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Fractal Theory-Based Analysis of Architectural Form Design for Rural Dwellings in Plain Regions: A Case Study of T Village in Z City, H Province

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Abstract: Fractal theory is a nonlinear research method that uses fractal geometry to study complex phenomena. This study applies fractal theory to analyze the individual housing units, spatial environment, and other influencing factors in T Village, a region located in the central plains of China. The analysis highlights the importance of considering local integration, the construction of a harmonious relationship between humans and the natural environment, and the impact of political, economic, and urban development factors on housing design. The aim of this study is to provide a broader path for the design of rural housing in the central plains region.

1. Introduction

Rural dwellings embody the wisdom of generations of villagers. Guided by the bottom-up self-organizing concept, villagers spontaneously create the architectural and cultural characteristics of their dwellings. However, most rural planning and design projects, including the New Rural Construction, Beautiful Countryside Construction, and Rural Revitalization Strategy promoted by the central government, are dominated by top-down organizational concepts, in which the government takes the lead, designers provide guidance, and villagers participate passively. [1]This contradicts the traditional self-organizing concept of dwelling design. As a result, there is a chaotic situation in the design of rural dwellings in the Central Plains region, with fashionable styles from southern and European housing designs being introduced. Drawing on fractal theory, this study analyzes the form of rural dwellings in the Central Plains region, explores the patterns and rules of dwelling form generation through the use of image geometry language, and provides architectural design ideas that are in line with the regional characteristics of the Central Plains countryside.

Researchers employ qualitative research methods, including historical literature review, field research, and classification analysis, to address these issues. They also draw on theories from the field of imageology to guide their research. Imageology is a discipline that studies image information and can be used to investigate and describe the morphology and spatial characteristics of architecture. In rural construction research, imageology theory can aid researchers in more accurately observing and describing the features of rural architecture, such as form, color, and spatial structure, thus providing insights for analysis and problem-solving.

The Central Plains region is located in the central part of China and belongs to the North China

Plain, including parts of Henan, Shanxi, and Hebei provinces. Historically, the Central Plains region was the location of the capital cities and the political and economic center of many dynasties, such as the Qin, Han, Tang, and Song dynasties.[2] It is also the site of early Chinese cultures, including the Xia, Shang, and Zhou cultures, as well as the Yangshao culture, representing the origins of Chinese civilization.

In terms of industrial development, the Central Plains region is mainly characterized by traditional agriculture, with a small amount of industry and tertiary industries. In terms of economic development, the overall level of economic development in the Central Plains region is considered to be at a moderate level compared to the three vertical regions in the east, central and west of China. In terms of transportation, the Central Plains region has a flat terrain and serves as a central hub for transportation in China. In terms of cultural integration, the Central Plains region has a higher number of people who travel overseas and is more accepting and adaptable to other regional cultures.[3]

T Village is located in the hinterland of eastern Henan Province, with a current population of over 300 permanent residents and 1060 acres of farmland mainly planted with traditional crops such as wheat, corn, sweet potatoes, and a small amount of Chinese medicinal herbs. According to local historians, T Village was built in the ninth year of Emperor Yongzheng's reign in the Qing Dynasty and completed in the twelfth year. The village is 90 zhang long from east to west and 66 zhang wide from north to south, with a gate on the south side, and a watchtower on each of the east, west, and north sides of the village. The village wall is 3 zhang high and 2 zhang wide, with a man-made moat surrounding it. In recent years, T Village has transformed from its original village structure into a common type of village in the Central Plains region. From the appearance of the buildings, the exterior of T Village's dwellings still retains the appearance of Central Plains villages in the 1980s and 1990s: dilapidated wooden gate towers, brick and cement-built main houses, temporary thatched huts, low and incomplete courtyard walls, bumpy dirt roads, scattered straw piles, and household garbage along the roadside... all of which, compared to the nearby villages with golden bricks and glazed tiles, two-story small buildings, and cement roads, seem more like a forgotten and backward place (see Figure 1). In the eyes of the local people, all of this represents poverty and backwardness. However, in the eyes of artists, the village has a rustic beauty of memory in its architectural form. With the development of village construction, T Village has been upgraded with the support of policies such as the "National Agricultural Science and Technology Park" and "Beautiful Countryside" projects, which have improved its infrastructure, including roads, greening, and lighting, over the course of three years. The newly prosperous villagers have also rebuilt and upgraded their dwellings.

