Analysis of the Ecological Adaptability of Tiny Houses in Urban Landscapes

Xiaoxi Tang *

Manchester Metropolitan University, Manchester, UK, M15 6BH, 621999

*Corresponding author's e-mail: tiaoxxi@163.com

Abstract. In order to evaluate the ecological adaptability and socio-economic benefits of tiny house in urban environments, a comprehensive evaluation model was developed, which integrates key parameters such as environmental impact index, energy efficiency coefficient, and resource allocation efficiency for analysis. The results show that tiny house perform well in reducing carbon emissions, improving energy efficiency, optimizing resource allocation, reducing construction and operation costs, and enhancing community cohesion. These advantages enable tiny houses to demonstrate good ecological adaptability in urban landscapes and promote sustainable development of cities.

Keywords: Tiny houses; Ecological adaptability; Environmental impact

1 INTRODUCTION

In the context of rapid urbanization, tiny houses have emerged as an innovative solution to address issues of high housing prices and land scarcity due to their economical and efficient use of space. On this basis, the ecological adaptability evaluation model of tiny houseg is constructed to analyze its environmental impact, energy efficiency and resource allocation efficiency, so as to provide a scientific basis for urban planning and landscape design. The evaluation method combines parameters such as the Environmental Impact Index and Energy Efficiency Coefficient to reveal the advantages of tiny houses in terms of ecological adaptability and socio-economic benefits, The diverse design and efficient use of space in tiny house can create a richer combination of buildings and natural elements in a limited urban space, enhancing the beauty and uniqueness of the city under sustainable conditions.

2 CURRENT APPLICATION OF TINY HOUSES IN CITIES

Tiny houses originated in Europe, the United States, and Japan (as shown in Figure 1). Initially conceived as a solution to housing crises and high real estate prices, they have gained widespread attention. This compact housing format not only offers an affordable living option but also provides a way for people to escape the constraints of fixed urban

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housing, allowing residents to switch freely between urban and natural environments [1]. Over time, tiny houses have come to symbolize physical and mental healing by reducing material burdens and living costs, offering a respite from fast-paced city life. Additionally, the design philosophy of tiny houses has increasingly aligned with trends toward nature conservation and sustainable living, with more people choosing this lifestyle to fulfill their aspirations for simplicity and environmental friendliness.

In China, tiny houses are gradually being introduced and promoted as an innovative solution, especially in the context of the country's large population, severe housing pressure, and tight land resources. Although tiny houses have shown some effectiveness in alleviating housing pressure, their impact on enhancing the connection between people and nature has not yet fully materialized. Compared to other countries, the application of tiny houses in China is still in its early stages, and there is considerable potential for exploration in urban landscape and sustainable development research [2]. This aligns with China's overall urban development goals, which aim to achieve green and sustainable development within limited urban land. Therefore, this study establishes an ecological adaptability assessment model to analyze the role and potential value of tiny houses in Chinese urban landscapes, with the goal of providing scientific references and guidance for the design of tiny houses and domestic urban planning.

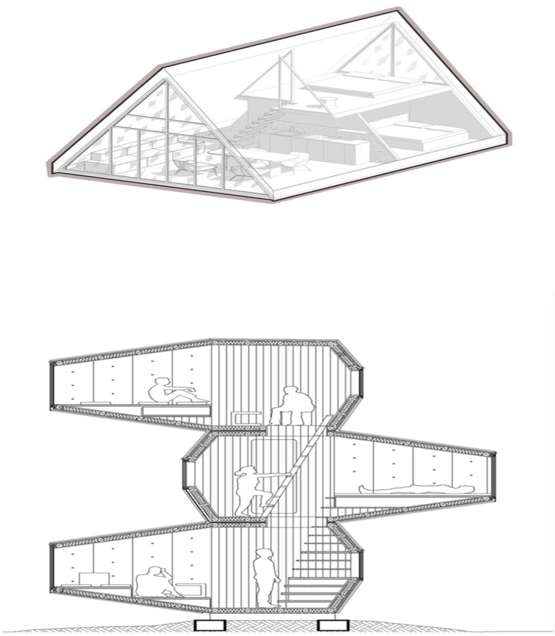

Fig. 1. Model Display of Tiny Houses

3 DEFINITIONS OF URBAN LANDSCAPE AND ECOLOGICAL ADAPTABILITY

Urban landscape refers to the visual and functional landscape composed of various natural and artificial elements in the city, including buildings, streets, squares, green spaces, and water bodies. In the context of rapid urban development and increasingly scarce land resources, the efficient use of urban land and the creation of landscape aesthetics often conflict. With the acceleration of urbanization, extensive construction activities continuously encroach on existing green spaces, significantly reducing the accessible natural environment for urban residents. This not only affects the ecological balance of the city but also lowers the quality of life for residents. For example, in most cities in China, to meet the demand for housing and commercial development, urban planners often prioritize dense development of construction land over the rational layout of ecological and recreational spaces.

