Sustainability in Environment
ISSN 2470-637X (Print) ISSN 2470-6388 (Online)
Vol. 11, No. 3, 2026
www.scholink.org/ojs/index.php/se

Original Paper

Digital Twin Technology for Sustainable Urban–Rural Economic Governance:Financial Innovation, Resource Optimization, and Coordinated Development

Jinghan Li[1]

[1] School of Business and Management, Lincoln University College, Petaling Jaya, 47301, Selangor, Malaysia

Corresponding author: Jinghan Li/jinghan.phdscholar@lincoln.edu.my

Received: April 07, 2026 Accepted: May 09, 2026 Online Published: May 27, 2026

doi:10.22158/se.v12n3p44 URL: http://dx.doi.org/10.22158/se.v12n3p44

Abstract

This study investigates the application of digital twin technology in driving the reform of urban–rural economic systems, with a particular focus on the pivotal role of financial elements. It examines how digital twin–enabled tools can facilitate rural financial innovation—such as precise credit allocation, inclusive finance, and dynamic risk assessment—and optimize capital flows between urban and rural areas, thereby enhancing the efficiency of resource matching and breaking down circulation barriers. By constructing high-fidelity, dynamically evolving virtual representations of urban–rural economic operations, digital twins offer a transformative platform for precision financial services and significant improvements in capital allocation efficiency. The findings suggest that leveraging digital twin technology for financial innovation and optimization constitutes a critical enabler for advancing urban–rural integration and promoting the modernization of economic systems. This research provides practical insights into how technology-driven financial development can serve as a core engine for systemic reform and coordinated regional development.

Keywords

Digital Twin, Urban–Rural Economic System, Economic Reform, Financial Innovation, Resource Optimization

1. Introduction

At present, the reform of urban–rural economic systems in developing countries has entered a critical phase of deep structural transformation. It faces a set of intertwined and formidable challenges,

including the dismantling of entrenched dualistic structures, the facilitation of equalized factor exchange and bidirectional mobility, and the advancement of regional coordination toward the goal of common prosperity. However, conventional reform paradigms exhibit inherent limitations in coping with the increasing interdependence, dynamism, and uncertainty of urban–rural systems. This underscores an urgent need for the integration of innovative technological approaches to enhance the effectiveness and adaptability of reform processes.

As a paradigmatic embodiment of next-generation information technology convergence, Digital Twin technology is characterized by the development of highly synchronized and interactively coupled virtual representations of physical systems, enabled by real-time data streams for the purposes of simulation, predictive analytics, and system optimization. The integration of digital twin technology into the reform of urban–rural economic systems offers a transformative analytical and governance framework. Specifically, it provides novel solutions to persistent challenges such as urban–rural information asymmetry, suboptimal resource allocation, and the limited evaluability of policy implementation outcomes, thereby generating substantial digital impetus for systemic reform.

Against this backdrop, this study seeks to systematically investigate the theoretical underpinnings, application scenarios, and future development trajectories of digital twin–enabled urban–rural economic system reform.

2. Literature Review

2.1 Digital Twin Technology in Economic and Urban Systems

Digital twin (DT) technology, originating from cyber-physical systems research, has rapidly evolved as a powerful tool for modeling, simulation, and optimization of complex socio-economic systems. Scholars have emphasized its capacity to create high-fidelity virtual replicas of physical entities, enabling real-time monitoring, predictive analysis, and scenario testing. In urban contexts, digital twins have been applied to smart city management, infrastructure optimization, and disaster response, demonstrating their effectiveness in integrating heterogeneous data sources such as IoT sensors, GIS, and remote sensing. Moreover, digital twin platforms enable dynamic decision support by simulating the interactions of multiple agents and predicting the effects of policy interventions, bridging the gap between data-driven insights and actionable governance strategies.

While existing studies focus primarily on urban infrastructure, industrial production, or supply chain optimization, few have explored the **systematic application of digital twins to urban–rural economic systems**, especially in the context of structural reform and coordinated regional development. This gap highlights the potential of digital twin technology to provide real-time, evidence-based decision support for complex economic policy implementation.

