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Application Studies on Eco-Musuem Theory on the Renewal Design of Pit-type Architecture—A Case Study of the Opera-themed Cultural Park in Baishe Village, Shaanxi Province

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Abstract: Existing research indicates that the renewal and transformation of traditional settlement spaces still face practical shortcomings in cultural preservation, spatial revitalization, and green sustainable development, necessitating the exploration of more systematic and effective renewal strategies. This paper takes the renovation project of the "Opera-themed Cultural Park" in the pit cave dwellings of Baishe Village, Sanyuan County, Shaanxi Province, as an empirical case. Based on the concept of Eco-museum and incorporating green building technologies, it systematically examines the renewal approaches for pit-type architecture in terms of cultural preservation and multifunctional spatial utilization. The study employs a combination of literature analysis, field research, and building performance simulation, focusing on the spatial transformation models of pit cave dwellings, the application of green technologies, and their impact on cultural inheritance and environmental adaptability. Additionally, it uses Swire software to conduct quantitative analyses of building carbon emissions, indoor airflow organization, and wind environment. The findings demonstrate that the design preserves the spatial layout and cultural characteristics of pit cave courtyards while significantly improving thermal performance and environmental adaptability through passive energy-saving strategies, Structural Insulated Panel Systems (SIPS) wall technology, and rainwater harvesting systems, meeting green building evaluation standards. This study provides a technical demonstration and innovative ideas for the conservation and adaptive reuse of pit-type architecture, as well as practical pathways and theoretical support for the preservation, revitalization, and green development of traditional settlement spaces in the context of rural revitalization.

1. Introduction

President Xi Jinping once emphasized the need to align the most fundamental cultural genes of the Chinese nation with contemporary culture and modern society. Against this backdrop, the "Assessment Standard for Green Building" (GB/T 50378-2019 [2024 partial revision]) specifically highlights the general conservation of traditional villages, including the preservation and restoration of distinctive vernacular architecture such as pit-type dwellings. Furthermore, the 14th Five-Year Plan for Building Energy Efficiency and Green Building Development explicitly advocates the application of green building technologies in rural construction to reduce energy consumption and environmental impact. These policy measures provide robust support for the protection and inheritance of traditional earthen architecture, including pit cave dwellings.

The origins of pit cave dwellings can be traced back to records in *The Book of Rites: Evolution of Rites*, which describes vertical pit dwellings in the Loess Plateau region as an adaptation to the local climate. Over time, these evolved into the distinctive sunken pit cave architecture seen today in the northwestern Loess Plateau[1]. Historical texts have extensively documented the forms, construction techniques, and regional distribution of cave dwellings. Since the 1980s, with the growing emphasis on energy efficiency and regional architecture, cave dwellings have once again become a focal point in academic research. In the 21st century, as awareness of vernacular architecture preservation and cultural heritage has strengthened, the pit cave dwellings of Baishe Village have emerged as a key subject of systematic study. However, due to the relatively late start in earthen architecture research, existing studies on pit cave dwellings have primarily focused on historical evolution and morphological classification, lacking systematic attention to spatial characteristics, environmental adaptability, and green renovation strategies. A comprehensive theoretical and technical framework has yet to be established. Additionally, the strong regional specificity of pit cave dwellings and limited public awareness hinder their preservation and promotion. In practice, the absence of empirical validation and long-term monitoring has led to renovation measures that often fail to meet actual needs, resulting in limited improvements in building performance and inadequate adaptation to modern lifestyles.

This study takes the Opera-themed Cultural Park as a case study, aiming to achieve harmonious coexistence between architecture and the natural environment while fostering cultural identity and living heritage. Furthermore, by employing green building technologies such as passive energy-saving techniques, Structural Insulated Panel Systems (SIPS), and rainwater harvesting and recycling systems, an integrated green building system is constructed to significantly enhance the thermal performance of pit cave dwellings, achieving an organic fusion of traditional architecture and modern green technology [2]. The proposed green technology integration system and cultural exhibition space design strategies in this study exhibit strong universality and promotional value, offering valuable insights for the preservation, renewal, and sustainable development of other traditional villages and vernacular architecture.

