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Biomimicry-informed deconstruction of the cognitive system for Sino–Western hybrid architecture: A case study of Lushan UNESCO Global Geopark

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Abstract

Sino–Western hybrid architecture serves as a medium for cross-cultural exchange; however, its preservation faces two major challenges: unclear conservation standards and differing perceptions of cultural value. The hybrid architectural forms at Lushan developed in response to local terrain and climate, but the difficulty in defining authenticity for such buildings complicates conservation efforts. This study examines the villa cluster in Guling town, Lushan, employing biomimicry not as a design methodology but as an analytical framework to evaluate hybrid heritage through characteristics of environmental adaptation. Based on a literature review, field surveys of 45 villas, and interviews with 15 participants, including residents, heritage managers, and scholars, the study analyzes environmental adaptation, hybrid architectural styles, typological classification, and preservation challenges. The investigation reveals that, despite differing cultural origins, both Chinese and Western building traditions in Guling town developed similar responses to mountainous conditions, suggesting that environmental adaptation provides common ground for heritage evaluation that transcends cultural boundaries. Accordingly, a four-dimensional preservation framework is proposed that integrates function and culture, coordinates ecology and heritage, links landscape and narrative, and incorporates community participation. The framework addresses the methodological challenge of evaluating buildings rooted in multiple cultural traditions without privileging either lineage. Limitations of the study include its qualitative approach and focus on a single site. Nevertheless, the findings offer insights for conserving comparable hybrid architecture in other mountainous areas and point toward future research on developing quantitative indicators of environmental adaptation.

Keywords: Sino–Western hybrid architecture; Biomimicry; Mountainous environment; Cultural heritage; Lushan UNESCO Global Geopark

1. Introduction

1.1. Research background and problem setting

Cultural heritage conservation has evolved from monument-focused protection toward integrated approaches that address the tangible and intangible dimensions simultaneously. The 1994 Nara Document on Authenticity challenged Western-centric conservation paradigms by recognizing that authenticity must be evaluated within specific cultural contexts rather than through universal criteria, a principle that continues to generate scholarly debate regarding its practical application (Nakonieczna & Szczepański, 2024). This recognition proved particularly significant for Asian nations, where architectural traditions involving periodic material renewal had been marginalized under Eurocentric frameworks. In China, the dialogue between international heritage discourse and domestic conservation philosophy has generated distinctive approaches, especially for modern built heritage exhibiting cross-cultural characteristics (Liang *et al.*, 2023). Recent scholarship indicates that the conceptual scope of heritage conservation in China has expanded from static monument preservation toward dynamic, living heritage approaches that incorporate community participation and functional continuity (Knapp, 2024). Within this evolving theoretical landscape, Sino–Western hybrid architecture presents particular challenges because it embodies the cultural negotiations of a specific historical period while defying classification within single cultural traditions.

The Lushan villa complex emerged from China's treaty port era. Following the establishment of foreign concessions in coastal cities after the Opium Wars, Western missionaries and merchants sought summer retreats in China's mountainous regions to escape lowland heat and disease. In 1895, Edward Selby Little, a British merchant, negotiated land rights in the Guling area of Lushan and initiated the construction of villas. Over the following decades, nationals from Britain, the United States, France, Germany, Russia, Japan, and other countries built approximately one thousand villas, creating a settlement that contemporaries termed the "World Village," a phenomenon that continues to define Lushan's cultural landscape significance (Q. Xu *et al.*, 2021). These structures were not simply transplanted Western buildings. Local constraints—steep terrain, humid climate, available materials, and Chinese labor practices—necessitated adaptations that produced genuinely hybrid forms. The villa builders combined European spatial planning with local stone construction, integrated Chinese feng shui principles with Western structural systems, and developed roof forms that responded to Lushan's heavy rainfall. This historical process produced architecture that documents intercultural exchange during a transformative period in Chinese history (H. Zhang *et al.*, 2023).

The difficulty in defining conservation standards for Sino–Western hybrid architecture reflects the complexity of cultural values. Academia has not yet established clear standards for prioritizing the preservation of different cultural elements in such buildings. The core of this controversy lies in differing interpretations of architectural "authenticity" (Spector, 2011). In expressing authenticity, China's traditional principle of "repairing the old as the old" (Boito & Birignani, 2009) differs significantly from the internationally prevailing concept of "minimal intervention" (Y. Zhang & Dong, 2021). International academic discourse on architectural authenticity has expanded from the material dimension to include spiritual and cultural dimensions.

This study focuses on the villa cluster in Guling town, Lushan. Against the backdrop of rapid tourism development, there is no academic consensus on how to assess later additions such as modern commercial signs and altered door and window structures. It remains unclear which modifications should be retained and which should be restored. This ambiguity in conservation standards has led to a dual dilemma in practice: some buildings have been over-commercialized, while others have been altered arbitrarily due to the lack of clear guidelines (Agnantopoulou *et al.*, 2023). These issues undermine preservation efforts. The absence of design guidelines for new construction has led to landscape fragmentation, disrupting the cohesive character of Lushan's architectural heritage (Jiang *et al.*, 2022; J. Wang *et al.*, 2024; L. Zou & Li, 2014).

1.2. Purpose of research

This study systematically reviews existing research on the conservation of Sino–Western hybrid architecture. It identifies prevailing issues and theoretical dilemmas in the current literature. Using the villa cluster in Guling town, Lushan, China, as a key case study, the research analyzes specific challenges and their underlying causes. It further explores potential pathways to theoretical innovation. The findings contribute to refining the theoretical framework for conserving Sino–Western hybrid architecture. They help fill a research gap regarding the cultural continuity of such architecture in mountainous settings. This study also provides theoretical support for recognizing the value and promoting the sustainable development of cross-cultural architectural heritage.

The study proposes a four-dimensional framework integrating environment, culture, function, and community participation to support sustainable conservation.

This framework offers direct operational guidance for preserving the villa cluster in Guling town, Lushan. It addresses practical issues such as ambiguous standards, landscape fragmentation, and functional disconnection. Specifically, the approach helps clarify conservation criteria, maintain visual coherence, and enhance functional relevance. It also serves as a reference model for other mountainous areas with Sino–Western hybrid architecture. Existing conservation approaches to Sino–Western hybrid architecture face a fundamental methodological dilemma: privileging either Chinese or Western cultural elements risks diminishing the architectural significance derived from their integration. Standard heritage frameworks, whether derived from international conservation charters or from Chinese principles emphasizing original state restoration, were developed for culturally homogeneous contexts and offer limited guidance for genuinely hybrid sites. This study addresses this gap by introducing biomimicry as an analytical framework that transcends cultural categorization through a focus on environmental adaptation—a logic shared across Chinese and Western architectural traditions. By doing so, it promotes the living sustainability of architectural heritage that embodies cross-cultural exchange.