2.2 Urban–Rural Economic System Reform

The reform of urban–rural economic systems has been a central concern in development economics, particularly in countries with dualistic economic structures. Prior literature identifies persistent

challenges such as segmented resource allocation, inefficiencies in factor mobility, and asymmetric access to public services. Studies have shown that traditional reform approaches—based on static planning, top-down governance, and partial policy experimentation—often fail to capture the **dynamic interactions between urban and rural economies**, resulting in uneven growth and limited effectiveness of financial and infrastructural interventions .

Recent scholarship emphasizes the need for **integrated, data-driven, and adaptive mechanisms** to facilitate factor mobility, optimize resource allocation, and coordinate regional development strategies. In particular, financial innovation—such as inclusive finance, microcredit schemes, and dynamic risk management—has been recognized as a critical enabler for reducing capital misallocation and supporting small-scale enterprises in rural areas.

2.3 Integration of Digital Twin and Economic System Reform

Emerging research highlights the intersection of digital twin technology and economic system reform. Scholars have proposed that digital twins can enhance governance capacity by:

1. **Breaking information silos**: integrating heterogeneous datasets across sectors and regions for holistic system visibility
2. **Simulating policy outcomes**: using agent-based models and dynamic optimization to test potential reforms before real-world implementation
3. **Optimizing factor allocation**: dynamically matching labor, capital, and land resources with real-time demand and supply patterns, thus reducing inefficiencies and mismatches.

However, most of these studies remain **conceptual or urban-focused**, and empirical evidence on digital twin–driven reform in urban–rural economic systems is limited. There is also a lack of comprehensive frameworks that integrate **financial innovation, infrastructure planning, and governance adaptation** into the digital twin modeling of urban–rural economies.

2.4 Research Gap

Existing literature establishes the foundational capabilities of digital twin technology and outlines the challenges of urban–rural economic reform, but several gaps remain:

- Limited research on **system-level, dynamic modeling** of urban–rural economies using digital twins.
- Sparse evidence on **digital twin applications for financial innovation and capital allocation** in rural contexts.
- Few studies connecting **technology-driven simulation with governance and institutional reform**, leaving the operationalization of digital twins in policy design underexplored.

This study addresses these gaps by proposing a **digital twin–driven framework for urban–rural economic system reform**, integrating financial innovation, resource optimization, and governance transformation. It aims to provide both **theoretical insights and practical guidelines** for leveraging digital twin technology to enhance decision-making, optimize factor flows, and promote coordinated economic development.

3. The Practical Necessity of Digital Twin–Driven Reform in Urban–Rural Economic Systems

3.1 The Imperative of Urban–Rural Integration in the Digital Economy Era

Against the backdrop of the sweeping expansion of the digital economy, advancing urban–rural integration has emerged as a critical pathway for achieving regional coordination and optimizing economic structures. However, the persistence of the traditional urban–rural dual structure continues to generate significant constraints, including impeded factor mobility, weak industrial linkages, and unequal access to public services. These structural deficiencies substantially hinder the improvement of overall economic efficiency.

To effectively dismantle entrenched urban–rural barriers and realize the efficient circulation of production factors, deep integration of industrial chains, and inclusive sharing of public services, robust technological support is urgently required to reconfigure both the modes and efficiency of urban–rural interactions. As a critical interface between the physical and digital worlds, Digital Twin technology, with its advanced capabilities in data integration, simulation, and dynamic optimization, offers unprecedented opportunities for accurately identifying development demands and constructing highly coordinated mechanisms for integrated urban–rural development. It thus represents an inevitable technological response to the demands of the digital economy era.

3.2 Structural Bottlenecks in Traditional Reform: Information Silos, Inefficient Resource Allocation, and Lagged Decision-Making

The reform of traditional urban–rural economic systems has long been constrained by deeply rooted structural bottlenecks. Foremost among these is the pervasive phenomenon of “information silos,” wherein data fragmentation across sectors, administrative levels, and urban–rural domains severely restricts the free flow and effective sharing of information. This fragmentation leads to a partial and disjointed understanding of overall economic operations.

