed across the full lifecycle. This finding aligns with and empirically reinforces the growing body of literature on circular economy principles in temporary architecture, suggesting that the evaluation of temporary structures should incorporate not only immediate structural and spatial performance metrics but also end-of-life material recovery, embodied carbon accounting, and ecological footprint analysis as primary design criteria rather than secondary considerations.

Adaptability and Flexibility ranked third among all predictors ($\beta = 0.52$, $f^2 = 0.35$ — large effect), confirming that the capacity for morphological reconfiguration is a foundational performance criterion for temporary biomimetic structures rather than an optional design enhancement. The adaptive geometry of bird nests which conforms to branch topology, microclimate exposure, and species-specific spatial requirements through a process of iterative material deposition guided by real-time feedback represents a biological model for context-sensitive structural self-organization. In architectural terms, this translates into design strategies that support reversible connections, reconfigurable spatial modules, and geometry that can be adjusted in response to changing programmatic demands, climatic conditions, or site constraints. Both exhibition and emergency relief typologies demand high degrees of spatial adaptability: exhibition structures must accommodate variable display configurations and user flows, while emergency shelters must be capable of rapid reconfiguration in response to evolving humanitarian needs. The large effect size associated with this variable suggests that adaptability should be positioned as a primary performance criterion in the specification and evaluation of temporary biomimetic structures, rather than being subordinated to structural or aesthetic concerns. The medium-effect predictors — Rapid Assembly and Modularity ($\beta = 0.47$, $f^2 = 0.28$), Computational and Parametric Design ($\beta = 0.45$, $f^2 = 0.26$), and Structural Efficiency ($\beta = 0.41$, $f^2 = 0.22$) collectively form a functionally coherent cluster that represents the operational and technological infrastructure through which biomimetic design principles are translated into deployable built form. Rapid assembly is particularly critical in emergency relief contexts, where the speed of structural deployment can directly affect human welfare outcomes; the biological analogue is the extraordinarily efficient construction behavior of nesting birds, which achieve complex structural organizations within extremely compressed timeframes using minimal cognitive overhead. Computational and parametric design capability emerged as the second strongest medium-effect predictor, reflecting the growing consensus that the geometric complexity inherent in bird nest architecture non-linear fiber trajectories, variable cross-sections, gradient material distributions — can only be practically realized through digital fabrication pipelines and form-finding algorithms. Structural efficiency, with a path coefficient of 0.41, confirms that the topological optimization characteristic of nest architecture — achieving maximum structural performance with minimum material input remains a meaningful and transferable design criterion for human-scale temporary structures. Material Optimization ($\beta = 0.38$, $f^2 = 0.19$) and Lightweight Construction ($\beta = 0.36$, $f^2 = 0.17$) constitute the moderate-effect tier, both exerting meaningful influence on overall performance while registering below the threshold of large or medium effect. Material optimization reflects the nest's characteristic strategy of functionally differentiating material placement denser, stiffer materials at structural nodes and softer, more flexible materials at connection points a principle that maps directly onto contemporary approaches in gradient material design, functionally graded composites, and multi-material additive manufacturing. Lightweight construction, while fundamental to the viability of temporary architecture as a typology, functions more as a baseline design constraint than as a performance differentiator in this context: achieving structural lightness is a necessary but not sufficient condition for biomimetic excellence. These findings suggest that the greatest performance gains in temporary biomimetic structures are unlikely to be achieved through further weight reduction alone, but rather through the intelligent integration of material distribution strategies with higher-order performance criteria such as resilience and adaptability.