Ecological adaptability refers to the ability of urban landscapes to respond to environmental changes and maintain ecological balance. Although this method of alleviating land pressure through urban expansion or the development of new land can indeed meet the needs of urban development in the short term, it overlooks the crucial role of urban green spaces in maintaining ecological adaptability. Urban green spaces, such as parks, roadside green spaces, and public open spaces, not only beautify the urban environment, enhance the aesthetics and uniqueness of the city, but also play an irreplaceable role in regulating the urban climate, reducing the heat island effect, carbon sequestration, releasing oxygen, improving air quality, conserving biodiversity, and providing psychological and physiological resting places for citizens. These functions are directly related to the health and sustainable development of urban ecosystems, and are important supports for cities to adapt to environmental changes and maintain ecological balance. Only through scientific landscape design and reasonable green space allocation can urban landscapes have sufficient ecological adaptability to meet the challenges of future environmental changes and achieve the sustainability goals of urban development.

4 DESIGN OF THE ECOLOGICAL ADAPTABILITY EVALUATION MODEL FOR TINY HOUSES

4.1 Model Framework

The design of the ecological adaptability evaluation model for tiny houses evaluates the adaptability and sustainability of tiny houses in urban environments, while also promoting the rational allocation of residential resources and improving the quality of living environments.Based on the theory of ecological adaptability, the model focuses on a comprehensive evaluation of the environmental impact and resource efficiency of tiny houses [3]. The model framework includes three main components: input, processing, and output. The input section collects relevant urban data, housing characteristics, and environmental impact indicators. The processing section uses algorithms to analyze the data and assess the ecological adaptability of the housing. The output section generates specific evaluation results, providing a scientific basis for urban planning and housing design, as shown in Figure 2.

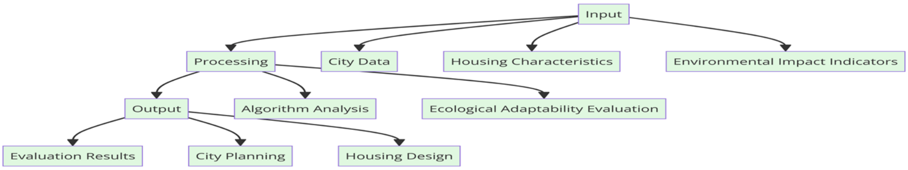

Fig. 2. Framework Diagram of the Ecological Adaptability Model for Tiny Houses

4.2 Determination of Key Parameters

In constructing the ecological adaptability evaluation model for tiny houses, the selection of core parameters is crucial [4]. These parameters must comprehensively cover the ecological and environmental impacts of tiny houses while being operable and scientifically sound to ensure the accuracy and practicality of the evaluation results. The following are the key parameters for evaluating the ecological adaptability of tiny houses:

1. Environmental Impact Index E : This index comprehensively evaluates the impact of tiny houses on the surrounding environment during construction and usage, including carbon emissions, waste generation, and its processing efficiency. The Environmental Impact Index can be calculated using the following formula:

$$E = \alpha \cdot C + \beta \cdot W + \gamma \cdot \mathrm{P} \tag{1}$$

Among them, C represents the annual carbon emissions, W represents the amount of waste generated, P represents the waste processing efficiency, and α , β , and γ are the corresponding weighting coefficients, adjusted according to the environmental policies and goals of different cities.

2.Energy Efficiency Coefficient: This coefficient reflects the energy consumption efficiency of the residence during its use and is an important parameter for measuring the sustainability of tiny houses. The Energy Efficiency Coefficient is usually calculated based on energy consumption and residential area:

$$\eta = \frac{Eused}{A} \tag{2}$$

Among them, $Eused$ represents the total energy consumption over a specific period, and A is the residential area.