Figure 1: The original state of the village, taken by the author in December 2017

However, these new buildings, with their colorful glass and stone decorations, do not match the original red brick and tile buildings. The existing buildings show that the village's dwellings have

only been decorated on the exterior while retaining their original architectural form. The buildings are uniformly painted with yellow exterior wall paint and gray wall skirts, leading to a lack of texture and layering, with only the high and low differences of the boundary lines remaining (see Figure 2).

Figure 2: Current situation of the village, taken by the author in January 2023

2. Fractal Theory and Architectural Design

Fractal theory is a nonlinear scientific research branch that applies fractal geometry to study disordered, unstable, unbalanced, and random objects and phenomena in nature, and reveals the unity of order and disorder, combining determinism and stochasticism. [4] The theory has gone through three stages of development. [5]The first stage began with the discovery of fractal phenomena. In 1904, the Swedish mathematician Koch constructed the Koch curve using elementary methods, which provided the most basic mathematical tool for fractal theory. The second stage delved into the properties of fractals. From 1926 to 1975, the theory of dimensionality, local forms of fractal sets, harmonic analysis, and other analytical theories enriched the theory of fractals. The third stage was the formation of the analytical theory, which was marked by the publication of "The Fractal Geometry of Nature" by the American mathematician Benoit Mandelbrot in 1975. The book established the theory of fractals, clearly defined the concept of fractals, and presented classic examples of fractals that cannot be explained by mathematical principles. Fractal theory analyzes fractal dimensions and self-similarity using quantifiable mathematical models, and is therefore applied in various interdisciplinary fields, such as humanities and social sciences, natural sciences, and philosophy.

The application of fractal theory in architectural design was first demonstrated in Carl Bovill's book "Fractal Geometry in Architecture and Design". Bovill focused on fractal analysis in architecture and design in a clear and systematic way, emphasizing the balance between predictability and surprise in art and design, stating that "without expectation, there can be no surprise". In terms of form, Bovill believed that traditional symmetry expresses more structural order, and that patterns may be generated in orderly processes that were not originally considered orderly in analysis.[6] The application of fractal theory in architectural design mainly focuses on expected construction and architectural analysis.In fractals, forms, opportunities, and dimensions, Mandelbrot not only integrated his observations of natural geometry for the first time, but also made numerous documented attempts to connect art and architectural history and criticism. When discussing architectural styles, Mandelbrot attempted to differentiate between Euclidean geometry and fractal geometry, stating that "in the context of architecture, Mies van der Rohe's architecture is a miniature of Euclidean architecture, while advanced art architecture has rich fractal features".[7]

Furthermore, in traditional aesthetic concepts, rules such as symmetry, array, repetition, rotation, and the "axis" in architectural drawings are relatively simple operations that can be replicated in human thinking and impression. Common design techniques in traditional architecture, such as "central axis symmetry" and "array centering", express an orderly sense that conforms to the "simple" order of Gestalt psychology. Nicoletta (2019)[8]divides architectural fractals into small-scale and large-scale analysis. Small-scale analysis mainly employs methods such as self-similarity analysis of buildings and fractal dimension calculation of buildings. In project research, the box-counting dimension method in traditional fractal geometry analysis is used to graphically analyze existing buildings, identify the self-similarity of original residential buildings, and analyze the ordered forms that appear to be disordered in architectural expressions, providing new methods for analyzing and constructing complex architecture.