1.3. Research framework

The research adopts a three-phase methodology. This study adopts a three-phase research design. First, a systematic literature review examines existing scholarship on Sino–Western hybrid architecture and biomimicry-related theories. Second, empirical investigations—including field surveys, archival research, and interviews—are conducted at the Guling town villa cluster in Lushan to analyze its environmental adaptation characteristics and conservation challenges. Finally, by integrating biomimicry principles with heritage conservation theory, the study develops an innovative conservation framework to promote the cultural continuity of Sino–Western hybrid architecture in mountainous environments. The study clarifies the current academic landscape and theoretical dilemmas in Sino–Western hybrid architecture research. It investigates the environmental features, architectural typology, and the status of cultural inheritance of the Guling town villas. The application logic and suitability of biomimicry thinking in architecture are introduced. Within the Lushan context, it proposes innovative strategies for sustaining the cultural legacy of Sino–Western hybrid architecture.

2. Related theories and state of research

2.1. The formation of Sino–Western hybrid architecture

The late nineteenth century produced diverse architectural expressions in Europe and North America. Victorian eclecticism drew upon neoclassicism, Gothic revival, and regional vernacular traditions. These styles preceded early modernism, which emerged after 1900 as a reaction against historicist ornamentation. The Lushan villas were built primarily between 1895 and 1935, when Victorian eclecticism and early modernist principles coexisted in Western residential architecture. This distinction matters for interpreting the stylistic diversity at Guling town—Chinese and European architectural traditions developed from different philosophical premises.

Traditional Chinese residential architecture embodies distinct spatial and structural principles. Courtyard-based organization arranges buildings around enclosed outdoor spaces, creating hierarchical sequences from public reception areas to private family quarters. Timber frame construction employs mortise-and-tenon joinery, providing structural flexibility without the use of metal fasteners. Feng shui principles guide building orientation, typically positioning structures to face south while backing against northern topographic features. Modular proportioning systems govern relationships between structural members, ensuring visual coherence across different building scales. Landscape integration occurs through borrowed scenery techniques that incorporate distant views into architectural compositions. These characteristics contrast with European residential conventions emphasizing masonry permanence, formal symmetry, and enclosed interior volumes (Chang, 2019; Knapp, 2024). The Guling Town villas required negotiation among distinct spatial logics as Western clients, Chinese craftsmen, and local environmental conditions shaped the buildings' outcomes.

Chinese architecture emphasized horizontal spatial organization, timber-framed construction, and landscape integration in accordance with feng shui principles. European residential architecture favored masonry construction, vertical emphasis, and formal symmetry. In treaty port contexts, builders negotiated between imported conventions and local conditions—climate, materials, labor, and topography—producing hybrid forms that neither tradition alone can explain (Gravari-Barbas *et al.*, 2024). From the late 19th to the early 20th century, China underwent significant social transformation and technological innovation. To meet modern societal needs, architecture featuring eclectic European styles began to appear in treaty ports such as Guangzhou, Xiamen, Fuzhou, and Shanghai. The Sun Yat-sen Mausoleum, completed in 1925 and designed by Lü Yanzhi, integrated traditional Chinese architectural elements with modern construction practices, becoming an iconic symbol of East–West cultural fusion. During the same period, despite

China's turbulent political changes, the villa cluster in Guling town, Lushan, exhibited a unique localization of Western planning concepts and mainstream architectural styles. This represents a classic case of cultural and aesthetic convergence within globalization. As a significant phenomenon in modern Chinese architectural history, Sino–Western hybrid architecture carries unique historical value for cross-cultural exchange and integration. It reflects both the localization process of Western architectural techniques and aesthetic concepts, and illustrates the inclusiveness and innovativeness of traditional Chinese architecture. However, current academic research on preserving such buildings faces challenges. The absence of evaluation criteria for hybrid authenticity and the tension between privileging either cultural lineage have exacerbated cultural narrative fragmentation (Chang, 2019; Knapp, 2024).

2.2. The current situation of academic research on the architecture of the Sino–Western hybrid combination

Sino–Western hybrid architecture represents an important branch in the study of modern Chinese architectural history. Its theoretical foundation stems from academic interest in China's architectural modernization since 1840. The opening and transformation of modern China created historical conditions for the introduction of Western architectural culture, leading to the unique phenomenon of Sino–Western hybrid architecture. In the evolution of this research field, scholars have progressively moved beyond viewing these buildings as mere stylistic hybridity, instead recognizing them as complex products of cultural integration (Coomans, 2014). Chinese researchers have systematically documented the study of modern Sino-eclectic architecture, with particular attention to vernacular architecture with local evolutionary characteristics and nationalist revival styles (Tung, 2018). Their work further reveals the localized integration mechanism between the Chinese "ti–yong relationship" (Cua, 2002) and Western "figure–ground relationship" (Hebbert, 2016) in these buildings. The international academic community has also shown growing interest in this phenomenon. Studies examining Shanghai's Shikumen housing have shown how Western terraced house typologies merged with Chinese courtyard spatial organization (Tung, 2018). Research on Tianjin's concession architecture revealed similar integration mechanisms where foreign building practices combined with local construction traditions (Gravari-Barbas *et al.*, 2024). These cross-cultural studies emphasize the complexity of architectural cultural fusion, providing theoretical support for understanding Sino–Western hybrid architecture (Coomans, 2014; Jia & Bin Syed Abu Bakar, 2025). Current research displays trends toward diversification and refinement, primarily focusing on architectural typology and style, technological and material innovations, and interpretation of cultural connotations (Kim & Luchkova, 2016). In typological studies, scholars conducting field research at the Guling town villa cluster have identified characteristic types, including interior-corridor, veranda-corridor, single-pavilion, double-pavilion, and castle-style structures, and have analyzed how these types adapt to mountainous environments through spatial layout and structural design. In technological and material studies, analysis of specific buildings has revealed innovative technical practices in Sino–Western hybrid architecture, providing technical references for conservation and restoration (Dananjaya, 2025).

2.3. The theory and application of biomimicry in architecture

In 1997, Janine Benyus systematically articulated the core concept of biomimicry in her book Biomimicry: Innovation Inspired by Nature. She proposed that by observing and understanding the structures, functions, and ecological logic of biological systems, innovative inspiration for human design and engineering practices can be drawn (Lurie-Luke, 2014).

The process of observation and comprehension in biomimicry involves philosophical issues such as epistemology, metaphysics, and ontology, with its core focus on the essence and mode of existence of entities. The core value of biomimicry lies not only in studying the relationship between form and function in organisms to guide design and engineering but also in its emphasis on the sustainability of nature and the integrity of ecosystems (Dicks, 2016).

In the field of architecture, the application of biomimicry is mainly reflected in two dimensions: first, on the technical level, by drawing on the structural principles and material properties of biological systems to refine architectural structural design and improve material performance, achieving better adaptation between buildings and the environment; second, on the ecological level, focusing on the sustainability of ecosystems to establish a harmonious coexistence between architecture and the surrounding ecological environment. The principles of environmental sustainability and cultural respect advocated by biomimicry offer a new perspective for the conservation of historical architectural and cultural landscapes. It not only focuses on the ecological restoration of building structures and materials but also emphasizes integration into the surrounding ecosystem to achieve synergistic development of architecture, environment, and culture (Rao, 2014).