2. The Introduction of Eco-museum

The concept of Eco-museum was first proposed in France in 1971 by Hugues de Varine and Henri Rivière as an innovative approach to cultural heritage preservation. China’s introduction of Eco-museum theory began in the mid-1980s when Mr. Su Donghai systematically introduced the achievements of the international Eco-museum movement in the Chinese Museum journal, laying a theoretical foundation for its subsequent development. In 1998, with support from the Norwegian government, China’s first Eco-museum—the Suojia Miao Eco-museum in Guizhou—was established, marking the official implementation of the Eco-museum concept in China. In the 21st century, the construction of Eco-museums accelerated, with clusters of Eco-museums successively established in Guangxi, Yunnan, Zhejiang, and other regions (Table 1), making them an important model for cultural heritage preservation in China [3].

Table 1 An Overview of Eco-museums in China (Hand-drawn)

Name	Location	Opening Date
Suoga Ecological Museum	Leishan County, Qiannan Prefecture, Guizhou Province	October 31, 1998
Sanjiang Dong Ethnic Ecological Museum	Sanjiang Dong Autonomous County, Liuzhou City, Guangxi	2004
Anji Ecological Museum	Anji County, Huzhou City, Zhejiang Province	2006
Baisha Li Ethnic Ecological Museum	Baisha Li Autonomous County, Hainan Province	2008
Qianxinan Buyi and Miao Autonomous Prefecture Ecological Museum	Qianxinan Buyi and Miao Autonomous Prefecture, Guizhou Province	2010
Naxi Dongba Culture Ecological Museum	Lijiang City, Yunnan Province	2013
Hani Rice Terrace Ecological Museum	YuanYang County, Yunnan Province	2015
Panzhou Ecological Museum	Panzhou City, Liupanshui City, Guizhou Province	2019

3. Research Focus and Analysis

3.1 The location analysis

The case study is located in Baishe Village, Sanyuan County, Xi'an City, Shaanxi Province (Figure 1). With origins dating back to the Jin Dynasty (266-420 AD), Baishe Village flourished as a commercial town during the Song Dynasty (960-1279 AD) and later served as an important revolutionary base in modern times. Over its 1,700-year evolution, the village has developed a unique settlement of pit cave dwellings [4]. Baishe Village features flat terrain and abundant historical-cultural resources, preserving numerous heritage sites from the Northern and Southern Dynasties (420-589 AD) to the Ming (1368-1644 AD) and Qing (1644-1912 AD) dynasties. These include the ancient fortress site from the Northern and Southern Dynasties, ruins of a Bodhisattva Temple from the Tang Dynasty (618-907 AD), the former residence of a Ming Dynasty imperial examination candidate, remnants of a commercial street from the Ming and Qing Dynamites period, ancient opera stages and so on(Figure 1).

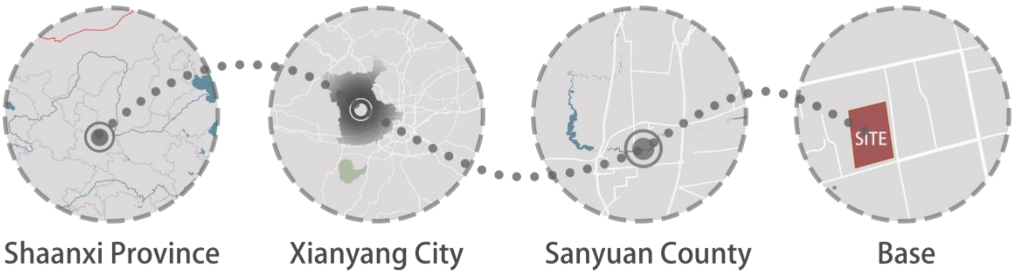

Figure 1 Location Map (Source: Hand-drawn)

Figure 2 Maps of Historical Relics in Baishe Village and Its Historical Evolution (Source: Hand-drawn)