3. Fractal Analysis of Residential Form in T Village

3.1. Visual analysis of residential buildings

When observing an object, the essence of visual perception is to find the optimal observation point within an appropriate scale range. The distance from the building and the grid size used in box counting in residential analysis are related. People only focus on the position of the visual center when observing buildings (see Figure 3). The most detailed parts can be observed within 2 °, while important details can be observed at 10 °, 15 °, and 20 °.(see Figure 4)

Table 1: The distance from the observer to the building

Human Vision Angle	1.5M	3M	6M	12M
2	5CM	10CM	20CM	43CM
5	10CM	25CM	82CM	106CM
10	25CM	55CM	106CM	213CM
15	40CM	82CM	164CM	325CM
20	55CM	109CM	222CM	444CM

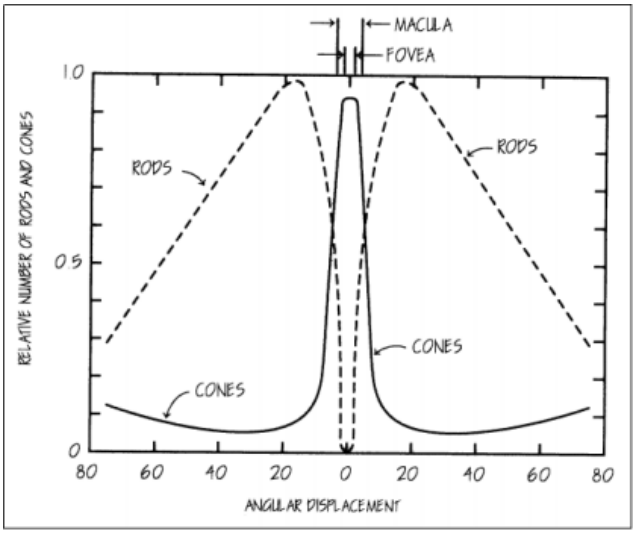

Figure 3: Normal human eye field of view

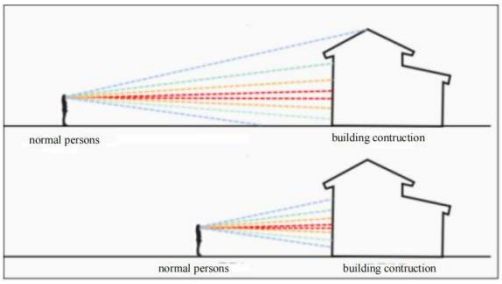

Figure 4: The frontal observation range of normal human eyes on the building

From Table 1, it is evident that there is a significant difference in the ability to observe details between standing near a building and standing at a distance of 6 meters or 12 meters from the building, for a person of normal height. Using the box-counting method, three fractal dimensions can be calculated. The first dimension is the number of boxes with lines increasing from a grid of 8 boxes at the bottom (2.4 meters) to a grid of 16 boxes at the bottom (1.2 meters) (see Table 2, see Figure 5).

Table 2: Number of Facade Boxes of Houses in T Village

Number of boxes	grid size	grid size
20	8	2.4M
72	16	1.2M
244	32	0.6M
929	64	0.3M

$$D(box2.4-1.2)=\frac{[\log(72)-\log(20)]}{[\log(16)-\log(8)]}$$

$$=\frac{1.857-1.301}{1.204-0.903}$$

$$=\frac{0.556}{0.301}$$

$$=1.85$$

The next calculation involves comparing boxes that are 1.2 meters wide and boxes that are 0.6 meters wide.

$$D(box1.2-0.6)=\frac{[\log(244)-\log(72)]}{[\log(32)-\log(16)]}$$

$$=\frac{2.387-1.857}{1.505-1.204}$$

$$=\frac{0.530}{0.301}$$

$$=1.76$$

The final calculation involves comparing boxes that are 0.6 meters wide and boxes that are 0.3 meters wide.

$$D(\text{box}0.6-0.3)=\frac{[\log(924)-\log(244)]}{[\log(64)-\log(32)]}$$
$$=\frac{2.966-2.387}{1.806-1.505}$$
$$=\frac{0.579}{0.301}$$
$$=1.92$$

In the elevation grid with the drawn gridlines, we can see that the largest grid is so large that each box in the grid contains lines from the elevation. The initial grid size should usually be small enough and somewhat coarse and general so that not all boxes are counted. In Figure 5, the building outline is filled in black on the right to show the boxes that have been counted. This is a way to simplify the counting process and also helps to understand what is actually being measured. Boxes are excluded for two reasons: first, to provide a more accurate description of the building facade; and second, for blank or indeterminate areas on the exterior. Therefore, the counted boxes represent areas of the facade where something can be seen. The shape shown on the left in Figure 5 has a distant relationship with the Sierpinski carpet. The Sierpinski carpet has a fixed rule that governs which solid form is left at each stage of its construction. The black shadow box shown on the left in Figure 5, on the other hand, has a more complex rule that controls which areas of the solid shape are omitted at each stage of its generation.

