Research on Innovation of Urban Village Renovation Path Based on Complex Adaptive System Theory

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Abstract: Urban village renovation is a complex project in the process of urbanization, involving dynamic interactions and interest games among multiple subjects. Traditional linear thinking is difficult to cope with its systemic complexity. Based on the Complex Adaptive System (CAS) theory, this paper analyzes the characteristics of the urban village renovation system, such as adaptability, emergence, and nonlinearity, and constructs an analytical framework including subject definition and behavior rules, subject interaction model, and system evolution model. By introducing utility functions, fitness functions, and system evolution functions, the paper quantitatively studies the strategic interactions among various subjects and the laws of system evolution, and presents examples of subject strategic interactions and characteristics of system evolution states in the form of tables. The research proposes paths such as collaborative governance of multiple subjects, flexible planning and design, innovation of interest-sharing and risk-sharing mechanisms, and integration of information technology, so as to provide theoretical support for improving the efficiency and quality of urban village renovation.

Keywords: Complex Adaptive System; Urban Village Renovation; Path Innovation; Subject Interaction; System Evolution

1. Introduction

Urban village renovation is a key link in the process of urbanization to optimize the urban spatial structure and improve urban functions, which involves multiple subjects such as governments, residents, and developers, and the interaction between various subjects is complex and dynamic [1,2]. The traditional urban village renovation path often adopts a linear and static thinking mode, which is difficult to cope with the complexity and dynamics of the transformation system [3]. The Complex Adaptive System (CAS) theory provides a new perspective for understanding and solving this complex problem, emphasizing that the adaptive behavior of individuals in the system is the core driving force of system evolution, and promotes the evolution of the system from simple to complex, from disordered to orderly through the interaction between individuals. Based on this, this paper will use the theory of complex adaptive systems to construct a system model of urban village renovation, analyze the adaptive behavior and system evolution law of each subject, and then put forward the path innovation strategy of urban village renovation, so as to provide theoretical support for improving the efficiency and quality of urban village renovation.

2. Theoretical Basis

2.1 Urban Villages Theories

Urban villages are areas that still retain and implement rural administrative management in urban built-up areas in the process of urbanization [4]. Its formation stems from the contradiction between rapid urbanization and the relatively lagging land system and household registration system. Urban villages have unique characteristics, in terms of space, the building density is extremely high, the layout of houses is chaotic, and there is a lack of reasonable planning; In terms of social structure, aborigines live together with a large number of foreign tenants, and social relations are complex and social management is difficult. Economically, the low-end rental economy and self-employment are dominant, the industrial structure is single, the level of economic

development is low and the stability is lacking [5-7]. These characteristics are intertwined, making urban villages a complex socio-economic spatial unit, and their transformation involves many complex issues such as land ownership change, housing demolition compensation, resident resettlement, industrial upgrading, and infrastructure construction [8].

2.2 Complex Adaptive Systems (CAS) Theory

The theory of complex adaptive systems was developed by Holland, which argues that a system is made up of a large number of adaptive subjects that are able to constantly adjust their behavior in response to changes in the environment and interactions with other subjects. The system has the characteristics of adaptability, emergence, nonlinearity, feedback mechanism, and self-organization. In complex adaptive systems, the adaptive behavior of the subject is the key driving force for the evolution and development of the system [9,10]. Applying this theory to the field of urban research, the city could be regarded as a complex adaptive system, in which residents, enterprises, governments and other subjects shape the development trajectory of the city through interaction. In the context of urban village renovation, CAS theory is helpful to deeply understand the behavioral logic of various stakeholders and the dynamic interaction relationship between subjects in the renovation process, and provides a theoretical basis for formulating scientific and reasonable renovation strategies.

3. Construction of Urban Village Renovation Model Based on CAS Theory

3.1 System Element Composition and Interaction Relationship

According to CAS theory, the urban village renovation system is composed of the Subject layer, the interaction rule layer and the environment layer, and the specific content and mechanism of each element are shown in **Table 1**:

Table 1. Urban Village Renovation Model Based on CAS Theory

System Layer	Core Elements	Mechanism of Action
Subject Layer	Government	Set the boundaries of transformation through policy formulation and reduce coordination costs through financial subsidies
	Developers	Invest capital and technology to pursue reasonable profit returns
	Residents	Influence the renovation plan through voting, consultation, etc., and protect asset rights and interests
Interaction Rules Layer	Policy Rules	Standardize the legality of the subject's behavior and reduce transaction costs
	Economic Rules	Adjust the pattern of benefit distribution, encourage subject cooperation, and improve efficiency
	Social Rules	Maintain social network stability, reduce the probability of conflict, and reduce disputes
Environment Layer	Policy Environment	Guide the flow of resources and set the priority of transformation
	Market Environment	Affect the income expectations of the main body and adjust investment and consumption strategies
	Social Environment	Shape the subject's behavioral preferences and affect the intensity of cooperation willingness

3.2 Subject Definition and Rules of Conduct

3.2.1 Government (G)

The goal is to optimize urban planning, stabilize society, and maximize public benefits. Its rules of conduct include formulating renovation policies, approving renovation plans, supervising the renovation process, and coordinating the interests of all parties. The government's strategy set is $S_G = \{S_{G1}, S_{G2}, \cdots, S_{Gn}\}$, where S_{Gi} represents the government's i-th strategy, such as raising compensation standards and improving public service facilities.