However, many of the pit cave dwelling sites in Baishe Village remain abandoned and unused. Some cave courtyards have collapsed due to long-term neglect, with significant undulating terrain and inadequate drainage systems. (Figure 2) During the rainy season, water accumulation easily erodes the foundations, posing challenges to the long-term preservation of the site. The surrounding area retains historical relics such as ancient opera stages, the Niangniang Temple, and the Mawang Temple, which hold considerable cultural value. Yet, the lack of systematic conservation and rational utilization has left them in urgent need of restoration and revitalization to achieve sustainable protection and regeneration of this cultural heritage (Figure 3). On top of that, recent years have witnessed that the impact of extreme weather events [5] has led to rising temperatures and reduced precipitation in Sanyuan County. Although the pit cave dwellings, with their semi-subterranean structure, offer natural thermal insulation—keeping warm in winter and cool in summer—their ability to withstand heavy rainfall, floods, and geological hazards remains insufficient. There is a pressing need to integrate modern technologies to enhance their environmental adaptability and disaster resilience.

Figure 3 Current Status of Pit Cave Dwellings (Source: Hand-drawn)

3.2 Research Content

Under the guidance of Eco-museum, this study aims to optimize spatial configurations, enhance functional layouts, develop distinctive spatial characteristics, and integrate green building technologies. In this sense, the study will facilitate the preservation and revitalization of Baishe Village's pit cave dwelling heritage (Figure 4).

Figure 4 Rendering of the Project After Renovation (Source: Self-drawn)

3.2.1 Spatial Optimization and Functional Enhancement

The original pit cave dwellings primarily served residential purposes, with some courtyards additionally functioning as storage spaces or workshops. While the overall layout remained stable, individual courtyards operated relatively independently with limited interconnection. With village development, some pit cave courtyards have collapsed due to long-term disrepair or natural disasters, leading to abandoned residential functions, overgrown vegetation, and inadequate drainage systems—all compromising long-term preservation and utilization, thus demanding systematic maintenance and revitalization [6].

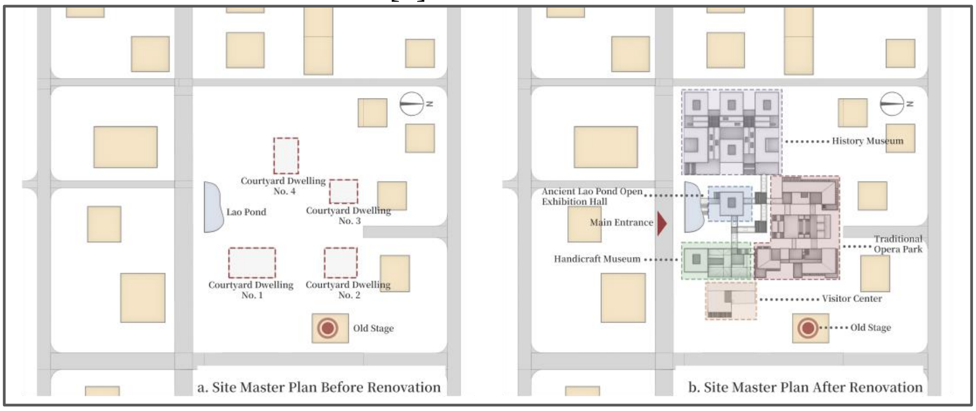

Figure 5 Comparative Site Plans Pre- and Post-Renovation (Source: Hand-drawn)

This study proposes a multifunctional complex with a cultural exhibition, handicraft workshops, opera performances and visitor services, with the master plan featuring ancient water pond open exhibition hall, visitor center, handicraft museum, history museum and opera-themed art center. These elements form a cohesive visitor circulation, with the Opera-themed Cultural Park as the terminal node adjacent to the historic opera stage. This design fosters a dialogue between old and new stages while facilitating Qin Opera, Suona performances, and cultural activities to promote living heritage [6]. (Figure 5)

The Opera-themed Cultural Park centers on horizontally expanded pit caves, unifying four courtyard entrances into a communal space that connects, namely opera exhibition hall, interactive experience zone, cultural lounge, and opera museum. (Figure 6) The courtyard employs ramps, staircases, and landscaped greenery to optimize circulation and create layered spatial experiences [7]. The central opera stage serves dual purposes: performance venue and open cultural exchange space to revitalize village cultural vitality. The western museum displays opera history and folk artifacts, while the eastern interactive zone enhances immersion through participatory activities. All functional areas are seamlessly linked via underground passages and ramps, ensuring fluid visitor movement.

