Dilemmas and Optimization Paths of Digital Rural Construction from the Perspective of Complex Adaptive Systems Theory

Yilun Gai
Nanjing Agricultural University, Nanjing, Jiangsu, China

Abstract: Combined with the Complex Adaptive Systems theory, this paper explores the practical problems and optimization paths of digital rural construction. Currently, digital rural construction faces issues such as insufficient digital literacy of villagers, disconnection between technology and actual needs, poor collaboration among multiple subjects, and weak support for funds and talents. To address these problems, this paper proposes optimization suggestions from the aspects of subject collaboration, technology integration, institutional guarantee, and model innovation, emphasizing the importance of villagers' participation, adapting measures to local conditions, and long-term resilience, while avoiding a one-size-fits-all approach and formalism. This paper argues that digital rural construction should go beyond mere technology introduction and shift towards a people-oriented, systematically promoted and sustainable development path. In the future, strategy design should focus on encouraging grassroots innovation and safeguarding villagers' rights and interests, and technical applications should integrate humanistic care and local characteristics, thereby truly enhancing the adaptability and endogenous motivation of rural areas in the digital age.

Keywords: Complex Adaptive Systems; Digital Empowerment; Rural Construction; Systematic Thinking

1. Introduction

Comprehensively promoting rural revitalization and accelerating the modernization of agriculture and rural areas have become important strategic tasks in China at present and in the future. As a key practical path for rural revitalization, digital rural construction is a core starting point for promoting the modernization of agriculture and rural areas, narrowing the urban-rural digital divide, and achieving common prosperity. However, in the process of practical advancement, digital rural construction is confronted with a series of structural dilemmas that urgently need to be resolved. On the one hand, during the construction process, problems such as the disconnection between technology and the actual needs of rural areas, poor collaboration among multiple subjects, and weak support for funds and talents often arise, leading to low utilization rates and poor sustainability of some digital facilities, and even exacerbating digital exclusion among certain groups. On the other hand, existing practices mostly focus on hardware investment and technological application, often ignoring the inherent complexity, dynamics, and self-organization of rural society, resulting in homogenized construction models and disconnected governance. These problems collectively indicate that digital rural construction is far more than a simple project of technology introduction or project implementation, but a complex systematic project involving profound transformations in multiple dimensions such as economy, society, governance, and culture. Therefore, there is an urgent need to transcend traditional linear thinking and a single technical perspective, and seek a more systematic and dynamically adaptive theoretical framework to guide practice. The CAS theory provides a powerful analytical perspective for this purpose. Some scholars have attempted to use this theory to analyze the spatial evolution of rural e-commerce, the internal logic of digital empowerment for rural revitalization, and the construction of digital rural resilience, revealing the important roles of multiple subjects, flowing factors, and system self-organization in the development of digital rural areas. However, research on analyzing digital rural construction using the CAS theory is still in the preliminary exploration stage, with a relatively small number of studies in this field, leaving more research space. Based on this, this paper takes the CAS theory as the overarching

Copyright @ STEMM Institute Press

analytical framework, systematically explores the core issues existing in digital rural construction, and proposes optimization paths, inspirations and reflections, aiming to promote the practice of digital rural construction towards a new stage of greater adaptability and vitality, and provide systematic thinking support for the implementation of the rural revitalization strategy.

2. Literature Review

2.1 Core Essentials and Research Evolution of Complex Adaptive Systems Theory

The CAS theory was proposed by J.H. Holland. Its core idea is to attribute the root cause of system complexity to the interactions among a large number of active adaptive agents within the system. In his foundational work, Holland described a complex adaptive system as a dynamic network composed of many agents that operate in parallel and continuously respond to the behaviors of other agents. The control of the entire system is highly decentralized, and any coherent system behavior must arise from the spontaneous competition and cooperation among agents. This theory transcends the traditional view of systems as static structures or linear causal chains, and instead emphasizes that adaptive learning of agents is the fundamental driving force for system evolution. Agents accumulate experience through interactions with the environment and other agents, and then modify their own behavioral rules, i.e., internal models. This continuous adaptive process ultimately leads to the emergence of novel and unpredictably simple patterns and orders at the overall system level. Centering on adaptability, Holland further elaborated on seven basic characteristics, including aggregation, nonlinearity, flows, diversity, tagging, internal models, and building blocks, which collectively constitute a conceptual system for analyzing the evolutionary mechanisms of complex systems[1].