3. Resource Allocation Efficiency R :This parameter considers the efficiency of resource allocation for tiny houses in the city, such as geographical location, transportation convenience, and completeness of infrastructure. The Resource Allocation Efficiency can be expressed by the following formula:

$$R = \delta \cdot L + \in \cdot T + \zeta \cdot \mathrm{I} \tag{3}$$

Among them, L represents the geographical location score, T represents the transportation convenience score, I represents the completeness of infrastructure score, and δ , $\in$, and ζ are their respective weights. These parameters are comprehensively evaluated through a mathematical model, providing urban planners and architectural designers with scientific evidence on the ecological adaptability of tiny houses in urban landscapes [5].

4.3 Model Validation Methods

Model validation is primarily achieved through quantitative analysis and experimental design, involving the application of various techniques and tools [6]. The validation methods include historical data fitting, parameter sensitivity analysis, and practical case application testing to ensure that the model accurately reflects the ecological adaptability of tiny houses. By fitting the model to historical data, the difference between the model's predicted values and actual observed values is compared to assess the model's prediction accuracy. Prediction accuracy can be quantified by the Mean Squared Error (MSE), which is calculated using the following formula:

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 \tag{4}$$

Among them, Y_i is the actual observed value, $\hat{Y}_i$ is the model's predicted value, and n is the total number of data points. The smaller the MSE value, the higher the model's fit, and the more reliable the prediction results.

Conduct parameter sensitivity analysis by adjusting the key parameters, such as the weights of the Environmental Impact Index E , Energy Efficiency Coefficient η , and Resource Allocation Efficiency R , and observe the changes in the model output. This analysis helps identify which parameters the model is most sensitive to, guiding the model's optimization and precise parameter setting [7]. The results of the sensitivity analysis can be expressed by the Sensitivity Coefficient S , which is defined as the proportion of output change caused by the parameter change:

$$S_k = \frac{\partial Y}{\partial X_k} \cdot \frac{X_k}{Y} \tag{5}$$

Among them, X_k is the key parameter, Y is the model output, and $\partial Y / \partial X_k$ represents the partial derivative of the output with respect to the parameter X_k . Further validate the model's practicality and effectiveness through practical case application tests. Select representative tiny house projects and apply the model to evaluate their ecological adaptability, comparing the evaluation results with the actual performance of the projects. The experimental design of this part should detail the conditions, process, and evaluation results of the model application to provide complete validation evidence [8]. Table 1 summarizes the key steps of model validation and their related indicators and calculation methods.

Table 1. Validation Methods and Indicators of the Ecological Adaptability Model for Tiny Houses

Validation Steps	Techniques/Tools	Key Indicators	Calculation Methods
Historical Data Fitting	Statistical Analysis Software	MSE	$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$
Parameter Sensitivity Analysis	Sensitivity Analysis Software	S_k	$S_k = \frac{\partial Y}{\partial X_k} \cdot \frac{X_k}{Y}$
Practical Case Testing	On-site Evaluation and Data Recording	Fit Degree	Comparison between model predicted values and actual performance

5 EXPERIMENTAL RESULTS AND ANALYSIS

5.1 Analysis of Environmental Adaptability of Tiny Houses

As an innovative measure to cope with the rising housing prices and tight land resources in the process of urbanization, tiny houses mainly contribute to reducing the demand for residential space and improving land use efficiency in the urban environment[9]. In terms of environmental impact, tiny houses achieve a lower ecological footprint by reducing the use of building materials, lowering energy consumption, and decreasing carbon emissions, as shown in Table 2.

Table 2. Experimental Parameters of Environmental Impact of Tiny Houses

Experimental Parameters	Value Range	Average	Standard Deviation
Annual Carbon Emissions (tons)	1.2 - 2.5	1.8	0.45
Annual Energy Consumption (kWh)	500 - 1500	1000	250
Building Material Usage (tons)	2-4	3	0.5
Waste Processing Efficiency (%)	85 - 95	90	2.5

In terms of annual carbon emissions, tiny houses have an average emission of 1.8 tons, which is relatively low, indicating a smaller ecological footprint. Energy consumption also shows a similar trend, with an average annual energy consumption of 1000 kWh, significantly lower than traditional houses. These data reflect the effectiveness of tiny houses in reducing carbon emissions and energy use, which are important indicators of urban sustainability. Further exploration of resource allocation efficiency is shown in Figure 3.