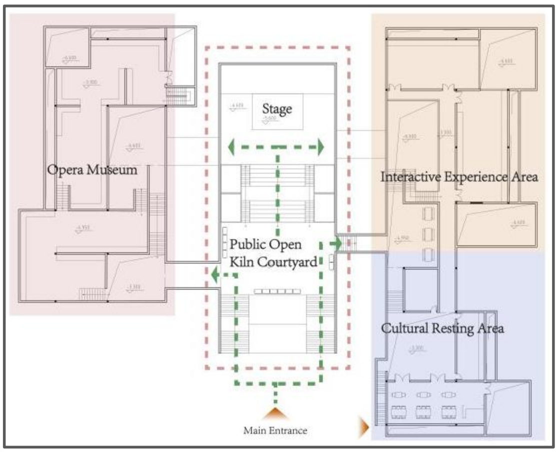

Figure 6 Opera-themed Cultural Park Floor Plan (Source: Hand-drawn)

3.2.2 Application of Green Building Technologies

1) Green Roof and Water-Saving Design

To adapt to the climatic characteristics of Bashè Village, this study introduces a multi-layered green roof system, combining a sloped roof with locally sourced drought-resistant plants to enhance thermal insulation. The roof structure consists of a planting layer, a sintered layer, a drainage layer, and a concrete protective layer. Cement-based permeable crystalline waterproofing material and an asphalt layer are used to improve waterproofing and prevent leakage. Locally sourced natural rammed earth and shale fly ash are used, leveraging their water absorption and insulation advantages to enhance the building's sustainability. (Figure 7)

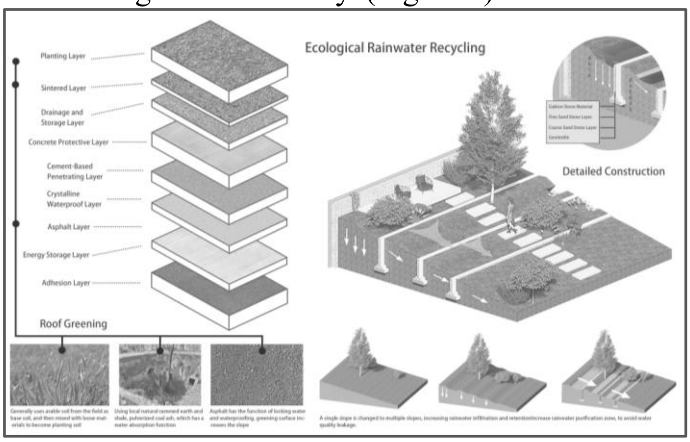

Figure 7: Green Roof and Water-Saving Design (Source: Hand-drawn)

2) Solar Photovoltaic System

To improve the building's energy self-sufficiency, this study installs solar photovoltaic panels on suitable roof areas to meet the renewable energy needs of the building's interior. The installation angle of the photovoltaic panels directly affects their power generation efficiency; the optimal tilt angle is usually related to the local latitude. Sanyuan County is located at 34.6° North latitude; therefore, the optimal tilt angle for the photovoltaic panels should be around 34.6°. To optimize seasonal power generation efficiency, the tilt angle can be set to 19° in summer to reduce sunlight reflection and maximize power generation, and adjusted to 49° in winter to fully capture low-angle sunlight and improve power generation efficiency. (Figure 8)