This study applies biomimicry in a way that differs from its typical use in new building design. Rather than extracting principles from biological systems for novel structures, biomimicry here serves as an analytical framework for existing hybrid architecture. Both Chinese and Western architectural traditions, despite different philosophical foundations, share an orientation toward environmental adaptation. Chinese architecture developed responses to monsoon climates and timber resources; European architecture evolved strategies for temperate climates and masonry construction. When builders from both traditions constructed villas at Lushan, they faced a specific mountain environment demanding practical responses regardless of cultural origin. Biomimicry provides a framework for analyzing these environmental adaptations as common ground underlying apparent cultural differences (AlAli *et al.*, 2023; Verbrugghe *et al.*, 2023). Conservation scholarship has debated authenticity criteria for hybrid heritage but has not developed operational frameworks for sites where cultural hybridity itself constitutes heritage value. Biomimicry research has shown applications in new construction, but has rarely been applied to heritage conservation. This study addresses this gap by proposing biomimicry as an analytical framework for evaluating existing hybrid architectures based on environmental adaptation characteristics.

3. Research design and methods

This study focuses on the villa cluster in Guling town, Lushan. Given the interdisciplinary nature of historical architecture research, it adopts an integrated methodological approach (**Figure 1**).

3.1. Literature study method

This study reviews literature on modern Chinese architectural history, Sino–Western cultural exchange history, and local historical records of Lushan. Examined sources include published studies on treaty port architecture (Coomans, 2014; Tung, 2018), heritage conservation frameworks (Chang, 2019; Knapp, 2024), and biomimicry applications in architecture (AlAli *et al.*, 2023; Verbrugghe *et al.*, 2023). Local historical records from the Lushan archives and published regional studies document the villa's development since 1895. This review clarifies the formative context of Sino–Western hybrid architecture and provides a historical foundation for the research (Susilawati *et al.*, 2025).

3.2. Field survey method

Field surveys were conducted at the Guling town villa cluster. The investigation documented spatial layout, structural systems, material applications, and stylistic features of villas, recording their adaptive relationships with mountainous terrain and climatic conditions. Semi-structured interviews were conducted with local residents, heritage management personnel, and architectural scholars. Interview questions addressed conservation challenges, perceptions of architectural value, and local construction knowledge. Interviews were audio-recorded with participant consent, transcribed, and analyzed through thematic coding to identify recurring patterns in conservation challenges and local wisdom (Flick *et al.*, 2025; Ruslin *et al.*, 2022).

3.3. Interdisciplinary analysis method

This research integrates theories from architecture, ecology, cultural anthropology, and environmental science. It analyzes conservation challenges of Sino–Western hybrid architecture from technical, cultural, and ecological dimensions. Biomimicry theory is operationalized through four analytical dimensions: climate adaptation (ventilation, thermal regulation, moisture management), terrain response (foundation systems, spatial layout, slope integration), material ecology (local sourcing, durability, environmental compatibility), and ecosystem integration (vegetation relationships, water management, landscape harmony). Each villa was assessed against these dimensions using field observations, archival building records, and interview data to evaluate environmental adaptation characteristics (Allen, 2025).

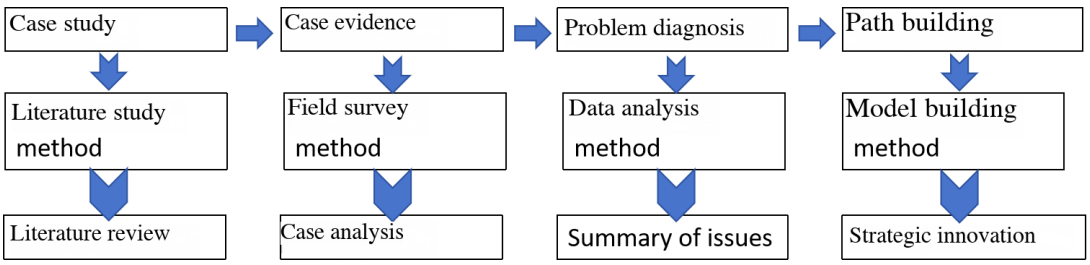


Figure 1. Methodological framework integrating literature review, field investigation, and biomimicry analysis. Source: Diagram by the authors

3.4. Case analysis method

The Guling town villa cluster was selected as the case study based on its documented Sino–Western hybrid characteristics spanning multiple national building traditions, United Nations Educational, Scientific, and Cultural Organization (UNESCO) recognition as part of Lushan National Park's cultural landscape, and presence of both well-preserved and deteriorating structures enabling comparative analysis. From the 636 registered villas, 45 were selected using stratified sampling based on four criteria: typological representation across corridor-style, pavilion-style, and distinctive categories; temporal coverage spanning three construction periods (1895–1910, 1910–1925, 1925–1940); diversity of national origins including British, American, French, German, and Chinese European-imitation styles; and variation in conservation states from well-preserved to significantly altered structures. This sampling strategy ensured comprehensive documentation of the architectural diversity within the villa cluster while enabling comparative analysis across different conditions. This case study examines the applicability of biomimicry principles in cross-cultural architectural heritage conservation (Arda *et al.*, 2025).

4. Current status of the Sino–Western hybrid villa complex in Guling town, Lushan

4.1. Environmental shaping and cultural heritage characteristics in Lushan

Lushan, as a typical mountainous scenic area, features an elevation range of 25–1,473.8 meters, complex folded terrain, a humid, foggy climate, and rich vegetation. These elements collectively shape the distinctive attributes of the Guling town architectural cluster as a carrier of cultural heritage. At the spatial layout level, the building group strictly adheres to the traditional Chinese principle of "following the mountain's form and adapting to the terrain." Western-style villas with terraced layouts and Chinese-style courtyards with layered spatial experiences are organically integrated within the mountainous topography. This deep integration with the mountainous environment endows the architectural cultural transmission with an inherent "environmental embeddedness." The cultural significance of the architecture is reflected not only in its stylistic elements but also in its symbiotic relationship with the mountain ecosystem. At the technical inheritance level, the mountainous environment gave rise to unique Sino–Western hybrid construction techniques. Buildings in Guling town often employ a triple composite technical system: "stone and brick foundations–wooden structural decorations–sloped roof drainage." Western brick-and-stone structures effectively address foundation instability on slopes; Chinese wooden carvings and structures accommodate ventilation needs in the humid climate, and the integrated multi-slope roofs specifically handle the area's frequent rain and snow. This technical fusion, developed to adapt to the mountainous environment, constitutes the core technical gene of Sino–Western hybrid architectural cultural transmission. The quality of its preservation directly impacts the survival of the building structures and the continuity of their cultural value. Similar climate adaptation strategies have been documented in vernacular dwellings across Jiangxi province, where traditional construction techniques have been developed in response to the region's hot-humid summers and cold winters (Xiong *et al.*, 2025; Z. Zhou *et al.*, 2024) (Figure 2).