3.2.2 Residents (R)

The goal is to obtain reasonable compensation and resettlement to protect their quality of life and interests. Its rules of conduct include participating in renovation consultations, expressing interests, cooperating with renovation work, or resisting unreasonable renovation plans. The set of residents' strategies is $S_{\mathrm{R}} = \{S_{\mathrm{R}1}, S_{\mathrm{R}2}, \cdots, S_{\mathrm{R}m}\}$, where $S_{\mathrm{R}j}$ represents the residents' j-th strategy, such as accepting compensation plans, requesting additional compensation, etc.

3.2.3 Developers (D)

The goal is to obtain reasonable profits and maximize the return on investment. Its rules of

conduct include participating in the bidding of renovation projects, formulating development plans, organizing construction and construction, and selling renovated properties. The developer's strategy set is $S_D = \{s_{D1}, s_{D2}, \cdots, s_{Dk}\}$, where S_{Dl} represents the developer's lth strategy, such as increasing investment, adjusting the development type, etc.

3.3 Subject Interaction Model

Suppose that in the urban village renovation system, the interaction between the government, residents and developers could be expressed as a utility function. The utility function of the government is U_G, the utility function of residents is U_{R}, and the utility function of the developer is U_D, which are the functions of each subject's own strategy and other subject strategies.

$$U_G = f_G(S_G, S_R, S_D) \quad (1)$$

$$U_{\mathrm{R}} = f_R(S_G, S_R, S_D) \quad (2)$$

$$U_D = f_D(S_G, S_R, S_D) \quad (3)$$

Each subject continuously adjusts its own strategy to maximize its own utility. During the interaction, the subject will update its own policy according to the policy changes and environmental information of other subjects. When residents adopt a strategy of resisting renovation, the government may adjust compensation policies and raise compensation standards to improve the utility of residents and encourage them to accept renovations.

3.4 System Evolution Model

In order to describe the evolution process of urban village renovation system, the fitness function of the subject is introduced. The fitness function is used to measure the subject's ability to survive and develop in the system, and the higher the fitness, the stronger the subject's ability to survive and develop. The fitness of the government is F_G, the fitness of residents is F_R, and the fitness of developers is F_D, which are related to the utility function of each subject:

$$F_G = \alpha_G U_G \quad (4)$$

$$F_R = \alpha_R U_R \quad (5)$$

$$F_D = \alpha_D U_D \quad (6)$$

where in, α_G、α_V、α_D are the fitness coefficients of governments, residents, and developers, respectively, reflecting the influence of the utility function on the fitness.

The evolution state of the system could be expressed as the rate of change of the fitness of each subject. If the system evolution state is *V*, then the following:

$$V = \beta_G \frac{dF_G}{dt} + \beta_R \frac{dF_R}{dt} + \beta_D \frac{dF_D}{dt} \quad (7)$$

In which, β_G、β_R、β_D are the weights of the rate of change in the fitness of the government, residents, and developers on the evolution state of the system, respectively, and $\frac{dF_G}{dt}$、$\frac{dF_R}{dt}$、$\frac{dF_D}{dt}$ are the rates of change of the fitness of the government, residents, and developers respectively. The system evolution V are shown in **Table 2**.

Table 2. System Evolution V

System Evolution V	System status	Features
V>0	Development	The adaptability of each subject has been improved, the transformation has progressed smoothly, the urban space has been optimized, and social harmony has been achieved
V=0	Stable	The adaptability of each subject has changed steadily, and the transformation progress has been slow, and there are no obvious contradictions
V<0	Decline	The adaptability of each subject is declining, the transformation is hindered, and social instability factors may occur

4. Model-Based Innovation of Urban Village Renovation Path

4.1 Design Flexible Transformation Planning Scheme

Considering the nonlinearity and emergence of the urban village renovation system, a flexible renovation planning scheme is designed to adapt to the dynamic changes of the system. The first is to adopt a modular planning method. The urban village renovation area is divided into several modules, each with relatively independent functions and construction requirements. According to the evolution and

actual needs of the system, the function and construction timing of the module could be adjusted to improve the flexibility and adaptability of planning. The second is to reserve flexible development space: reserve a certain amount of flexible development space in the renovation plan, such as reserving part of the land for future public facility construction, industrial development or ecological protection. The reservation of flexible development space can respond to new needs and problems that arise in the process of system evolution. The third is to introduce a dynamic evaluation mechanism: establish a dynamic evaluation mechanism for the transformation plan and regularly evaluate the implementation effect of the plan. According to the evaluation results, the problems in the planning are discovered in a timely manner, and adjustments and optimizations are made to ensure the scientific and feasibility of the plan.