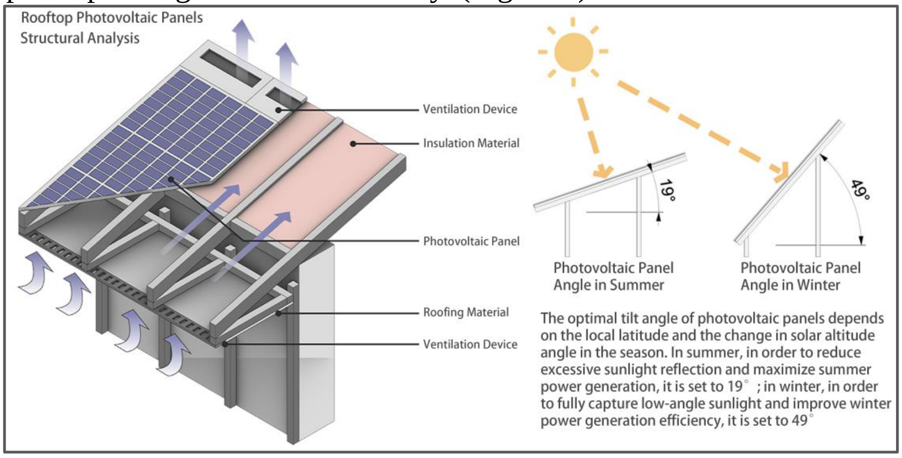

Figure 8: Solar Photovoltaic System (Source: Hand-drawn)

3) Passive Energy-Saving Design

Traditional earth-pit courtyards are 6 to 7 meters deep, mostly single-story spaces, failing to fully utilize vertical resources. This study vertically expands to add multi-story spaces, improving land use efficiency and functional flexibility; horizontal expansion incorporates a light well and green landscaping to enrich spatial layers [8] and improve the living environment. In vertical optimization, ventilation corridors combined with courtyard layouts promote air circulation and daylighting, drawing in breezes for cooling in summer and creating a buffer layer to reduce heat loss in winter. The courtyard serves as the core for daylighting and ventilation, enhancing the interaction between the building and the environment. A small ventilated courtyard is added in front of the side kiln room to improve lighting and ventilation on the lowest floor, reducing humidity and increasing comfort. (Figure 9)

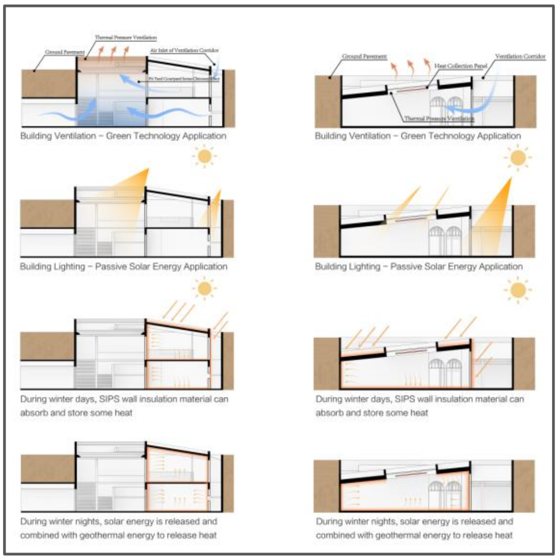

Figure 9 Passive Energy-Saving Design (Source: Hand-drawn)

4) Application of SIPS Walls

To integrate modern construction technology with local culture, this study combines SIPS with rammed earth walls, leveraging the thermal inertia and hygroscopicity of rammed earth. SIPS, consisting of load-bearing panels and a rigid foam core, possesses excellent thermal insulation, sound insulation, and airtightness. Simultaneously, SIPS are prefabricated in factories and assembled on-site, resulting in efficient construction and aligning with green building concepts. SIPS, as the inner layer, enhances the building's supporting force and insulation performance, compensating for the insufficient durability and seismic performance of rammed earth. Lightweight steel structures are embedded inside, forming a composite system of "steel structure – SIPS – rammed earth wall", enhancing seismic resistance, durability, and flexibility for vertical expansion [9]. (Figure 10)

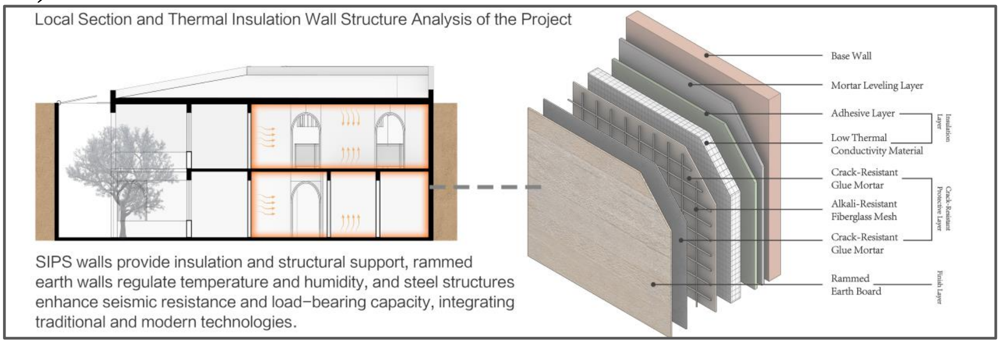

Figure 10 Application of SIPS Walls (Source: Hand-drawn)