4.2. The uniqueness of cultural inheritance endowed by the environment of Lushan

The relative isolation and landscape scarcity of the Lushan environment have endowed the cultural transmission of Sino–Western hybrid architecture with a unique value dimension. On the one hand, the enclosed mountainous space has mitigated excessive external cultural influences, allowing the integrated characteristics of the Guling town architectural cluster to be preserved in their complete form (Q. Xu *et al.*, 2021). During the late 19th and early 20th centuries, the vacation community established by Western missionaries and Chinese political elites in Lushan developed an architectural style that was neither entirely Western nor strictly traditional Chinese. Instead, it achieved an organic fusion of Western and local cultures within a relatively independent mountainous setting, providing a tangible record of modern Sino–Western hybrid cultural exchange. On the other hand, the scarcity of mountain landscapes has enhanced the experiential value of architectural cultural transmission. The Guling town architectural cluster forms a tripartite resonance of "architecture–nature–culture" with Lushan's sea of clouds, pine forests, and waterfalls. While experiencing the mountain scenery, visitors can directly perceive the spatial appeal and cultural significance of Sino–Western hybrid architecture. This landscape-empowered mode of cultural transmission represents a unique advantage that similar architectures in plain areas cannot replicate. Previous research has indicated that Lushan's cultural landscape values derive from the integration of natural scenery with historical built heritage, creating experiential qualities that transcend individual architectural assessment (Cai *et al.*, 2021; Liu *et al.*, 2025; Q. Xu *et al.*, 2021).



Figure 2. Villa integration with mountainous terrain shows traditional construction techniques developed in response to humid summers and cold winters. Source: Photos by the authors (2025)

4.3. The type and style characteristics of the Guling town building complex

The architectural cluster in Guling town, Lushan, stands as significant historical testimony to modern Sino–Western hybrid cultural exchange. In 1895, British missionary Edward Selby Little acquired a leasehold for the Changchong area of Lushan through a series of historical processes, initiating the development of Guling. Subsequently, foreign nationals from Britain, the United States, France, Japan, Russia, and other countries successively purchased land on the mountain to build villas, forming an agglomeration of diverse architectural cultures. According to records from the Lushan Cultural Heritage Administration, Lushan currently preserves 636 modern and contemporary villas representing architectural styles from 18 countries (Q. Xu *et al.*, 2021). These include 259 Chinese European-imitation villas, 185 American-style, 125 British-style, 17 German-style, 12 Swedish-style, 11 Japanese and European-imitation, 7 French-style, 3 Finnish-style, and 3 Norwegian-style villas. The concentrated presentation of such diverse international architectural styles remains rare worldwide (Q. Xu *et al.*, 2021).

Based on their spatial layout and morphological characteristics, the villas in Guling town can be divided into three categories. The first category consists of corridor-style villas (Figure 3). This category includes interior-corridor and veranda-style villas. Interior-corridor villas feature enclosed corridors surrounding the structure, with covered passageways on three sides. Constructed of stone, they feature arches above doors and windows. External windows are glazed to address Lushan's cold and foggy climate. Veranda-style villas are characterized by exterior corridors supported by wooden columns. Arched wood carvings span between columns, topped with wooden spherical decorations. These compact structures exhibit complex contour lines, with ceilings typically made of wooden slats forming diamond-shaped patterns that provide strong light transmission while emphasizing wood's natural texture (L. Zou & Zhong, 2009).

The second category comprises pavilion-style villas (Figure 4). This classification includes single-pavilion and double-pavilion types. Single-pavilion villas feature a regular hexagonal pavilion incorporated into the structure, positioned either at the left, right, or center. These pavilions are exposed on three sides, with the remaining three sides connecting to interior spaces. The design employs a conical roof separated from the main building's roof, creating a combination of hipped and conical roofs that enhances geometric variation and aesthetic appeal. Double-pavilion villas present two symmetrical hexagonal pavilions at the front facade. Each pavilion remains exposed on three sides and connects to interior spaces through enclosed interior corridors and exterior verandas. The main structure typically features a hipped roof, forming a three-point composition on the front elevation that emphasizes the architectural form's sculptural beauty (Fan, 2014).

The third category consists of distinctive types, represented by the castle-style villa. Only one such structure remains in Lushan—a two-story building constructed entirely of stone, featuring a flat roof and arched doors and windows, presenting a steady, ancient overall style. While possessing strong exotic characteristics, these buildings were primarily constructed with the core purpose of harmonizing with the mountainous environment.

In terms of architectural element integration, the Guling town villas extensively utilize local bluish–gray stone as exterior wall material, retaining rough stone surfaces to blend with the natural environment. Simultaneously, they incorporate traditional Chinese architectural elements into design and decoration, such as Chinese-style corner pavilions on roofs, traditional Chinese gate designs, dougong brackets, and drum-shaped bearing stones. Some villa layouts appear to have been influenced by the spatial



Figure 3. Corridor-style villas featuring interior corridors and veranda structures adapted to Lushan's humid climate. Source: Photos by the authors (2025)



Figure 4. Pavilion-style villas featuring hipped roofs and a three-point front elevation composition. Source: Photos by the authors (2025)

composition of Chinese character forms derived from Song-dynasty (960–1279) traditions. The Meilu Villa's arrangement follows the traditional feng shui principle of "nestled against the mountain and facing water." The bluestone slab tiles of Villa No. 24, Zhongliu Road, feature square or rectangular designs with 5:3 aspect ratios, conforming to classical harmonic ratios. This shows both European stone usage characteristics and adaptation to Lushan's climatic conditions (Yang & Liu, 1995) (Figure 5).

The integration of Chinese and Western elements in Guling town villas extends beyond decorative additions to Western structures. Field investigation reveals that spatial organization in many villas reflects Chinese courtyard principles adapted to Western building volumes, with interior circulation patterns following feng shui considerations regarding orientation and hierarchy. Construction techniques demonstrate hybrid practices in which Western masonry methods were modified using local stone-cutting traditions and Chinese joinery for wooden components. The triple composite technical system of stone–brick foundations, wooden structural decorations, and sloped roof drainage represents a genuine synthesis rather than a stylistic overlay, as neither Western nor Chinese building traditions employed this specific combination on their own. These findings suggest that cultural hybridity at Guling town operated at structural and spatial levels, not merely in applied ornamentation (Huang *et al.*, 2024).

At the spatial level, interior circulation patterns in many villas follow Chinese hierarchical principles within Western building volumes. Primary reception spaces face the building entries following Chinese conventions, while secondary rooms occupy lateral positions. Verandas function simultaneously as Western porches for outdoor living and Chinese corridor spaces mediating between interior rooms and exterior gardens. Room proportions in 15 documented villas showed intermediate values between standard Western and Chinese conventions, suggesting negotiated design decisions rather than direct transplantation from either tradition.

At the symbolic level, feng shui considerations influenced villa siting even in buildings with entirely Western elevations. The Meilu Villa illustrates the principle of backing against mountains while facing water, a fundamental feng shui requirement, despite its European architectural vocabulary. Dragon motifs appear on Western-style chimney caps, and Chinese moon gates frame views within otherwise European garden layouts.

This integration extends beyond decorative addition to structural incorporation of Chinese spatial concepts within Western building forms.

Archival architectural drawings from the General Survey of Modern Chinese Architecture: Lushan Volume provide documentary evidence of villa spatial organization and terrain adaptation (Figures 6–8). The Villa Regalier drawings present a pavilion-style villa featuring a domed corner pavilion, with the floor plan showing room arrangement around a central circulation space. The Villa Mrs. Barré floor plans reveal a spatial hierarchy characteristic of hybrid design: the reception room occupies a central position facing the main entry following Chinese conventions, while bedrooms and service spaces are distributed along lateral wings. The courtyard functions as an intermediary space between interior rooms and the mountain environment. The section drawings of both villas illustrate terrain adaptation through terraced foundations and split-level designs that follow natural slope contours, reducing excavation while maintaining structural stability on mountainous sites.