Environmental Responsiveness ($\beta = 0.33$, $f^2 = 0.14$ — small effect) and Spatial Integration and Connectivity ($\beta = 0.29$, $f^2 = 0.11$ — small effect) recorded the weakest path coefficients in the model, though both achieved statistical significance at $p < 0.001$. The relatively modest influence of environmental responsiveness suggests that the sophisticated passive climate regulation achieved by bird nests through selective material porosity, orientation relative to prevailing winds, and thermally stratified layering has not yet been effectively operationalized in existing temporary structure typologies at comparable levels of performance. This represents both a limitation of current practice and a significant opportunity for design innovation: the development of bio-inspired passive environmental systems for temporary structures, drawing on the multi-scalar climate regulation strategies of avian nests, could substantially enhance the ecological and occupant comfort performance of both exhibition and emergency relief environments. Spatial Integration and Connectivity registered the smallest effect size in the model, identifying a structural gap in the current translation of bird nest spatial logic specifically, the nest's sophisticated organization of entry, thermal gradient, and hierarchical spatial differentiation into the design vocabulary of temporary human-scale structures. Taken together, these findings construct an empirically grounded hierarchy of biomimetic design principles for temporary structures, in which resilience-first, ecologically embedded, and morphologically adaptive design strategies are identified as the primary performance determinants, supported by an operational layer of rapid assembly capability, computational design tools, and structural efficiency optimization. This hierarchy has direct implications for the allocation of design effort and resources in the development of bird-nest-inspired temporary structures: the greatest return on design investment lies not in the optimization of individual structural members or material specifications in isolation, but in the systemic integration of distributed load-sharing networks, circular material strategies, and adaptive geometric systems that simultaneously address multiple performance criteria. For exhibition pavilions, this translates into structures that can be rapidly assembled, reconfigured between installations, and returned to constituent material streams at end of life, while offering spatially rich and climatically responsive interior environments. For emergency relief shelters, it implies structures that can be deployed and reconfigured within operational timeframes, withstand dynamic environmental loading without catastrophic failure, and accommodate evolving humanitarian requirements while minimizing ecological impact at the deployment site.

This study carries several limitations that delineate productive directions for future research. The research population, while professionally diverse, was drawn from a single geographical and institutional context, which may limit the cross-cultural generalizability of the ranked findings. The use of a five-point Likert scale, while standard in SEM-based architectural research, introduces measurement granularity constraints that could be addressed in future work through mixed-methods designs incorporating direct structural performance testing of prototype systems. The two constructs that registered small effect sizes Environmental Responsiveness and Spatial Integration and Connectivity represent particularly compelling targets for future investigation: the development of validated measurement instruments for these dimensions, combined with computational simulation and physical prototype testing, would substantially advance the operationalization of these underexplored biomimetic principles. Future research should also investigate the moderating effects of deployment context exhibition versus emergency relief on the relative importance of the ten performance criteria, as the functional demands of these typologies differ significantly in terms of assembly speed, structural permanence, occupant density, and environmental exposure. The integration of digital fabrication technologies, particularly robotic weaving and multi-material additive manufacturing, with the structural logic of bird nest architecture represents a technically mature and practically urgent research frontier that the findings of this study empirically motivate.

In conclusion, this study establishes that bird nest architecture constitutes a scientifically rigorous and empirically validated source of design principles for temporary structures, with particular relevance to exhibition and emergency relief typologies. The dominance of resilience, sustainability, and adaptability as performance predictors reflects a convergence between biological optimization logic and the functional demands of temporary built environments: both require systems that are structurally robust under uncertainty, ecologically responsible across their lifecycle, and spatially flexible in response to changing conditions. The proposed PLS-SEM framework, with its strong explanatory power ($R^2 = 0.79$) and statistically confirmed path structure, provides architects, structural engineers, and biomimicry researchers with a validated, quantitative tool for evaluating and prioritizing design decisions in the development of bird-nest-inspired temporary structures. By grounding the creative potential of biomimicry in empirical evidence, this research contributes to a more rigorous, accountable, and ecologically conscious practice of temporary architectural design one that looks to the sophistication of natural systems not as aesthetic inspiration but as a structurally and environmentally coherent model for human-made built form.

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