4. Result and Discussion

To verify the actual effects of the renovation of the earth-pit courtyard buildings, this study uses SWEET (Sustainable Whole-Environment Energy Technology) building performance analysis software to quantitatively evaluate the performance of the renovated building in terms of building carbon emissions, indoor airflow organization, and building wind environment, ensuring the scientific validity and effectiveness of the renovation strategy [10].

4.1 Carbon Emission Analysis

Based on the calculation of building life cycle carbon emissions using SWEET software, the results show that the renovated earth-pit courtyard effectively reduces carbon emissions in building material selection, construction process, and use phase, meeting the requirements of the national Green Building Evaluation Standard (GB/T 50378-2019 [2024 partial revision]). Through the adoption of passive energy-saving design, SIPS structural walls, and roof soil covering, the heating and cooling energy consumption of the building is significantly reduced [11], and the carbon emission intensity is reduced by about 18% compared to before the renovation, achieving energy saving and emission reduction goals and complying with the technical path of low-carbon development in green buildings. (Figure 11)

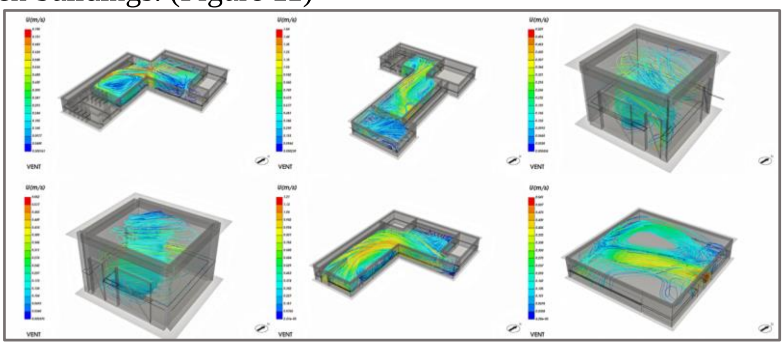

Figure 11: Building Indoor Airflow Streamline Analysis Diagram (Source: SWEET software calculation)

4.2 Indoor Airflow Organization Analysis

This study adopted reasonable technical measures for the evaluated rooms and conducted a detailed analysis of indoor airflow organization through CFD (Computational Fluid Dynamics) simulation, verifying the scientific validity and effectiveness of the airflow distribution. Simulation data shows that the airflow velocity and air exchange rate in the main functional spaces meet the requirements of Clause 5.1.2 of the Green Building Evaluation Standard (GB/T 50378-2019 [2024 partial revision]) regarding indoor air quality and thermal environment. (Figure 12)