4.4. The inheritance dilemma of Guling town's architectural complex

4.4.1. Biases in value perception

Current research and practice suggest a fragmented understanding of the value of the Guling town architectural



Figure 5. Sino–Western hybrid elements, showing local bluestone construction combined with Chinese architectural ornamentation. Source: Photos by the authors (2025)

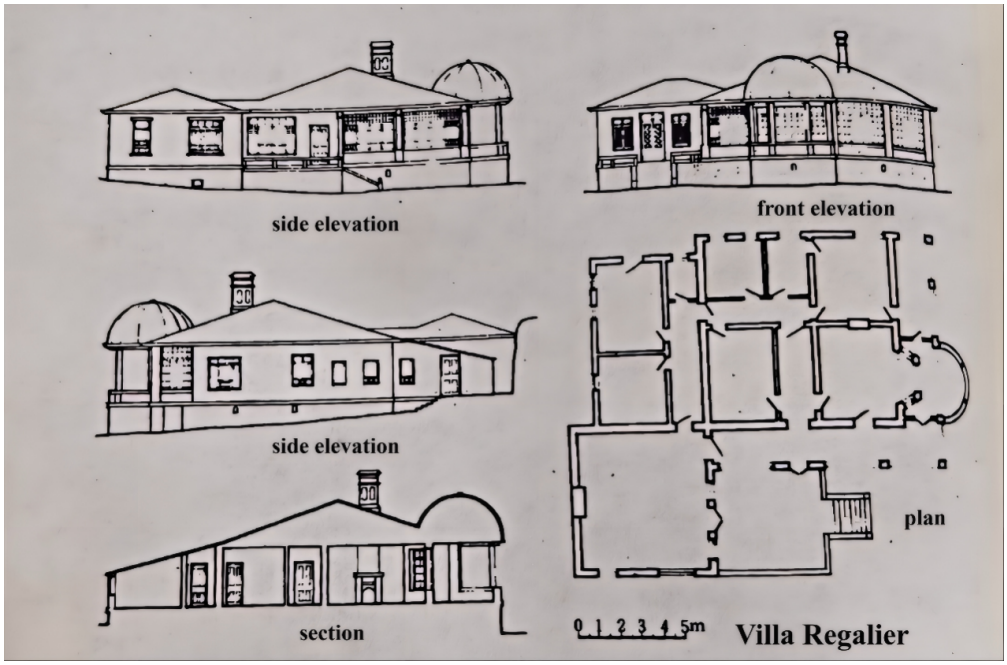


Figure 6. Architectural drawings of Villa Regalier, showing a pavilion-style design with a domed corner pavilion. Source: Reproduced from 中国近代建筑总览·庐山篇 [*The Architectural Heritage of Modern China: Lushan*] (Beijing: China Architecture & Building Press; 1993)

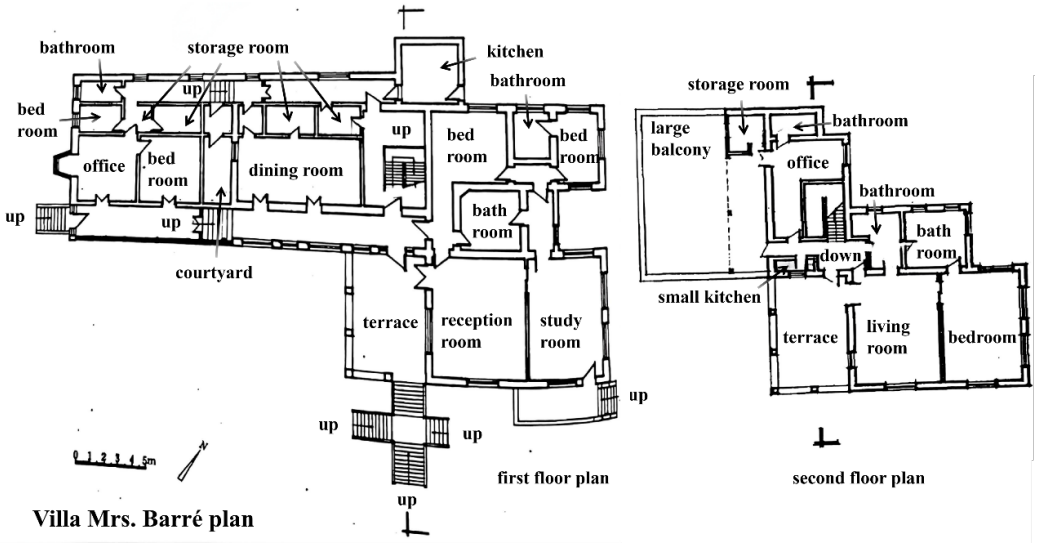


Figure 7. Floor plans of Villa Mrs. Barré showing the spatial hierarchy with a central reception room and lateral service wings. Source: Reproduced from 中国近代建筑总览·庐山篇 [*The Architectural Heritage of Modern China: Lushan*] (Beijing: China Architecture & Building Press; 1993)

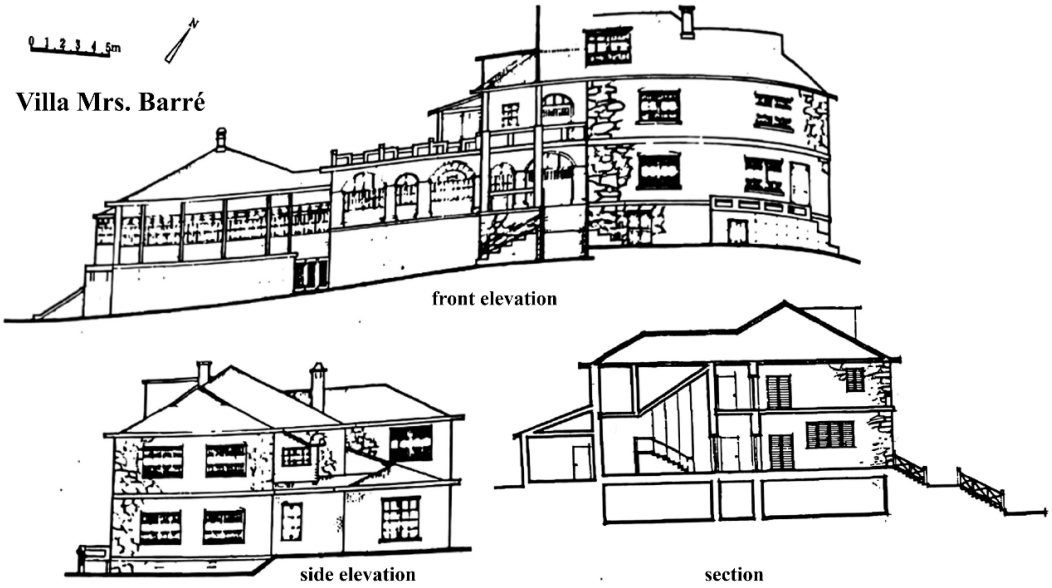


Figure 8. Elevations and section of Villa Mrs. Barré illustrating terrain adaptation through terraced foundation design. Source: Reproduced from 中国近代建筑总览·庐山篇 [*The Architectural Heritage of Modern China: Lushan*] (Beijing: China Architecture & Building Press; 1993)