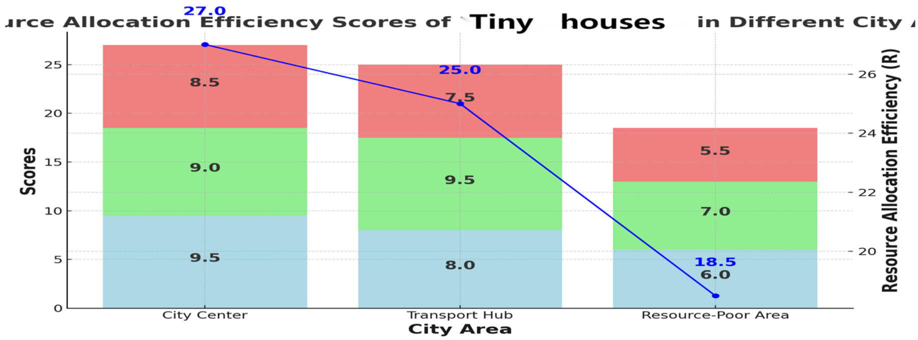

Fig. 3. Resource Allocation Efficiency Scores of Tiny Houses in Different Urban Areas

Tiny houses in city centers have the highest resource allocation efficiency score of 27.0, attributed to their excellent geographical location and convenient transportation, while resource-poor areas have the lowest score of 18.5. This indicates that the geographical location and the completeness of infrastructure have a decisive impact on the adaptability of tiny houses. Figure 4 further illustrates the adaptability of tiny houses in different areas, with the highest overall adaptability score in city centers, reflecting the positive impact of superior geographical location on ecological adaptability. Although micro housing may slightly increase the burden in certain areas, it still significantly enhances urban adaptability overall. This type of housing design is compact, effectively utilizes limited space, reduces dependence on large areas of land, and provides a land saving living solution in densely populated cities. Its flexibility is reflected in the ability to adjust and integrate according to different urban blocks and existing urban layouts, allowing urban planners to more freely consider the combination of landscape and residential functions in their design. The promotion of micro housing not only optimizes land use, but also brings new design ideas, such as rooftop gardens and vertical greening, which are effective means to improve urban ecological quality and residential aesthetics.

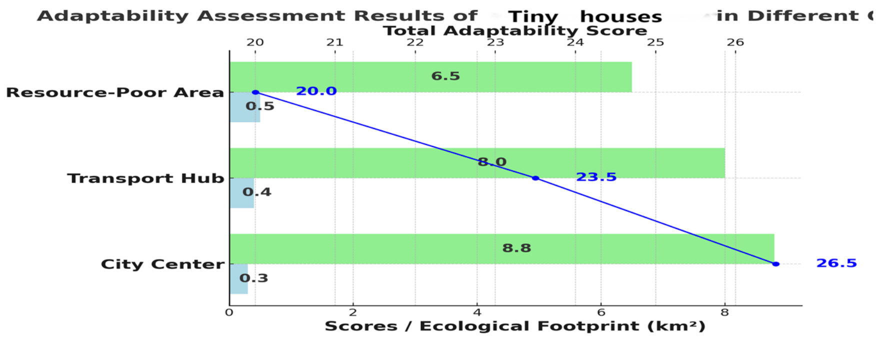

Fig. 4. Adaptability Evaluation Results of Tiny Houses in Different Urban Areas

By increasing the weights of geographic location, transportation convenience, and infrastructure scores by 10% each, the actual impact of these parameters on the overall adaptability score can be observed. In the city center, the increase in infrastructure score resulted in the most significant improvement in adaptability, with an increase of 0.34 points, indicating that high-quality infrastructure is crucial for improving the quality of life and adaptability of micro homes. Similarly, in transportation hubs and resource scarce areas, the impact of increasing transportation convenience scores is also more significant, improving adaptability scores to 0.285 and 0.21, demonstrating the direct benefits of good infrastructure and convenient transportation in improving the adaptability of micro housing. Not only does it make micro homes more attractive, but it also encourages more residents to consider relocating to areas with fewer populations.

This transfer can effectively disperse the population density in the city center, alleviate the infrastructure pressure in the central area, and drive the development of suburban economy. Due to their smaller footprint and flexible construction characteristics, micro homes can be more easily integrated into natural landscapes, providing more living environments in direct contact with nature. This layout strategy not only improves the quality of life for residents, but also helps to form new urban landscape patches and enhance the coherence of existing landscape corridors. Over time, this strategy can promote the sustainable development of cities, improve their ecological environment, and achieve harmonious coexistence between humans and nature. Therefore, extending infrastructure and transportation convenience to peripheral areas has important strategic significance for promoting the widespread application of micro housing and optimizing urban development models, as shown in Table 3.