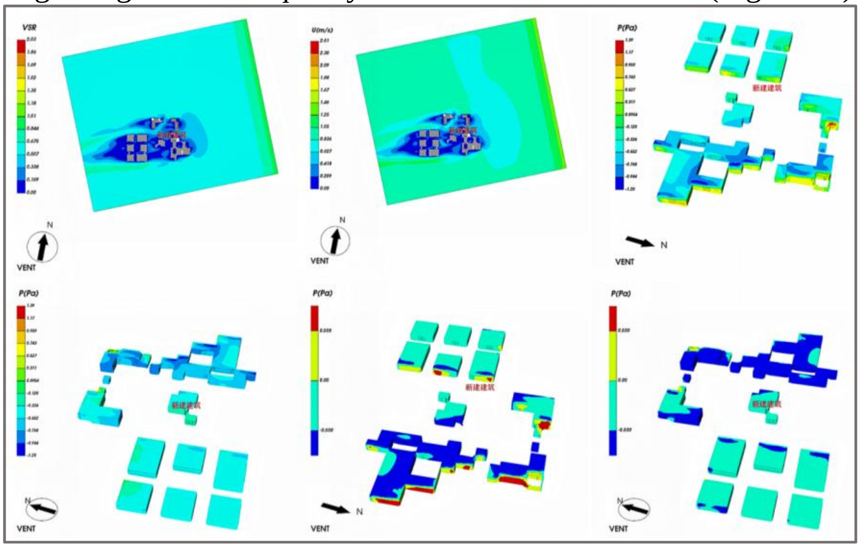

Figure 12: Building Wind Environment Analysis Diagram (Source: SWEET calculation)

4.3 Wind Environment Analysis

For the external wind environment of the building, software simulation analysis shows that the height difference between the earth-pit courtyard and the terrain forms an effective wind pressure difference. Combined with the shielding and wind-guiding design around the courtyard, this significantly improves the penetration effect of natural wind into the interior, reducing wind erosion and dust accumulation on the building surface [12]. The wind speed around the renovated earth-pit courtyard site is uniform, and a gentle breeze environment of 0.8 m/s-1.2 m/s is formed within the courtyard, which enhances ventilation while avoiding strong winds from damaging the slopes of the earth-pit courtyard.

4.4 Summary

In summary, the renovated earth-pit courtyard meets relevant green building standards in terms of carbon emission control, indoor airflow organization optimization, and external wind environment regulation. Through passive energy-saving design and optimized ventilation strategies, the building's energy utilization efficiency and environmental adaptability are effectively improved, achieving the goal of low-carbon and sustainable development.

5. Traditional Settlement Space Renewal Strategies Based on Eco-museum Theory

5.1 Cultural Preservation and Adaptive Reuse

The Eco-museum theory emphasizes in-situ conservation, community participation, and living heritage transmission, focusing on the symbiosis between cultural landscapes and residential lifestyles to foster dialogue between architecture and environment, history and future. The pit cave dwellings of Baishe Village embody profound regional culture and intangible heritage skills. Their renewal guided by Eco-museum theory can maintain cultural authenticity, sustain community memory, and achieve multidimensional symbiosis across cultural, ecological, and social dimensions [13-15].

5.2 Spatial Continuity and Functional Optimization

The renewal of Baishe Village's pit cave dwellings adheres to principles of spatial continuity and functional diversification. It preserves the integrity of the "courtyard-cave dwelling" structure through collapsed area restoration and heritage space integration, ensuring cultural memory continuity. For functional regeneration, the design incorporates visitor centers, cultural exhibitions, and handicraft workshops based on Eco-museum display requirements while respecting original architectural forms and material characteristics. This transforms traditional settlements into multifunctional spaces for cultural experience and community co-creation, establishing a diverse cultural ecosystem [16].

5.3 Multidimensional Perspectives and Sustainable Development

The renewal adopts multidimensional approaches encompassing ecosystems, cultural landscapes, and community symbiosis. Ecologically, it enhances soil-water conservation and stormwater management through ecological restoration, achieving dynamic balance between architecture and nature. For cultural aspects, it combines historical texture analysis, contextual design, and cultural narratives to enable holistic conservation of tangible and intangible heritage. At the community level, it centers on villager participation, leveraging handicraft workshops and cultural education to hand down heritage with rural development.

6. Conclusion

This study demonstrates innovation mainly in three aspects. Firstly, it Introduces Eco-museum theory to develop integrated conservation strategies that transcend material preservation limitations. Secondly, considering the technical application, the study adapts passive energy-saving, green roofs, and PV technology to local climate and architectural features for improved thermal performance. Thirdly, it transforms traditional spaces into multifunctional hubs through cultural displays and community participation. Therefore, The research establishes a renewal model for Baishe Village's pit cave dwellings that balances cultural continuity, functional enhancement, and ecological benefits—preserving spatial patterns while upgrading environmental adaptability through green technologies. Current limitations include reliance on surveying and software simulation for performance analysis, necessitating future long-term monitoring. While green technologies focus on energy efficiency and disaster resilience, smart management systems could be incorporated to strengthen environmental responsiveness through intelligent monitoring and operational solutions.

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