cluster. Most studies focus on architectural appearance and tourism potential, while neglecting its significance as a testament to cross-cultural exchange and as a source of technological innovation. Field interviews with heritage management personnel indicated that conservation decisions often prioritize visible stylistic features over structural or spatial characteristics that embody cultural synthesis. This biased perception of value leads to conservation strategies that may preserve facades while altering the spatial relationships and construction techniques that constitute the villas' hybrid character. Regarding later interventions such as modern commercial signage and modified door/window structures in the villa cluster, the academic community has yet to establish unified evaluation criteria. This absence of standards has resulted in the coexistence of "over-commercialization" and "arbitrary alterations" in practical conservation work, severely compromising the buildings' authenticity and integrity (Knapp, 2024).

4.4.2. Ambiguous protection standards

New constructions have failed to adequately respond to the original villas' architectural scale, stylistic characteristics, and landscape-integrated layout concepts. This has resulted in fragmented architectural scenery in Lushan, damaging the holistic character of its "Museum of Global Architecture." The insufficient coordination between architecture and the mountainous environment further exacerbates the severance of cultural narrative. The cultural transmission of architecture has become disconnected from modern functional requirements. Some buildings face challenges in effectively conveying cultural value due to functional obsolescence, while other commercial developments excessively intervene in building structures. This failure to organically integrate cultural continuity with functional adaptation has undermined the sustainable preservation of architectural heritage (S. Xu & Zhou, 2025).

5. Biomimicry-informed conservation strategies

Architecture is fundamentally a discipline centered on data relationships. Structural selection, material application, and aesthetic expression all originate from the designer's understanding of the surrounding environment, forming systematic thinking through proportional data as the key link. In the study of Sino–Western hybrid architecture, the importance of proportional data has gained academic consensus. However, a core dilemma in current conservation practice is the difficulty in defining priorities between Sino–Western hybrid cultural elements. Can this dilemma be resolved by returning to the fundamental data relationship between architecture and environment? From a biomimicry perspective, Sino–Western architectural concepts are not opposing binary systems but rather part of the same adaptive process of responding to environmental conditions. Traditional Chinese architecture seeks a holistic balance with nature, while Western architecture emphasizes functional responses to environmental challenges. Field investigation at Guling town supports this interpretation: despite different cultural origins, corridor-style and pavilion-style villas developed similar responses to Lushan's humid climate and steep terrain, including elevated foundations, deep eaves, and ventilated subfloor spaces. This convergence suggests that environmental adaptation constitutes common ground underlying apparent cultural differences. Although the academic community generally recognizes challenges in integrating Sino–Western hybrid architectural concepts, both European Romantic-era cross-cultural architectural practices and the development of the Guling town villa cluster in Lushan suggest that environment-centered learning and construction provide a viable path for organic integration of Sino–Western hybrid elements (Figure 9) (Rana, 2024).

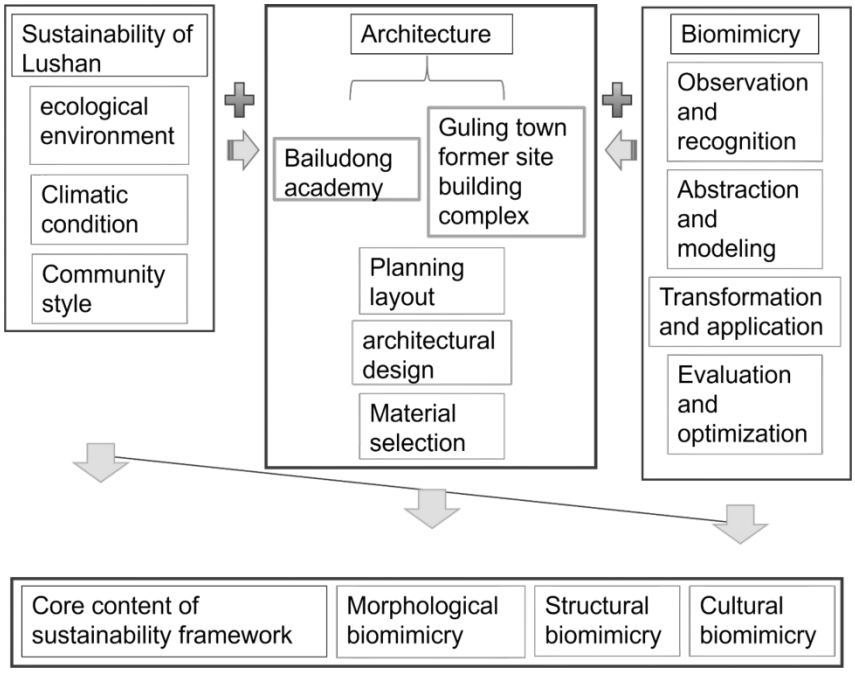


Figure 9. Biomimicry framework showing conceptual and design dimensions for heritage conservation analysis. Source: Conceptual framework diagram by the authors

It is noteworthy that traditional architectural cultural landscape conservation often follows the core principle of "restoring original appearance," emphasizing archeological reconstruction of historical states. However, this approach frequently overlooks the dynamic nature of historical evolution: while restoring based on historical blueprints, how to incorporate contemporary understandings of architecture, the environment, and culture becomes an urgent issue requiring a response. The formation and development of the Guling town villa cluster in Lushan, as a typical case of Sino–Western hybrid architecture, provides a vivid response to this question. It also offers important empirical support for innovating conservation pathways from a biomimicry perspective (Metwally, 2025).

5.1. Application logic of biomimicry in heritage conservation

The biomimicry-informed approach addresses a methodological challenge in hybrid heritage conservation. Conventional authenticity assessments developed for single-culture heritage prove inadequate when applied to Guling town villas, where Chinese and Western elements are structurally integrated rather than merely juxtaposed. Environmental adaptation provides an alternative evaluation criterion because both Chinese and Western builders, regardless of stylistic preferences, necessarily responded to Lushan's mountain climate and terrain. Biomimicry thus serves not as a design methodology but as an analytical framework identifying measurable relationships between architectural form and environmental conditions (Q. Xu *et al.*, 2021). Based on the core principle of "environmental adaptation" in biomimicry, technical strategies for architectural conservation at Lushan are refined in accordance with its climatic and topographic characteristics. In terms of climate adaptation, learning from the temperature regulation and ventilation mechanisms of biological systems, building envelope systems, door/window designs, and material selections are refined. Traditional multi-slope roofs and veranda structures are preserved and restored, leveraging stone's thermal insulation and wood's breathability to address Lushan's humid, foggy climate with distinct seasonal variations. For modern additions that provide insulation and ventilation facilities, concealed designs are adopted to avoid compromising architectural stylistic integrity. Regarding topographic adaptation, the traditional layout concept of "following the mountain contours" is maintained. Drawing on biological adaptation mechanisms to terrain, elevation differences are fully utilized in building restoration and new constructions through terraced layouts and split-level designs, reducing the need for mountain excavation and modification. In foundation treatment, traditional stone and brick foundation techniques are preserved and combined with modern ecological foundation technologies to enhance buildings' adaptability to mountainous terrain. Field documentation of 45 villas identified that structures retaining original stone foundations exhibited fewer moisture and structural problems than those with modified foundations, supporting the continued application of traditional techniques (Shen *et al.*, 2025) (Figure 10).