Table 3. Analysis of the Impact of Parameter Weight Changes on Overall Adaptability Score

Parameter	Original Weight	Increased Weight by 10%	Change in Total Adaptability Score (City Center)	Change in Total Adaptability Score (Transport Hub)	Change in Total Adaptability Score (Resource-Poor Area)
Geographical Location Score (L)	0.3	0.33	0.3	0.24	0.18
Transportation Convenience Score (T)	0.3	0.33	0.27	0.285	0.21
Infrastructure Score (I)	0.4	0.44	0.34	0.3	0.22

5.2 Analysis of the Socio-Economic Adaptability of Tiny Houses

The construction cost of tiny houses is relatively low, usually not exceeding half of traditional housing, thereby reducing the cost of buying and renting [10]. This economic characteristic enables low-income families to afford their own housing. In addition, the design of tiny houses is flexible and diverse, which can meet the living needs and aesthetic preferences of different groups of people. Buyers can choose different design styles and interior layouts within their budget, making each micro residence unique. The diversity of this design not only enriches market choices, but also increases the possibility of personalized living, allowing people to not only purchase houses with limited budgets, but also customize and decorate them according to personal preferences and needs. Table 4 shows the cost comparison data of micro housing and traditional housing in different urban areas. By comparison, it can be found that the average purchase cost of micro homes in city centers, transportation hubs, and resource scarce areas is 300000, 250000, and 200000 yuan, respectively, while the cost of traditional homes is 600000, 500000, and 400000 yuan. This data clearly demonstrates the advantages of micro housing in reducing the threshold for home purchases.

The affordability and efficiency of micro homes also contribute to their important role in urban landscapes. As a form of housing with strong ecological adaptability, tiny houses have shown their potential value in saving land resources and reducing energy consumption. In the urban environment of China, this form of housing not only provides more living options for low - and middle-income groups, but also promotes community diversity and vitality. By offering affordable housing options, micro homes help attract more young people and creative workers to enter the city center and other high cost areas, thereby activating the cultural and economic life of these areas. In the long run, this will help to form more inclusive and diverse urban communities, promote sustainable development and ecological balance of the city, and improve the overall quality of life and living environment of the city.

Table 4. Cost Comparison of Tiny Houses and Traditional Houses in Different Urban Areas

Urban Area	Average Purchase Cost of Tiny Houses (10,000 yuan)	Average Purchase Cost of Traditional Houses (10,000 yuan)	Operating Cost of Tiny Houses (yuan/month)	Operating Cost of Traditional Houses (yuan/month)
City Center	30	60	800	1500
Transportation Hub	25	50	700	1300
Resource-Poor Area	20	40	600	1200

Tiny houses prioritize aesthetics and space efficiency, focusing on smaller private areas and enhancing public and outdoor spaces. This design strategy not only optimizes home functionality but also fosters neighborly interactions and social cohesion. As illustrated in Figure 5, the community interaction scores in tiny houses are notably higher in urban and transit areas at 8.5 and 8.0, compared to traditional houses at 6.5 and 6.0, demonstrating their effectiveness in promoting community integration.Tiny houses demand that landscape designers enhance functionality by incorporating leisure zones, community gardens, and walking paths. These additions enrich outdoor activities and boost social interactions, thereby improving living quality and community cohesion. This approach positively influences urban landscape aesthetics and development by enhancing public space interactivity.