With the development of the theory, the application scope of CAS theory has expanded from the initial fields of biology and computer science to many social system analyses involving multi-agent interactions, such as economics, management, sociology, and urban-rural research. In the spectrum of system science methodologies, the CAS theory, with its emphasis on agent initiative, system self-organization, and dynamic evolution, provides a powerful perspective beyond the traditional for understanding socio-economic processes full of uncertainty and change.

2.2 Research Context and Core Issues of Digital Rural Construction

As a key practical field of the rural revitalization strategy, academic research on digital rural construction presents clear phased evolutionary characteristics. Early research mostly started from the perspective of policy tools and technological applications, regarding digital technology mainly as an advanced means to improve efficiency and bridge the urban-rural information gap. Scholars' concerns focused on hardware construction and initial applications, emphasizing how the popularization of infrastructure such as broadband networks and mobile communications directly improves the intelligence level of agricultural production and the digitalization of rural governance[2]. With the deepening of digital technology's integration into rural society, the focus of research has gradually shifted from efficiency improvement to broader socio-cultural impacts. Some scholars have begun to pay attention to the reshaping effect of digital technology on the existing social structure and power relations in rural areas, such as how digital governance platforms change the interaction mode between grassroots governments and villagers, and the alienation phenomena such as formalism or disconnected governance that may be caused by technological applications[3]. At the same time, the collision and integration between digital culture and local culture have become an emerging issue. Studies explore how standardized digital logic adapts and integrates with traditional rural social networks based on human relationships and geographical ties[4]. In recent years, facing the uncertainty of the internal and external environment, the resilience construction and sustainable development paths of digital rural areas have begun to attract more attention. Research attempts to explore the adaptability and recovery mechanisms of rural digital systems in response to economic fluctuations and social risks[5]. These multi-dimensional and multi-level issues collectively indicate that digital rural construction is far more than a simple technology introduction project, but a complex social process involving profound economic transformation, governance reform,

 Copyright @ STEMM Institute Press

and cultural adaptation.

2.3 Application and Enlightenment of Complex Adaptive Systems Theory in Digital Rural Research

Although systematic research on digital rural areas from the perspective of CAS theory is still developing, some scholars have conducted insightful explorations, which have initially demonstrated the explanatory potential of this theoretical framework. These explorations generally proceed along several interrelated paths.

Some studies focus on using the core concepts of CAS theory, such as agent heterogeneity and adaptive interaction, to analyze the behavioral logic and collaborative dilemmas of multiple agents in digital rural construction. For example, some scholars have constructed a four-dimensional analytical framework including agents, technology, services, and the environment, pointing out that if the differences in goals and capabilities among different agents are not effectively integrated, the overall system functions will be limited[6]. Other scholars have revealed through the phenomenon of disconnected governance that when the rigid logic of digital technology fails to effectively embed with the flexible organizational culture of rural society, adaptive failure will occur where digital technology is disconnected from governance practice[7]. Another path of research focuses on analyzing how the flow of digital factors drives the evolution of rural spatial structures and industrial forms. Through a case study of typical Taobao villages in Hebei Province, some scholars have revealed how factor flows such as information, logistics, and capital have promoted the phased emergence of rural space from point-like to networked agglomeration under the action of e-commerce platforms[8]. Scholars have also regarded urban-rural integration as a complex adaptive system, analyzing how digital technology promotes more efficient flow of various factors among heterogeneous urban-rural agents, thereby spurring the spontaneous emergence of new orders for integrated development[9]. Additionally, research has focused on the value of the CAS theory for understanding and constructing digital rural resilience. From the perspective of risk governance, it points out that the resilience of digital rural areas depends on whether multiple internal agents such as the public service system, grassroots political power, social organizations, and villagers can form a dynamic learning and collaborative adaptive network, which is essentially the core mechanism of CAS theory in responding to external shocks[10].

These studies from different aspects indicate that understanding digital rural areas as complex adaptive systems helps to go beyond the single discussion of technology and instead focus on the dynamic evolutionary process of inter-agent relationships, interaction rules, and overall structures within the rural system after the intervention of technology, providing a more systematic analytical tool for grasping its in-depth operational logic.

2.4 Literature Review

Overall, initial progress has been made in applying the CAS theory to digital rural research, but this field is still in the stage of exploration and deepening, with several areas for further advancement. Although existing research has demonstrated the insight of the CAS theory on local issues, most of them focus on using one or several core concepts of the theory, such as agent interaction or emergence, to explain specific digital rural phenomena or dilemmas. While this application method is enlightening, there is still room for improvement in terms of systematicness and integration.