The core logic of biomimicry—"learning from nature"—emphasizes solving challenges in human design and engineering by drawing inspiration from the adaptive mechanisms, ecological logic, and sustainability principles of biological systems. Applying this logic to the conservation of Sino–Western Hybrid architecture addresses three methodological challenges.

First, it transcends the dilemma of cultural binary opposition. From a biomimicry perspective, Sino–Western hybrid architectural concepts are not in opposition; rather,

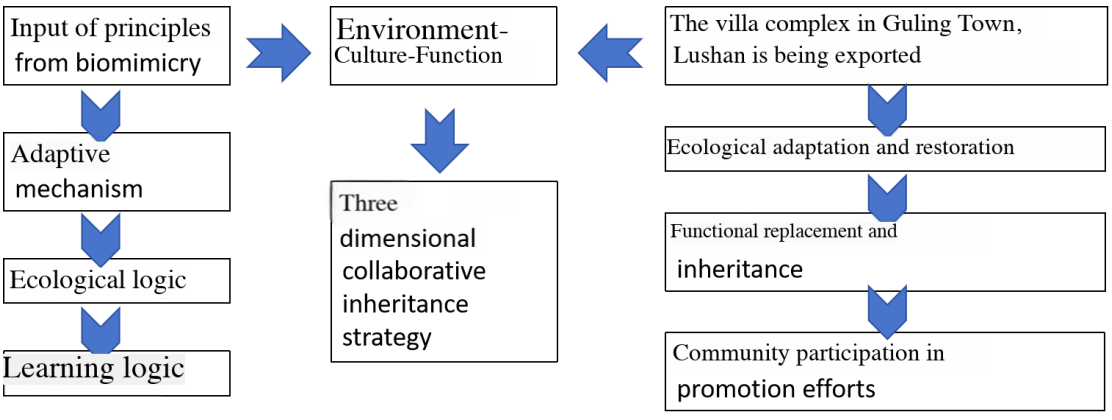


Figure 10. Application logic of biomimicry in heritage conservation, showing environmental adaptation as a common ground for evaluation. Source: Schematic diagram by the authors

both represent processes of "learning from nature" centered on "environmental adaptation." Traditional Chinese architecture emphasizes "harmonious coexistence with nature," while Western architecture focuses on "adaptive modification of the natural environment." Essentially, both seek synergistic development between architecture and the environment. This perspective helps overcome the cognitive limitations of a "Sino–Western hybrid cultural dichotomy" and provides a theoretical foundation for their integration (Metwally, 2025).

Second, it provides objective evaluation criteria. Architecture is fundamentally "a data relationship based on proportions established between humans and the environment" (Peng *et al.*, 2025, p. 791). Biomimicry prioritizes objective data—such as topographic compatibility, climate adaptability, and material ecology centered on environmental adaptation—as evaluation benchmarks. This effectively addresses the current challenge in conserving Sino–Western hybrid architecture, where "defining the priority of cultural elements is difficult," and offers an objective basis for establishing conservation standards (Yin *et al.*, 2025, p. 3).

Third, it enables sustainable conservation goals. The principle of environmental sustainability advocated by biomimicry aligns closely with the needs of living heritage conservation by integrating "function and culture." By learning from the sustainability mechanisms of natural ecosystems, it becomes possible to achieve synergistic development between architectural cultural continuity, ecological protection, and functional renewal, thereby avoiding the cultural fragmentation resulting from static preservation approaches (Wamane, 2025).

5.2. Ecological and cultural continuity mechanisms

To prioritize mountain ecosystem conservation, a synergistic mechanism between cultural continuity and ecological protection shall be established to achieve their positive interaction. At the technical restoration level, the concept of "eco-adaptive restoration" is implemented. For repairing brick-wood mixed structures, priority is given to combining traditional techniques with ecological materials. Examples include using local stone for wall repairs and employing coatings mixed from tung oil and pine resin to protect wooden decorations. This approach ensures the authenticity of the restoration while enhancing the building's adaptability to the mountainous climate. In projects such as foundation reinforcement and courtyard renovations, eco-construction technologies such as vegetative concrete and ecological gabions are adopted to reduce damage to mountain vegetation and soil. Concurrently, a dynamic monitoring system for building restoration and mountain ecology is established. Through technologies such as drones and sensors, it tracks in real time the impact of restoration works on mountain slope stability, soil moisture, and vegetation coverage, ensuring cultural continuity always remains within ecological carrying capacity. At the planning level, protected zones for architecture and mountain ecosystems are demarcated. Clear standards govern the spatial distances between buildings and mountain features, vegetation, and water bodies, prohibiting any architectural modification or commercial development in core ecological areas. By integrating ecological protection redlines with cultural heritage boundaries, a harmonious coexistence pattern of "mountain–architecture–people" is constructed, making cultural continuity a vital vehicle for mountain ecosystem conservation (H. Wang, 2025).

Based on the functional characteristics of mountainous spaces, the cultural heritage of Sino–Western hybrid architecture can be organically integrated with functional renewal to achieve living conservation.

On the one hand, functional replacement-based conservation is explored. For buildings within core protected areas, core structures and stylistic elements are preserved while original functions are appropriately restored. Interviews with heritage management personnel indicated that villas converted to boutique accommodations that retain cultural symbols such as Western fireplaces and Chinese corridors achieved higher visitor satisfaction than those with extensive interior modifications. This finding suggests that functional adaptation need not compromise heritage character. Other buildings can be converted into cultural and creative spaces, utilizing mountain courtyards for Sino–Western Hybrid cultural exchange events and traditional craft exhibitions, thereby bridging cultural heritage with modern life. This functional replacement approach not only extends the buildings' practical value but also enables the transmission of implicit cultural values through actual use (Xiaoying & Zhang, 2025).

The functional layout of mountainous spaces can be improved to create a composite functional system integrating "cultural heritage and ecological experience." In areas with concentrated building clusters, pedestrian cultural corridors are planned to connect structures of different styles. These corridor designs should fully utilize the mountainous terrain, incorporating viewing platforms and cultural stations to enhance the visitor experience and protect the environment. In general villa zones, business transformation should be guided toward cultural experiential models, such as establishing Sino–Western Hybrid architectural craft workshops and mountain culture-themed restaurants. This allows commercial

operations to become vehicles for cultural transmission, achieving mutual benefits for both economic and cultural values (Catherine *et al.*, 2025).

5.3. Integrating landscape and narrative in heritage interpretation

Leveraging the mountainous landscape as a foundation, multi-dimensional cultural narrative scenarios can be constructed to enhance the depth and impact of heritage transmission.