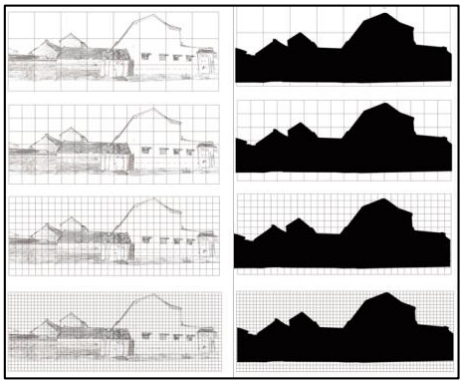

Figure 5: Architectural Box Dimensions

3.2 Analysis of residential living environment

At the beginning of its establishment, the purpose of T village was to defend against bandits, and the village's layout still follows the shape of the surrounding moat. Over time and with changes in residents' lifestyles, the original layout of the village's stockades has not changed, but with the drying up of the moat, people who could not live within the stockades began building new houses along the east, south, and north directions. The houses, which were self-built by the villagers, were constructed according to their own spatial requirements and demands. T village has a grid layout of streets and alleys. The main street layout in the form of a grid shown in Figure 7 is for row houses. Each house's height and width are distributed in a disorderly manner according to the house's own height and depth, capturing the complex rhythm found in natural forms and local architecture. The layout of single-row buildings shown in Figure 6 (1) captures the interlacing and cross-positioning of high roofs and building facades. The layout of the buildings in Figure 6 (2) adds the vertical layout of the rear buildings, creating a hierarchical variation in the height of the skyline. If the

village's housing was designed and planned uniformly and as a whole, the housing form would become like the style shown in Figure 6 (3), resembling a city building standing in the countryside. When analyzing the fractal dimension of the housing using the box-counting method, the skyline and horizon are particularly important. We can see from the box-counting method that the fractal dimension of the upper and lower parts of the building is higher than that of the middle part. Additionally, T village is located in a plain area, and the bottom of the village's buildings is basically on a horizontal dimension. Observers are also on this horizontal dimension, making analyzing the housing skyline of T village particularly important (see Figure 7). In recent years, the uniform skyline shown in Figure 7 (3) has become a common style in new rural architectural design. However, such a neat and uniform style lacks order and rhythm in the buildings.

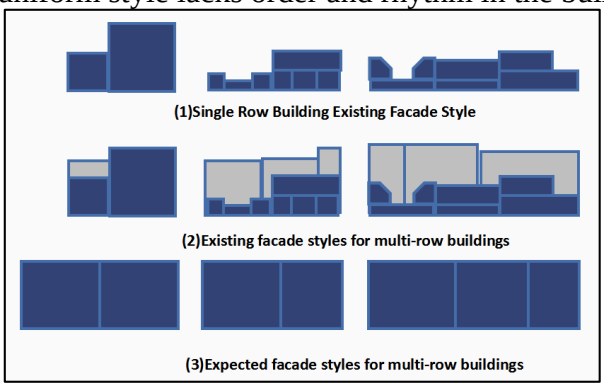

Figure 6: The outline of the village street facade self-drawing

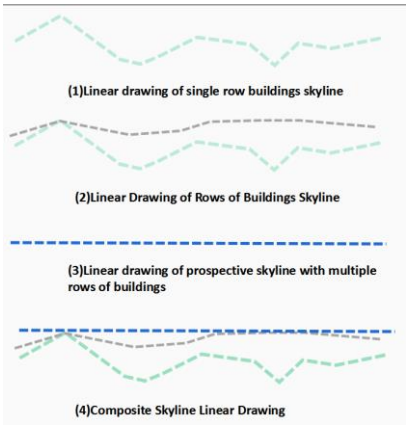

Figure 7: Village Street Facade Skyline

The interesting aspect of residential and environmental architecture is not only in the individual buildings and clusters, but also in the plant landscape that adjoins the buildings, providing more "ordered forms" in the rural landscape amidst the disorderliness.