In this context, this paper aims to draw on the core essentials of the CAS theory more systematically and comprehensively, to systematically examine the interrelated deep-seated issues in digital rural construction, such as the adaptive differences among multiple agents, the obstruction of key factor flows, the imbalance in the evolution of interaction rules, and the insufficient cultivation of system diversity. On this basis, it proposes optimization paths and reflections, hoping to provide a reference and enlightenment with both theoretical thinking and practical insights for deepening the application of the CAS theory in the vivid field of digital rural areas and promoting the practice of digital rural construction towards a more inclusive and sustainable stage of system adaptation.

3. Compatibility between Complex Adaptive Systems Theory and Digital Rural Construction

Copyright @ STEMM Institute Press

As an open system composed of interactions among multiple agents and continuous evolution, digital rural areas have a high degree of inherent compatibility with the CAS theory, especially reflected in the operational logic of its seven core components. From the perspective of the "aggregation" mechanism, heterogeneous agents such as governments, enterprises, villagers, and social organizations form collaborative networks through digital platforms, promoting the emergence of system functions such as governance and industry. "Nonlinear" interaction reveals that the interaction among various agents in digital rural areas is not a simple linear superposition; the behavior among agents is multi-directional and the evolution of behavior is unpredictable. For example, the introduction of a digital technology may stimulate innovative applications by villagers, or encounter resistance due to conflicts with local culture, making the system development present multi-path characteristics. The dimension of "flows" points to the continuous input and circulation of factors such as funds, information, talents, and technology in digital rural areas, forming the material basis and driving force for system evolution. "Diversity" means that rural areas have natural diversity in terms of geographical environment, industrial types, cultural customs, etc. Digital rural construction needs to respect and utilize this difference, avoiding homogenized models. The higher the system diversity, the stronger its ability to respond to external shocks and internal changes. The "tagging" mechanism is reflected in the role labels and trust identification of various agents in the digital environment, which can reduce collaboration costs and promote precise interaction. The "internal model" refers to a set of learning and behavioral rules based on experience formed by each agent in the process of participating in digital rural construction, such as villagers accumulating sales strategies through e-commerce practices and governments optimizing policy tools through pilot projects. The "building blocks" structure is manifested as modules for reorganizing different functions within the system, such as smart agriculture and digital governance platforms, supporting the system to achieve innovative upgrading through module iteration. Overall, digital rural areas are essentially complex adaptive systems with self-organization, self-adaptation, and dynamic evolution capabilities. Their construction should emphasize the collaboration and optimization of various internal elements of the system, so as to achieve sustainable development in a dynamic environment. Analysis through the CAS theory is reasonable.

4. Practical Dilemmas of Digital Rural Construction from the Perspective of Complex Adaptive Systems Theory

4.1 Insufficient Agent Adaptability Leading to Weakened "Aggregation" Effect

In the CAS theory, "aggregation" is the foundation for agents to form synergistic effects, but the adaptive differences among multiple agents in digital rural construction lead to aggregation failure. On the one hand, as the core agents, villagers have significant shortcomings in digital literacy and adaptive capacity. Some villagers struggle to integrate into digital production and living scenarios, and even develop resistance to digital platforms. On the other hand, governments copy standard models mechanically, ignoring the adaptive needs of villagers, resulting in low platform utilization rates and insufficient willingness of agents to participate. In addition, the lack of participation of social organizations further weakens the cohesion of agent aggregation. A network of collaborative governance among multiple agents has not yet been formed, making it difficult to exert the scale effect and synergistic effect brought by aggregation in the CAS theory.

4.2 Obstructed Factor Flows Causing Blockage of "Flows"

The smooth flow of "flows" is a key driving force for the evolution of CAS. There are blocking problems in the capital flow, information flow, talent flow, and technology flow in digital rural construction. From the perspective of capital flow, the funds for digital rural construction mainly rely on government financial investment, with insufficient participation of social capital, leading to a single and unsustainable supply of funds. From the perspective of information flow, the phenomenon of "data silos" is prominent. A large amount of data is scattered across different departments and platforms, lacking a unified sharing mechanism, so information cannot flow and integrate effectively. From the perspective of talent flow, there is a shortage of compound talents who understand digital technology and

 Copyright @ STEMM Institute Press

are familiar with rural reality, making it difficult for technology flow to be transformed into actual productivity. From the perspective of technology flow, there is a mismatch between the supply of digital technology and rural needs, and technology has not been effectively embedded into rural production and living scenarios.