First, establish an integrated "architecture–mountain" narrative system. In architectural displays, interpretive content is enhanced to connect the mountain environment with architectural culture. Augmented reality technology is used to recreate the interactive relationship between buildings and the mountain landscape across different historical periods, allowing visitors to intuitively understand the adaptation logic of Western terraced layouts to mountainous terrain and the borrowed scenery techniques between Chinese courtyards and Lushan's sea of clouds. Cultural markers at key landscape nodes are installed to explain how mountain vegetation and topography influenced architectural styles, forming a narrative chain of "viewing architecture–understanding culture–comprehending the mountain" (Abdulwahab *et al.*, 2025, p. 281).

Second, the layered nature of mountain spaces is utilized to create immersive heritage experiences. Capitalizing on Lushan's elevation variations and changing landscapes, a mountain cultural heritage route is planned: from Chinese-style dominant buildings in low-elevation areas, through Sino–Western hybrid fusion architecture in mid-elevation zones, to Western-style dominant structures at higher elevations. This allows visitors to experience the historical process of Sino–Western hybrid cultural integration as they ascend. Cultural experience points should be set up along the route—hosting tea art performances in Chinese courtyards and classical music concerts in Western villas—enabling visitors to immerse themselves in the cultural charm of East–West fusion as they transition through mountain landscapes (Privitera *et al.*, 2025). The biomimicry-informed framework contributes to heritage conservation scholarship by providing evaluation criteria applicable to hybrid heritage sites where conventional authenticity standards prove inadequate. The framework's transferability requires consideration of site-specific conditions: it may prove most applicable to heritage sites where buildings from multiple cultural traditions coexist within shared environmental contexts. Limitations include the qualitative nature of environmental adaptation assessment and the focus on a single mountain site, which would benefit from comparative studies at other hybrid heritage locations (Zhao *et al.*, 2024).

5.4. Community participation and implementation mechanisms

Harnessing the central role of mountain communities, a resident-participatory cultural transmission guarantee mechanism shall be established to ensure the sustainable continuity of heritage.

On the one hand, a tripartite collaborative management system involving "residents–experts–government" is created. As users and guardians of the buildings, residents participate in developing architectural restoration plans and cultural transmission activities, while the experts provide technical guidance and theoretical support to ensure scientific validity. The government provides policy direction and financial support, establishing a special fund for the transmission of mountain architectural culture and providing subsidies to actively participating residents. By clarifying the rights and responsibilities of all parties, a co-construction, co-governance, and shared conservation framework is formed (Au Yong *et al.*, 2025).

On the other hand, community cultural education and skills training should be strengthened. Regular training sessions can be organized for residents on Sino–Western hybrid construction techniques and mountain ecological protection, thereby enhancing cultural conservation awareness and professional competencies. Residents should also be encouraged to explore family and building-related historical stories and living customs, and to compile these materials into oral history archives to enrich cultural transmission. In addition, support for household-based cultural exhibitions—such as opening villa courtyards to display traditional living utensils—can transform residents into active living carriers of cultural continuity (Wani *et al.*, 2025).

Furthermore, enhancing public awareness of the cultural value of Sino–Western hybrid architecture is essential. Educational and communication initiatives should be implemented to foster public understanding and respect for this cultural landscape. Leveraging Lushan's tourism advantages, interpretive signs and thematic exhibitions can be set up within the villa cluster to explain the architectural fusion characteristics, environmental adaptation principles, and the application logic of biomimicry. New media platforms should be used to produce popular science video series and online exhibitions, expanding the reach of cultural dissemination. Simultaneously, advanced international experiences in architectural heritage conservation should be referenced. Key documents such as the 1964 Venice Charter, which

emphasizes the authenticity and originality of historic structures, the 1994 Nara Document on Authenticity, which highlights the diversity of cultural landscapes and the importance of socio–cultural context, and the UNESCO World Heritage Convention's principles of safeguarding "integrity and authenticity" provide theoretical guidance for the conservation of the Guling town villa cluster. In terms of restoration techniques, a composite approach integrating "scientific analysis, traditional craftsmanship, and ecological materials" should be adopted. This model addresses the loss of traditional construction techniques and the limitations of modern replication methods, preserving the essential and defining features of original structures while ensuring the long-term sustainability of the buildings (Eflova *et al.*, 2025).

6. Conclusion

This study examined the Guling town villa cluster through a literature review, field surveys of 45 villas, and interviews with 15 participants, including residents, heritage managers, and architectural scholars. The investigation identified four challenges in hybrid heritage conservation: unclear technical standards for restoration, fragmented approaches to recognizing cultural value, insufficient coordination between architecture and environment in planning, and limited mechanisms for interdisciplinary collaboration.

These challenges are interconnected. The absence of technical standards leads to inconsistent conservation practices, biases in value perception toward stylistic features that overlook environmental adaptation characteristics, and insufficient interdisciplinary collaboration limits problem-solving capacity. Field observations indicated that villas retaining original climate-responsive features exhibited fewer structural problems than those with modifications that compromised environmental adaptation.

The study contributes to heritage conservation scholarship in three respects. First, it provides evidence that environmental adaptation characteristics can serve as evaluation criteria for hybrid heritage sites where conventional authenticity standards prove inadequate. Second, it offers operational methods for identifying heritage values that transcend cultural boundaries, enabling assessment of stylistically diverse building stocks within unified analytical frameworks. Third, it suggests that living heritage approaches may be more appropriate for hybrid architectural heritage than preservation models developed for single-culture monuments.

Based on biomimicry principles, the study proposes a four-dimensional framework that integrates function and culture, coordinates ecology and heritage, links landscape and narrative, and incorporates community participation. The framework's transferability requires consideration of site-specific conditions: it may prove most applicable to heritage sites where buildings from multiple cultural traditions coexist within shared environmental contexts, and where cultural hybridity itself constitutes heritage value.

Limitations of this study include the qualitative nature of environmental adaptation assessment, which would benefit from quantitative building performance measurement in future research, and the focus on a single mountain site, which constrains generalizability. Future research should examine whether the biomimicry-informed framework applies to hybrid heritage in other geographical contexts and develop quantitative indicators for environmental adaptation assessment.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Conceptualization: Tanot Unjah
Formal analysis: Lyuxin Xiong
Investigation: Lyuxin Xiong
Methodology: Mazlan Mohd Tahir
Writing–original draft: Lyuxin Xiong
Writing–review & editing: Tanot Unjah, Mazlan Mohd Tahir

Ethics approval and consent to participate

This study involved semi-structured interviews with adult participants to explore their perceptions of architectural and landscape spaces. The research is low-risk, does not recruit vulnerable groups, and does not cover sensitive private information or traumatic topics. According to the human research ethics guidelines of Universiti Kebangsaan Malaysia, this study qualifies for ethics exemption and does not require formal review by the institutional ethics committee. Verbal informed consent was obtained from all participants before each interview.

Consent for publication

Participants were clearly informed of the research purpose, audio recording arrangement, data usage, and their right

to withdraw at any time or refuse to answer any questions. All interview materials were anonymized using coded identifiers, and all personally identifiable information was removed.

Availability of data

All data analyzed during this study are included in this published article and its references, or obtained from publicly available archival resources. No additional raw data were generated.

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