3.3 Analysis of other factors of residential space

According to the construction of rural homesteads in H province, in accordance with Article 7 of Chapter 2 of the H province Rural Homestead and Self-built Housing Management Measures (trial) which states that "In plain areas with an average of more than 667 square meters of cultivated land per capita, the area of each homestead shall not exceed 167 square meters." The project site is designed to meet the needs of each household within a maximum area of 15 meters by 15 meters, leaving a "hutong" of around 5 meters between every two back-to-back houses. The main roads left behind in the village have become "streets" with a width ranging from 10 meters to 15 meters. By

categorizing the housing into grids, nine grids in the first stage have a probability of (2/3), (1/2) in the second stage, and (1/3) in the final stage, resulting in a fractal that provides an explanation for order. The process of village settlement formation contains a mixture of order and chaos (see Figure 8), similar to the random condensation process of matter in the universe that forms the stars we see in the night sky. The mixture of order and disorder in the night sky provides humans with a pattern from the very beginning.

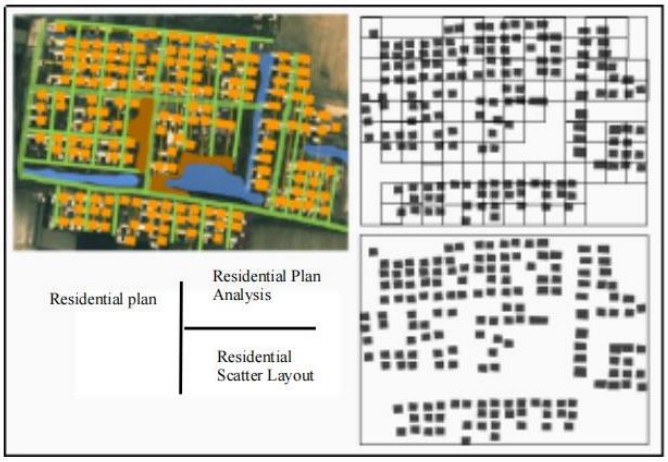

Figure 8: Architectural plane analysis self-drawing

As described above, an analysis of the rural housing clusters has been conducted, and the building clusters can be analyzed not only through the technical dimension of building outlines but also through building details, especially building decorations. In the lower image of Figure 9, the exterior paint of the village buildings replaces the original brick and cement wall textures. Although the overall visual effect is unified, the flatness of the overall building image is slightly weak compared to the original building's varying concave-convex mechanism. By analyzing and extracting the building outlines and drawing on the modeling forms of other traditional houses in the Central Plains region, the building facades in T village can be expressed as shown in Figure 9 (2) and (3). This kind of building style not only enriches the texture but also increases the village's recognizability and avoids the homogeneity of the village design. Compared to the excessive design, uniform height, and uniform building appearance and texture in cities, the beauty of the countryside lies in its complexity and variation. The beauty of the buildings lies in their richness and diversity, and the lack of texture levels is the reason why modern architecture is not widely accepted by the public. The intention diagram shown in Figure 10 relies on the existing public square in T village to meet the functions of public gathering, village entertainment, public waiting, cultural promotion, village notices, and highlight the local traditional agricultural planting culture.