4.2 Establish A Multi-Subject Collaborative Governance Mechanism

Based on the characteristics of subject adaptability and interaction in the theory of complex adaptive systems, a multi-subject collaborative governance mechanism is constructed to promote effective communication and cooperation between governments, residents, developers and other subjects. The first is to establish a collaborative decision-making platform. Build a collaborative decision-making platform composed of the government, resident representatives, developers, social organizations, etc., and hold regular meetings to discuss and solve major problems in the renovation process. Information sharing is achieved through the platform to improve the transparency and scientific nature of decision-making. The second is to improve the interest coordination mechanism. Establish and improve the interest coordination mechanism, and clarify the interests of each subject and the distribution method. When formulating renovation policies and programs, fully consider the compensation and resettlement needs of residents, the reasonable profit margins of developers, and the government's public interest goals, and achieve a balance of interests through consultation and negotiation. The third is to strengthen the dynamic adjustment mechanism. According to the actual situation in the transformation process and the feedback of various subjects, adjust the transformation policies and plans in a timely manner. For example, when the market environment changes, adjust the developer's investment return expectations in a timely manner; When residents' interests and demands change, the compensation standards and resettlement plans should be revised in a timely manner.

4.3 Innovate the Mechanism of Benefit Sharing and Risk Sharing

Based on the relationship between subject fitness and system evolution state in the system evolution model, the benefit sharing and risk sharing mechanism is innovated to improve the fitness of each subject and the evolution state of the system. The first is to establish a benefit-sharing fund: set up a benefit-sharing fund for urban village renovation, and include part of the value-added income generated during the transformation process into the fund to improve residents' living conditions, improve public service facilities, and support regional industrial development. Through benefit sharing, improve the support and participation of residents and other subjects in the transformation. The second is to design diversified risk sharing methods: according to the roles and risk tolerance of each subject in the transformation process, design diversified risk sharing methods. For example, the government bears policy risks and social risks, developers bear market risks and construction risks, and residents bear some relocation risks. Through risk sharing, reduce the risk pressure of each subject and improve the feasibility of the renovation project. The third is to establish a risk early warning and response mechanism: establish a risk early warning and response mechanism to identify, assess and warn of possible risks in the transformation process. Formulate corresponding response plans, and when risks occur, timely measures could be taken to reduce risk losses.

4.4 Promote the Deep Integration of Information Technology and the Transformation Process

The advantages of information technology should be used to improve the information processing ability and interaction efficiency between subjects of the urban village renovation system, and promote the benign evolution of the system. The first is to build a digital transformation management platform. Build a

digital transformation management platform to realize the digital management of the whole process of transformation projects. Through the platform real-time monitoring of transformation progress, quality, safety, etc., problems are discovered and solved in a timely manner. At the same time, the platform provides channels for information inquiry and interaction for various subjects, improving the efficiency of information sharing and collaborative work. The second is the application of big data analysis technology. Use big data analysis technology to collect, sort and analyze various data in the process of urban village renovation, such as residents' interests, market demand, environmental changes, etc. Through data analysis, it provides decision-making support for the formulation of transformation policies, optimization of planning plans, and coordination of interests. The third is the introduction of artificial intelligence technology. Introduce artificial intelligence technology, such as intelligent decision support systems and intelligent prediction models, to improve the scientific decision-making and prediction accuracy in the transformation process. For example, the intelligent prediction model is used to predict the return on investment and risk of the renovation project to provide reference for the developer's investment decision.

5. Conclusions

Based on the theory of complex adaptive systems, this paper conducts in-depth research on urban village renovation, constructs a system model of urban village renovation including subject definition and behavior rules, subject interaction model and system evolution model, analyzes the adaptive behavior and system evolution law of each subject, and puts forward corresponding path innovation strategies. The results show that the urban village renovation system is a complex adaptive system, and the adaptive behavior and interaction of each subject promote the evolution of the system. By constructing a multi-subject collaborative governance mechanism, designing flexible transformation planning schemes, innovating benefit sharing and risk sharing mechanisms, and promoting the deep integration of information technology and the transformation process, the adaptability of each subject and the evolution state of the system could be improved, and the smooth progress of urban village renovation and the healthy development of the system could be promoted.

Future research could further improve the urban village renovation system model, consider more influencing factors and subject types, such as environmental organizations and financial institutions, and improve the accuracy and applicability of the model. At the same time, the effectiveness of the path innovation strategy could be verified through empirical research, and more specific guidance could be provided for the practice of urban village renovation.

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