4.3 Imbalanced "Nonlinear Interaction" Leading to Deviation of Innovation Effects from Expectations

The CAS theory emphasizes that nonlinear interaction among agents is the core for the emergence of innovative forms in the system, but there is an imbalance in interaction in digital rural construction. Firstly, the rigid governance led by the government suppresses the independent adaptability of villagers. In some areas, digital rural construction is simplified into indicator assessment, ignoring the actual needs and right to participation of villagers. Secondly, there is a conflict between the market logic of enterprises and the public value logic of rural areas. Enterprises pursue short-term economic benefits and tend to layout profitable areas such as e-commerce and live broadcasting, while the investment in digital technology in public areas such as rural ecological protection and cultural inheritance is insufficient. Thirdly, there is a conflict between technical rationality and local culture. The standardized and procedural characteristics of digital technology are inconsistent with the cultural characteristics of rural areas such as "differential order pattern" and "human relationship society", leading to insufficient adaptability between technological applications and rural society.

4.4 Lack of "Tagging" Mechanism and Insufficient "Diversity" Restricting System Evolution

"Tagging" is the key for agents to identify and select interaction objects in the CAS theory. However, digital rural construction currently lacks differentiated tagging systems. Some areas blindly imitate the construction models of other regions, ignoring local resource endowments and industrial characteristics, resulting in serious homogenization of digital rural construction. "Diversity" is the foundation for the system to resist risks and achieve evolution, but the current development model of digital rural areas is single, mostly focusing on the e-commerce industry. There is insufficient innovation in fields such as digital culture, digital ecology, and digital governance, and the system's ability to respond to external shocks such as market fluctuations and policy adjustments is weak.

5. Optimization Paths of Digital Rural Construction from the Perspective of Complex Adaptive Systems Theory

5.1 Construct a Multi-Agent Co-Governance Network to Activate the Effectiveness of Collaborative Governance

Collaboration among multiple agents is the key to digital rural governance. Clarify the guiding role of the government, which is responsible for formulating plans, coordinating infrastructure, and allocating resources, promote the extension of "Internet + government services" to villages, and build an integrated rural management platform. Activate the main role of villagers, encourage their participation in the decision-making of public affairs and rural construction, and carry out digital skills popularization training to bridge the digital divide. Strengthen the enabling role of enterprises, attract e-commerce and technology enterprises to participate in the digitalization of rural industries, and reduce the technical use costs of small-scale farmers through sharing models. Gather social collaborative forces, link universities and research institutes to provide technical guidance, and guide public welfare organizations and returned talents to provide services at the grassroots level.

5.2 Promote In-Depth Technology Integration to Resolve the Mismatch between Supply and Demand

Technology integration should focus on demand orientation. Firstly, consolidate the infrastructure foundation, promote the full coverage of 5G and the Internet of Things in rural areas, renovate traditional facilities, and build an integrated urban-rural data sharing platform. Secondly, focus on industrial transformation, apply the Internet of Things and big data to precision planting and breeding, promote intelligent agricultural machinery and blockchain traceability, and develop new formats such as rural e-commerce and VR rural tourism. Thirdly, optimize governance services, improve governance efficiency through

Copyright @ STEMM Institute Press

intelligent security inspections, build remote medical care and smart education platforms, and realize the sinking of high-quality resources between urban and rural areas. Fourthly, promote technology adaptation, develop lightweight and easy-to-operate rural digital products, establish a closed loop of "demand, R&D, and implementation", and reduce application thresholds through sharing models.

5.3 Improve the Institutional Guarantee System to Consolidate the Foundation for Digital Transformation

Institutional improvement is the support for the sustainable development of digital rural areas. In terms of investment mechanisms, establish a diversified fund system, the government sets up special funds for digital rural construction, provides risk compensation for social capital participating in rural digital industries, and promotes digital inclusive finance to solve the financing difficulties of farmers and micro-enterprises. In terms of data systems, introduce rural data sharing standards, build county-level data sharing and exchange platforms, and clarify the sharing scope and security specifications of different data. In terms of talent systems, implement a digital rural talent plan, attract digital talents to rural areas through subsidies for returning entrepreneurship and housing preferences, and regularly carry out training for local digital talents. In terms of assessment systems, abandon the "only indicator theory", include villagers' satisfaction and the practical value of digital technology into the assessment system, and avoid digital formalism.