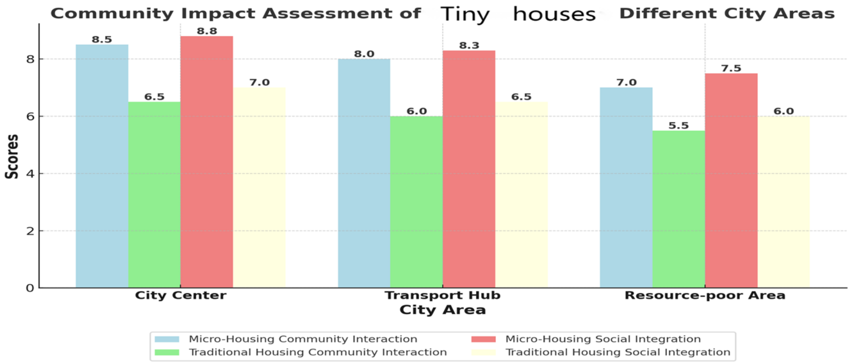

Fig. 5. Community Impact Assessment of Tiny Houses in Different Urban Areas

5.3 Analysis of the Technological Adaptability of Tiny Houses

As an emerging form of modern urban housing, tiny houses widely adopt various technological innovations in their design and construction processes. These innovations include modular construction, smart home systems, and the application of green building materials. The modular construction method, which involves prefabricating modules in a factory and assembling them on-site, significantly shortens the construction period, reduces building costs, and minimizes construction waste and environmental pollution. The integration of smart home systems allows tiny houses to achieve automated control, improve energy efficiency, and enhance the living experience for residents. Additionally, the use of green building materials, such as renewable wood, low-carbon concrete, and high-efficiency insulation materials, further enhances the environmental performance of tiny houses, as shown in Table 5.

Table 5. Technological Innovations and Their Application Effects in Tiny Houses

Technological Innovation	Application Effects	Cost Efficiency	Environmental Benefits
Modular Construction	Shortens construction period to 3-6 months, reduces construction costs by 20%-30%	High	High
Smart Home Systems	Increases energy utilization efficiency by 20%, enhances living comfort	Medium	High
Green Building Materials	Reduces carbon emissions by 30%, improves building energy efficiency	Medium	High

From the data analysis in Table 5, it can be seen that modular buildings and smart home systems have excellent cost-effectiveness and environmental benefits. Especially modular building methods can significantly shorten the construction period and reduce costs, while significantly reducing environmental pollution during the construction process, demonstrating the importance of technological innovation in micro housing. When evaluating technological efficiency, the focus is on examining the effectiveness of these innovative technologies in improving energy efficiency and reducing environmental impact. Figure 6 shows the energy efficiency improvement and environmental impact mitigation of different technologies in micro homes. By comparison, it can be seen that the introduction of smart home systems has increased energy efficiency by an average of 20% while reducing energy consumption for residents. The use of green building materials has reduced the carbon emissions of micro homes by 30%, significantly reducing the environmental burden.

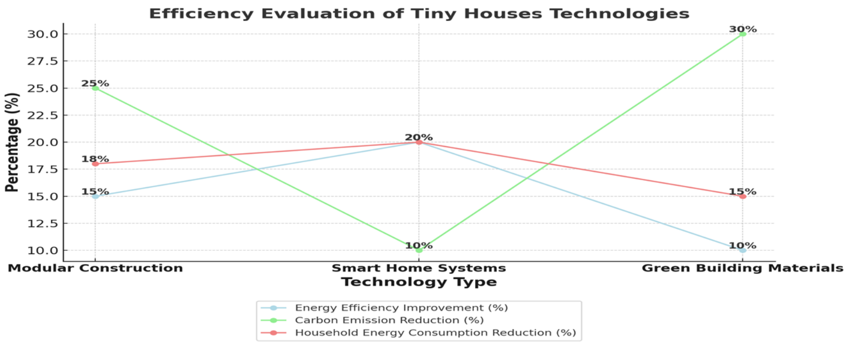

Fig. 6. Efficiency Assessment of Technologies in Tiny Houses

6 CONCLUSION

The ecological adaptability evaluation model of tiny houses in urban landscapes, combined with key parameters such as environmental impact index, energy efficiency coefficient, and resource allocation efficiency, demonstrates the significant advantages of tiny houses in reducing carbon emissions, improving energy utilization efficiency, and optimizing resource allocation.In terms of environmental adaptability, micro homes significantly reduce the ecological burden of cities and optimize energy use due to their low carbon emissions and high energy efficiency. In terms of socio-economic adaptability, micro housing reduces the threshold for living, promotes social integration, and enhances community cohesion through lower construction and operation costs. In addition, in terms of technological adaptability, micro homes adopt innovative technologies such as modular buildings and smart home systems, which not only shorten the construction period and reduce costs, but also significantly improve energy utilization efficiency and environmental performance. These research findings have profound implications for the transformation and enhancement of urban landscapes. In the future, it is necessary to further integrate the urban landscape planning and design of micro housing with adaptability in different urban areas, and combine technological innovation and policy support to enhance its ecological and socio-economic benefits, in order to promote sustainable urban development.

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