In addition, resource allocation mechanisms remain rigid and inefficient. Planning processes are frequently misaligned with actual demand, while distorted or obstructed market signals impede the effective distribution of resources. As a result, resources cannot be dynamically allocated or optimally combined in response to evolving urban–rural development needs, leading to significant inefficiencies, misallocation, and waste.

Furthermore, decision-making processes are often lagged relative to rapidly changing market conditions and development dynamics. Reliance on static data and experiential judgment limits the capacity to anticipate the dynamic evolution of complex economic systems and to respond in a timely and adaptive manner. Collectively, these systemic constraints underscore the urgent need for advanced governance tools capable of overcoming data fragmentation, enabling precise system mapping, and supporting scientific foresight alongside agile policy responses.

3.3 Breakthrough Capabilities of Digital Twin Technology: Virtual–Physical Interaction, Real-Time Simulation, and Dynamic Optimization

The transformative potential of Digital Twin technology directly addresses the aforementioned structural constraints by providing a comprehensive technological solution. Its capacity for virtual–physical interaction enables the construction of high-fidelity digital replicas of the physical world, facilitating holistic mapping and deep analytical insights into complex urban–rural economic systems, thereby fundamentally dismantling information silos.

Moreover, its real-time simulation capability allows for the dynamic modeling and prediction of the impacts of policies, planning interventions, and market fluctuations within virtual environments. This significantly enhances the scientific rigor and forward-looking nature of decision-making, effectively mitigating the lag inherent in traditional approaches.

More critically, its dynamic optimization functionality enables the continuous and automated adjustment of resource allocation strategies, industrial configurations, and infrastructure planning based on real-time data and simulation outputs. This fosters more efficient and fluid factor mobility, as well as more precise and adaptive resource allocation. In doing so, digital twin technology injects a powerful self-optimizing mechanism into economic system reform, ultimately inaugurating a new paradigm of coordinated and synergistic urban–rural development.

4. Theoretical Framework: Coupling Mechanisms Between Digital Twin Technology and Urban–Rural Economic System Reform

4.1 The Dimension of Technological Empowerment

4.1.1 Spatial Reconfiguration: Mirrored Mapping of Physical Urban–Rural Space in Virtual Environments

The core capability of digital twin technology lies in constructing a virtual digital space that is highly synchronized with and dynamically mapped onto real-world urban–rural physical environments. This process of “spatial reconfiguration” integrates multi-source data—including Geographic Information Systems (GIS), the Internet of Things (IoT), remote sensing, and Building/City Information Modeling (BIM/CIM)—to achieve a fine-grained and multi-dimensional digital reconstruction of complex urban–rural systems. These systems encompass topography, built environments, infrastructure networks, ecological conditions, and even socioeconomic activities.

Such mirrored mapping transcends mere visualization by creating a computational, analyzable, and simulatable digital replica. It provides decision-makers with unprecedented holistic perspectives and analytical depth. By overcoming the fragmentation and static limitations inherent in traditional planning and management approaches, this capability renders spatial configurations, resource distributions, and developmental dynamics more transparent and interpretable, thereby establishing a robust informational foundation for subsequent process optimization and evidence-based decision-making.

4.1.2 Process Reengineering: Cross-Departmental Coordination Based on the Digital Thread

Through the construction of a "digital thread" spanning the entire lifecycle of urban–rural planning, construction, governance, and service delivery, digital twin technology drives profound process reengineering. Centered on a unified data model, this digital thread seamlessly connects information systems and operational processes across multiple governmental domains, including spatial planning, land administration, housing and urban development, transportation, environmental protection, agriculture, and water management.

By dismantling traditional institutional silos and fragmented governance structures, it enables the real-time aggregation, integration, and on-demand circulation of critical information—such as planning schemes, approval processes, construction progress, operational states, and monitoring data—within a unified virtual environment. This facilitates synchronized collaboration, parallel approval processes, and joint supervision across departments on a shared digital twin platform, significantly enhancing both efficiency and transparency.

Such data-driven process reengineering optimizes and integrates complex workflows associated with urban–rural economic system reform—including project approval, resource allocation, and emergency response—thereby substantially improving administrative efficiency and service responsiveness.