5.4 Cultivate Differentiation and Diversity to Enhance the System's Risk Resistance Capacity

Diversity is the core for digital rural areas to respond to external shocks. Differentiated layout at the industrial level: agricultural main producing areas focus on smart planting and digitalization of cold chain logistics, ecologically advantageous areas develop digital cultural tourism and health care industries, and remote areas strengthen e-commerce assistance for agriculture and basic network coverage. Precise supply at the service level: optimize digital service interfaces for vulnerable groups, provide shared technical services for small-scale farmers, and customize integrated solutions for large-scale operation entities. Localized innovation at the model level: encourage the development of digital collections and characteristic agricultural product IPs combined with regional culture, and promote digital governance models that are in line with local resource endowments.

6. Multi-Dimensional Enlightenments of Complex Adaptive Systems Theory for Digital Rural Construction

6.1 Adhere to a Systematic and Holistic View to Coordinate the Evolution of Multiple Factors

The CAS theory emphasizes that a system is an organic whole composed of interrelated and co-evolving multiple factors. If digital rural construction only focuses on a single dimension such as technology introduction, hardware installation, or industrial digitalization, while ignoring related factors such as talent training, institutional adaptation, and cultural integration, it is likely to lead to internal imbalance of the system, resulting in problems such as idle technology, disconnected governance, or cultural disconnection. Therefore, digital rural areas must be regarded as a complex network of interlocking and co-evolving factors such as technology, agents, institutions, and culture. Planning and promotion should be carried out from an overall perspective to promote positive interaction and coordinated development among various factors.

6.2 Shift to Nurturing Governance to Stimulate the Endogenous Motivation of the System

As a complex adaptive system with self-organizational characteristics, the development of rural areas cannot rely entirely on external design and intervention. The traditional top-down promotion model pursuing standardization often inhibits the adaptability and creativity of the grassroots. Digital rural construction should draw more on the nurturing wisdom of gardeners, abandon detailed directive policies, and shift the focus of policies to creating conditions for the release of the system's endogenous motivation. This includes shifting the focus of investment from simple hardware installation to the cultivation of people's digital literacy in terms of resource supply; protecting the legitimate income of villagers in digital production and digital

 Copyright @ STEMM Institute Press

transactions in terms of institutional guarantee to stimulate the enthusiasm for grassroots innovation; and building an open and inclusive negotiation platform in terms of governance mechanisms to allow governments, enterprises, villagers, and social organizations to engage in equal dialogue and promote multi-agent independent exploration and adaptive innovation based on local contexts.

6.3 Deepen Rights Empowerment to Ensure Inclusive and Shared Technology

Digital empowerment is often simplified as the accumulation of hardware and software, but this materialized thinking is likely to bring risks. If digital technology only strengthens the control power of powerful agents and fails to be transformed into practical capabilities and rights that can be mastered, used, and benefited from by the majority of villagers, then this kind of empowerment will not only have limited effects but may also widen the digital divide and social inequality. The CAS theory focuses on agent adaptive differences and interactive fairness. Therefore, the core of true digital empowerment is to make technology a tool for villagers to improve their well-being, participate in governance, and develop production. This requires adhering to demand orientation and participatory design throughout the entire process of technology R&D and application. For example, designing simpler operation interfaces and dialect interaction functions for elderly villagers, providing lightweight and low-cost smart agricultural solutions for small-scale farmers, and extensively absorbing feedback from different groups in the development of digital platforms. The ultimate criterion for technological development is whether it effectively enhances the sense of gain, security, and development rights of the majority of villagers in the digital age.

6.4 Tolerate Orderly Trial and Error to Promote Dynamic System Adjustment

The evolution of complex systems is full of uncertainty and cannot be fully controlled through a perfectly preset blueprint. Trying to eliminate all errors and enforce a single model often inhibits the system's innovation vitality and adaptive capacity. Facing the diverse geographical conditions and development foundations, digital rural construction particularly needs strategic patience and policy tolerance. Therefore, the government should encourage and protect diverse and differentiated explorations by localities based on their own resource endowments, industrial characteristics, and cultural traditions. It can set up policy pilot projects or experimental zones to allow localities to try different digital rural construction models within a reasonable error-tolerance space. At the same time, establish an effective experience summary and learning mechanism, and regard some local and healthy failures as valuable knowledge assets to feed back and optimize the overall policy design. The maturity of digital rural areas must be a dynamic evolutionary process that combines top-down guidance and bottom-up exploration, and gradually approaches the goal through continuous trial and error, learning, and adjustment.