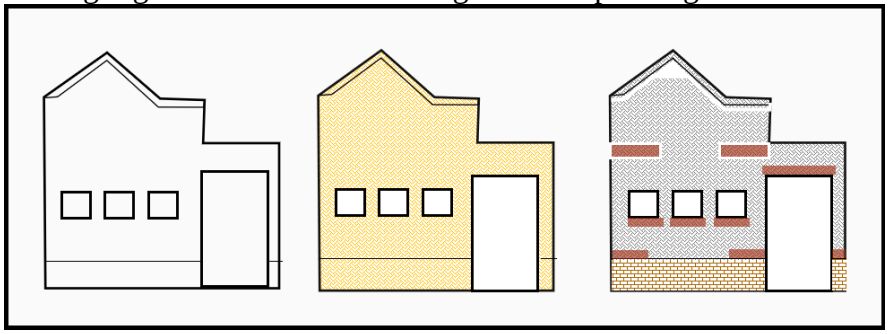

Figure 9: Comparison drawing of building facade decoration

Figure 10: Intention map of T village square Self-drawn

4. Practical strategies for rural housing design

Rural housing serves as the core carrier of rural landscape and delineates the differences and similarities of human settlements with urban order. As a major component of rural construction, rural housing plays an important role in shaping modern rural lifestyles. However, since the reform and opening-up, the advanced consciousness and culture represented by urbanization have shaken the self-confidence of rural culture, resulting in a sudden change in rural housing design, from tile-roofed houses to high-rise buildings, and from bungalows to villas, with housing forms tending towards uniformity. This trend has led to the loss of rural housing's distinctive features and cultural connotations, gradually robbing rural areas of their personality and charm, ultimately affecting their sustainable development.

Therefore, contemporary rural housing design should pay more attention to the protection and inheritance of rural culture, emphasizing the integration of local natural and cultural environments to create architectural forms with regional characteristics and personal charm. Simultaneously, it should avoid simply mimicking urban housing design, and instead, based on the actual needs and lifestyles of rural residents, integrate traditional local culture with modern design concepts to create more practical and sustainable rural housing. Only in this way can rural housing truly become an important carrier of rural culture while making a greater contribution to rural sustainable development.

4.1 Presentation of localized form of residential buildings

Throughout history, human ancestors have constructed local housing architecture based on factors such as climate and natural history conditions. Examples include the cave dwellings on China's Loess Plateau, the mud houses of African natives, and the igloos made of ice by Eskimos. Modern architecture has discovered the charm of self-construction or architecture without architects, as well as the unique and harmonious results that arise when different people produce similar units in different places. This architectural form is common in rural spaces where self-built housing is prevalent. The layout of villages in the plains is typically arranged in a regular pattern, and the visual form of rural architecture is reflected through building facades, with the complexity or simplicity of these facades determining the overall appearance of the village. Through fractal theory, the visual form of villagers' self-built architecture can be analyzed, providing new design forms for

village building styles. When categorizing or designing local architecture, it is important to follow their self-similar characteristics.

Before the reform and opening-up, Central Plains rural housing was characterized by single-story, single-unit enclosed spaces made of thatched straw or mud bricks. After the reform and opening-up, single-story, hard-topped enclosed spaces made of red bricks and blue tiles emerged. In the past two decades, multi-story, hard-topped single-unit enclosed spaces made of concrete and glazed tiles have become more prevalent. These architectural forms reinforce the regionality of the Central Plains, with locally-sourced materials forming the basis of construction and the geography and climate of the area influencing the appearance of building outlines. The emergence of rural housing inevitably involves the fusion of local characteristics.

4.2 Construction of the relationship between man and nature in the space environment

The existing Chinese book on residential architecture, "The Yellow Emperor's Book of Houses," emphasizes the harmonious relationship between humans, housing, nature, and the universe from the construction to the utilization of housing. Ancient Chinese people were accustomed to placing their actions within the context of the universe, believing that all actions must be based on astronomical calendars, choosing appropriate times and spaces to avoid misfortune and seek good fortune based on the combination of heavenly stems and earthly branches. Long (1990) [9]advocates for the building philosophy of the ancient Chinese, where architecture is based on the integration of heaven, earth, and humans and further promotes the cultural and philosophical ideas of combining architecture with the principles of Tao, morality, benevolence, wisdom, justice, and propriety. Here, we see that villages are not just individual buildings but rather a spatial carrier that integrates humans, nature, and ideas. Rural areas are a living community, with "a certain geographical area," "common bonds," "social interaction," and "identity awareness" being basic requirements and features of a living community.

Mandelbrot established fractal theory based on the self-similar characteristics of natural objects such as mountains, coastlines, and cloud layers in nature, as well as mathematical principles of generation. Fractal theory analyzes the form of architecture and the form of natural plant environments. Both natural and artificial forms are products of human adaptation to nature and represent the choices made for survival under human life trajectories. From an artistic perspective, classic independent buildings, urban planning, and rural design are born when natural objects serve as inspiration for design.