4.1.3 Decision-Making Upgrading: Big Data–Driven Policy Simulation and Ex Ante Evaluation

The aggregation of massive, multi-dimensional spatiotemporal data within digital twin platforms, combined with advanced computational capabilities and intelligent analytical models, fundamentally transforms decision-making processes in urban–rural economic system reform. Decision-makers are no longer confined to reliance on historical experience or limited datasets; instead, they can construct complex socioeconomic system models within virtual environments to conduct multi-scenario and dynamic simulations of proposed reform policies.

These policies may include land system reforms, industrial restructuring, population mobility regulation, and infrastructure investment strategies. Such a "policy sandbox" enables the systematic prediction of policy outcomes under varying conditions, as well as the identification of potential risks—including environmental, social, and economic impacts—and interregional spillover effects.

By comparing simulation outcomes across alternative policy scenarios, decision-makers can more rigorously evaluate feasibility, optimize policy design, and proactively mitigate potential challenges. This facilitates a paradigm shift from experience-based to data-driven decision-making, and from reactive adjustment to anticipatory governance, thereby significantly enhancing the precision and foresight of urban–rural reform policies.

4.2 The Dimension of Institutional Innovation

4.2.1 Transformation of Governance Models: From Bureaucratic Hierarchies to Platform-Based Governance

Traditional urban–rural governance systems are predominantly characterized by hierarchical bureaucratic structures. While such systems maintain clear lines of authority, they often suffer from

delayed information transmission and limited interdepartmental coordination, rendering them inadequate for addressing the complexity and dynamism of urban–rural integration.

The introduction of digital twin technology provides both technological support and conceptual impetus for a fundamental transformation of governance models. By constructing dynamic, data-integrated virtual representations that span the entire urban–rural spectrum, it dissolves the constraints imposed by physical and administrative boundaries.

Within this framework, governance is progressively shifting from vertically segmented, command-and-control bureaucracies toward flattened, collaborative, and platform-based models. This platform functions not only as a data aggregation hub but also as a nexus for cross-departmental, cross-level, and cross-regional coordination in decision-making and service provision. Through real-time system monitoring and policy simulation, it enables seamless information sharing and efficient circulation among government entities, markets, and society, thereby driving process innovation and enhancing governance capacity. Ultimately, this transformation fosters more agile, precise, and inclusive governance capable of managing complex socioeconomic systems in an integrated and coordinated manner.

4.2.2 Breakthroughs in Property Rights Systems: Data Ownership Clarification and Sharing Mechanisms

A central objective of urban–rural economic system reform is to unlock the potential of production factors. As a critical emerging factor, data faces significant constraints due to ambiguous ownership structures and limited mechanisms for circulation and sharing. The deep integration of digital twin technology offers an innovative pathway for institutional design in this domain.

Leveraging its capabilities in data aggregation, correlation, and modeling, digital twin systems can comprehensively map the full lifecycle of data generation, circulation, and application. This provides a foundation for establishing refined data ownership frameworks suited to the digital era—clarifying not only the ownership of raw data but also the value contributions and rights allocation associated with derived and integrated datasets.

Moreover, digital twin platforms can create secure, trustworthy, and controllable environments for data sharing. By integrating technological solutions—such as privacy-preserving computation and blockchain—with institutional arrangements, including tiered authorization and benefit-sharing mechanisms, these platforms enable the removal of barriers among governmental, corporate, and societal data. This facilitates the establishment of efficient, orderly, and equitable data circulation systems, thereby unlocking the transformative potential of data in industrial upgrading, public service optimization, and evidence-based policymaking.

4.2.3 Financial System Innovation: Optimization of Urban–Rural Financial Resource Allocation Mechanisms

The urban–rural dual structure is particularly pronounced in the financial domain, where resource allocation remains uneven. Rural and underdeveloped regions frequently face challenges such as

limited access to financing, high borrowing costs, and insufficient service coverage. Digital twin technology provides a powerful tool for addressing these challenges and advancing financial system innovation.

By constructing high-fidelity digital representations of urban–rural economic systems, digital twins enable real-time, dynamic, and multi-dimensional characterization of regional economic activities, industrial structures, credit environments, resource endowments, and even micro-level behavioral and risk profiles of economic agents. This unprecedented level of transparency significantly reduces information acquisition costs and risk assessment uncertainties for financial institutions, particularly those serving underserved markets.