6.5 Adhere to People-Oriented Approach to Balance Technical Efficiency and Human Development

Digitalization can undoubtedly improve the efficiency of rural governance and production, but if the optimization of efficiency or the improvement of data indicators is regarded as the sole pursuit, it may fall into the dilemma of technological alienation, ignoring that the fundamental goal of rural construction is the happy life and all-round development of people. The CAS theory pays attention to both system functions and agent well-being and system sustainability. Therefore, digital rural construction must always place humanistic care at the core and seek a balance between efficiency and warmth. This means that while promoting digitalization, special attention should be paid to the needs of vulnerable groups such as the elderly and low-digital-literacy groups, retaining necessary offline service channels and interpersonal interaction methods to avoid digital exclusion. In algorithm design and platform rules, careful consideration should be given to their social impacts to prevent algorithmic bias from exacerbating inequality within rural areas. In digital governance, we should adhere to a people-centered approach, not simplifying villagers into data points, but maintaining emotional connections and community warmth through a combination of online and offline methods. Technological progress is a means; enabling every rural resident to live a more dignified and caring life

Copyright @ STEMM Institute Press

in the digital age is the most fundamental value orientation and ethical bottom line of digital rural construction.

7. Conclusion

Digital rural construction is a profound systematic transformation. Its complexity and dynamics require us to take the CAS theory as a guide and promote it in a coordinated manner from multiple dimensions such as agent adaptability, technology integration, and institutional collaboration. The report of the 20th National Congress of the Communist Party of China has pointed out the direction for rural revitalization, and the CAS theory has provided methodological support for us. In the future, the success of digital rural areas will not only depend on the improvement of infrastructure or the breakthrough of individual technologies, but more fundamentally on whether a rural development system with resilience, inclusiveness, and continuous learning capabilities can be shaped. We should proceed from a systematic and holistic view, form a positive interaction between top-down guidance and bottom-up innovation, and seek a dynamic balance between technical efficiency and humanistic care, ultimately promoting rural areas to truly achieve the improvement of endogenous motivation and sustainable development in the digital age.

References

[1] Holland J H. Adaptation in Natural and Artificial Systems. Cambridge, M.A.: MIT Press, 1992.

[2] Shen F W, Ye W X. Digital Rural Construction: Strategic Choice for High-Quality Rural Revitalization. Journal of Nanjing Agricultural University (Social Sciences Edition), 2021(5):41-53.

[3] Jia X F. The Suspension Phenomenon of Digital Rural Construction: Multi-Dimensional Representation, Cause Exploration and Solution Path. E-Government, 2024(3):1-11.

[4] Lu Y L. "Digital Going to the Countryside": Experience, Dilemmas and Directions of Digital Rural Construction. Social Science Research, 2022(3):126-134.

[5] Wen J, Liu Y H. Rural Digital Construction Facing Uncertainty and Its Practical Enlightenment. Journal of Northwest A&F University (Social Sciences Edition), 2022(5):62-71.

[6] Zhou X L, Wang J A. The Internal Logic and Realization Path of Digital Empowerment for Rural Revitalization—An Analysis Based on the Complex Adaptive Systems Theory. Journal of East China University of Technology (Social Sciences Edition), 2024, 43(01):64-72.

[7] Gai H W, Zhang W Y. Rural Digital Transformation and Governance Suspension—An Analytical Framework Based on the Complex Adaptive Systems Theory. Journal of Tianjin Administration Institute, 2023, 25(04):41-49.

[8] Gu Y F, Ding J H, Wu Y H, et al. Research on the Spatial Evolution and Influencing Factors of Rural E-Commerce Based on the Complex Adaptive Systems Theory—A Case Study of Taobao Villages in Hebei Province. Geographical Research, 2024, 43(10):2721-2743.

[9] Li B, Hong Z N. The Realization Mechanism of Digital Technology Empowering Urban-Rural Integrated Development from the Perspective of Complex Adaptive Systems. Journal of Northwestern Polytechnical University (Social Sciences Edition), 1-8[2025-11-23].

[10] Hu W W, Wei K X. Multiple Logics and Realization Paths of Digital Rural Resilience Construction from the Perspective of Complex Adaptive Systems Theory. Journal of Northwest A&F University (Social Sciences Edition), 2025, 25(01):1-9.

 Copyright @ STEMM Institute Press