4.3 Economic policy and urban development give new opportunities for rural design

Since the reform and opening-up, China's open economic policies have broken the previous closed mode of rural areas. Influenced by factors such as globalization and urbanization, [10]the open economic policy has transformed the rural economy from a self-sufficient subsistence economy to one that is more dependent on urban economies. The influx of advanced urban culture and values has shaken the cultural self-confidence of rural areas. Urban design concepts have entered rural areas before rural areas have had the chance to develop their own design patterns, resulting in new rural housing designs that imitate urban housing - from tile-roofed houses to high-rise buildings, and from farmhouses to villas. This new path of development has deviated from the original trajectory of rural development.

How should rural areas be designed? Since the introduction of the "New Rural" and "Beautiful Countryside" policies in 2005, the Chinese government has provided policy support and investment in rural construction, promoting the healthy development of rural areas. In terms of the transformation of rural social structure, China's basic rural management system has formed a

semi-agricultural and semi-industrial structure based on intergenerational division of labor, which implies a transformation in the function of rural housing,[11] from meeting the needs of farming and storage to providing comfortable living and entertainment environments.

In terms of the development of new technologies and materials, rural housing construction can invest more in smart homes and modular construction to facilitate the promotion and research and development of new technologies. Design can also incorporate more technological functions.[12]

5. Conclusion

Fractal theory is a method used to solve complex problems. Rural dwellings, from individual buildings to villages to landscape plants, have constructed a complex system with different types, functions, and properties. This system corresponds to the system of rural life and culture and is a unified entity. Villages grow linearly along the entrance roads and commercial streets, with the village hall, theater square, and lotus pond forest as spiritual spaces and activity centers, and residential, ceremonial, production, and feng shui buildings as cells and textures. In these complex systems, different structural forms can be obtained by analyzing the architectural design forms using fractal theory. With the help of fractal theory, the rich forms of traditional rural settlements can be reproduced, and the entire rural system can be understood more effectively. Apart from the style of the building itself, exploring the relationship between humans, buildings, and the natural environment, social structure adjustment, economic policy support, new technology application, and the fate of surrounding cities and the global community have all brought new opportunities for the development of rural construction.

Acknowledgement

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References

[1] Zhang J. (2019). Seeking the Path of Rural Construction: A Comparative Study of Liang Shuming and Yan Yangchu's Rural Construction Theories and Practices. (Doctoral dissertation, Zhejiang University).
[2] Junjie Le. (2006). Economic Analysis of China's Rural Labor Market: Zhejiang University Press: 2-5.
[3] Yi H., & Azahari M. H. (2023). The Development Trend of Rural Dwellings in the Central Plains of China Taking County X in H Province as an Example. Indonesian Journal of Art and Design Studies, 2(1), 98-113.
[4] Bovill C. (1996). Fractal Geometry in Architecture and Design.
[5] Mandelbrot B. B. (1982). The Fractal Geometry of Nature. New York: W. H. Freeman.
[6] Helms R. (1980). Illumination Engineering for Energy Efficient Luminous Environments. Englewood Cliffs, NJ: Prentice-Hall.
[7] Ostwald M. J. (2001). "Fractal Architecture": Late Twentieth Century Connections between Architecture and Fractal Geometry. Nexus Network Journal, 3(1), 73-84.
[8] Nicoletta M. (2019). Fractal Geometry and Architecture: Design for Sustainability.
[9] Long Q. (1990). Chinese Architecture and the Chinese Nation. Guangzhou, China: South China University of Technology Press. (pp. 9-15)
[10] Ye L., & Huang Y. (2018). Designing in the Countryside: An Investigation of Rural Construction in the Early Days of Reform and Opening Up (1978-1994). Journal of Architecture and Planning, 35(12), 100-109.
[11] He X. (2014). On the Road of Chinese-style Urbanization and Modernization. China Rural Observation, 1.
[12] Chen Z. (2000). A Conversation Sparked by "On the Complete Chapter of Local Architectural Heritage". Times Architecture, (03), 21.