Based on these capabilities, financial systems can undergo substantial optimization in resource allocation mechanisms. On the one hand, digital twin–enabled insights facilitate the precision targeting of inclusive finance, enabling institutions to develop customized financial products tailored to the needs of agriculture, rural areas, and small and micro enterprises, while improving credit allocation accuracy and proactive risk management. On the other hand, they promote deeper integration with financial technology, streamlining credit approval processes, enabling innovative digital asset–based collateralization models, and enhancing the breadth, depth, and responsiveness of financial services. This ultimately bridges the urban–rural financial divide and injects more efficient and sustainable financial resources into coordinated economic development.

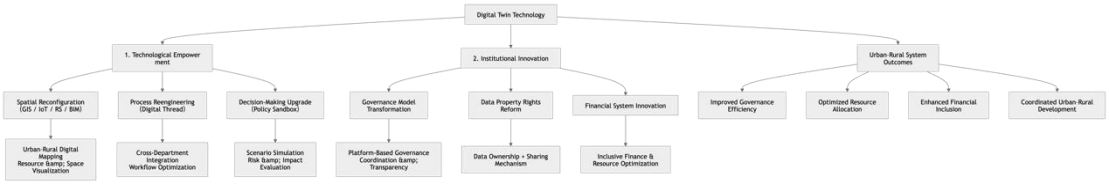

Figure 1. Theoretical Framework of Coupling Mechanisms Between Digital Twin Technology and Urban–Rural Economic System Reform

5. Practical Strategies for Digital Twin–Driven Urban–Rural Economic System Reform

5.1 Precision Matching of Industrial Factors

5.1.1 Construction of Digital Industrial Chain Maps for Real-Time Monitoring of Factor Flow Gaps

Leveraging multi-source data acquisition systems—including IoT sensors, satellite remote sensing, and enterprise big data—a three-dimensional and dynamically evolving digital map of the entire industrial chain (encompassing raw materials, production, circulation, and consumption) can be established. Through digital twin engines, such maps enable millisecond-level data fusion of key elements, including industrial foundations, capacity distribution, logistics networks, and market supply–demand conditions across urban and rural regions.

This framework generates visualized heatmaps of factor flows, enabling real-time identification of critical bottlenecks—such as shortages of agricultural processing inputs, fluctuations in industrial

energy supply, or underutilized cross-regional logistics capacity. By integrating Geographic Information Systems (GIS), the system can precisely locate nodes of factor stagnation. Government coordination centers can thereby dynamically adjust warehousing and distribution schemes, target infrastructure investments, and activate emergency supply-chain stabilization mechanisms, forming a closed-loop governance system of "monitoring–early warning–response."

Moreover, machine learning modules trained on historical data can predict seasonal trends in factor shortages—such as labor gaps or raw material price volatility—thus enabling proactive resource allocation and significantly reducing the risk of industrial chain disruptions.

5.1.2 Development of Virtual Investment Promotion Platforms with AI-Based Industrial Matching Simulation

To address inefficiencies in industrial relocation—such as mismatched investment attraction and poor project adaptability—a digital twin–based virtual investment simulation platform can be established. This platform constructs a comprehensive digital replica of target regions by integrating over 300 parameters, including land characteristics, environmental carrying capacity, labor structure, industrial ecosystem completeness, and regulatory constraints.

When evaluating potential enterprises, AI engines automatically analyze production processes (e.g., energy consumption patterns, emission coefficients, logistics dependencies) and conduct multi-scenario simulations in virtual environments:

- Economic feasibility: supply chain costs, market reach, and policy incentives
- Ecological compatibility: dynamic balance between emissions and environmental capacity
- Social impact: employment generation, technological spillovers, and fiscal contributions

The system generates quantitative evaluation reports, categorizing regions into "priority zones," "risk alert zones," and "required upgrading areas." For instance, if a water-intensive manufacturing firm conflicts with local water scarcity conditions, the system can recommend relocation to more suitable regions and propose infrastructure adaptation solutions, thereby avoiding long-term inefficiencies.

5.1.3 Establishment of a Digital Labor Skill Profiling System for Intelligent Job Matching

By integrating cross-domain datasets—including social security records, online learning platforms, and enterprise skill certifications—a dynamically updated digital labor skill profiling system can be constructed. Each worker is represented by an evolving digital twin profile, incorporating:

- Hard skills: certifications, technical competencies, operational experience
- Soft skills: communication and collaboration abilities derived from AI-based assessments
- Spatial mobility: commuting preferences, migration willingness, household constraints

When enterprises release job requirements, the system utilizes knowledge graphs to deconstruct complex skill demands and perform multi-level matching:

- Precision matching of core competencies
- Identification of transition-ready talent
- Geospatially optimized labor allocation

Simultaneously, governments can access regional skill gap heatmaps, enabling targeted vocational training programs and forming a digital closed loop of "demand–training–employment."

5.2 Economic Decision-Making Simulation Systems

5.2.1 Policy Simulation Sandbox for Multi-Dimensional Impact Forecasting

Policy simulation sandboxes, as core applications of digital twin technology, enable high-fidelity modeling of urban–rural economic systems. By integrating over 300 variables and employing agent-based modeling (ABM), the system simulates interactions among firms, households, and governments.

Policymakers can test reforms—such as land system adjustments or fiscal policies—within controlled virtual environments, generating dynamic reports on industrial transmission effects, employment fluctuations, and fiscal impacts. Machine learning further optimizes policy parameter combinations, reducing trial-and-error costs and enhancing decision robustness.

5.2.2 Macroeconomic Digital Laboratory for Development Path Testing

Built upon a Computable General Equilibrium (CGE) framework, the macroeconomic digital laboratory integrates real-time data streams across land use, finance, and energy systems. It supports:

- Stress testing under extreme scenarios
- Comparative analysis of alternative development pathways
- Policy package simulations

Through Digital Thread integration, physical infrastructure systems are dynamically coupled with virtual models, enabling spatiotemporal analysis of policy impacts and optimizing infrastructure investment decisions.

5.2.3 Risk Early Warning Dashboard for Dynamic Reform Monitoring

A real-time digital dashboard establishes a three-tier system of monitoring, evaluation, and response:

- Situational awareness layer: real-time data collection and anomaly detection
- Risk assessment layer: deep learning–based evaluation of reform health
- Decision response layer: automated generation of policy intervention scenarios

A "reform resilience dashboard" further employs Monte Carlo simulations to anticipate systemic risks and support adaptive governance.

5.3 Intelligent Upgrading of Public Services

5.3.1 Deployment of Digital Twins in Healthcare and Education

The deployment of digital twins in healthcare and education enables high-precision mapping and optimization of service systems. AI-driven allocation algorithms improve emergency response, resource distribution, and service accessibility, facilitating a transition from reactive provision to proactive adaptation.

5.3.2 Lifecycle Management Systems for Infrastructure

Digital twin–based lifecycle management systems enable full-process monitoring of infrastructure—from design to operation—through real-time data integration and predictive maintenance, significantly enhancing system resilience and efficiency.

5.3.3 Digital Rural Governance Platforms for Transparency and Accountability

By integrating 3D GIS and remote sensing data, digital governance platforms create comprehensive village-level digital replicas. Core modules enable transparent management of collective assets, real-time policy tracking, and participatory governance, thereby strengthening institutional trust and governance efficiency.

5.4 Financial Factor Marketization Reform Support

5.4.1 Simulation-Based Decision Platforms for Reform

Digital twin platforms provide multi-scenario simulation environments for testing reform policies, enabling precise identification of systemic bottlenecks and policy impacts.

5.4.2 Precision Pricing and Efficient Allocation of Financial Factors

By constructing multidimensional asset and credit profiles, digital twins facilitate accurate valuation and risk assessment, enabling more efficient allocation of financial resources across sectors and regions.

5.4.3 Full-Chain Factor Market Integration Enabled by Digital Twin Technology

By creating an integrated digital space spanning all economic activities, digital twin technology supports the coordinated marketization of land, labor, capital, technology, and data, ultimately fostering efficient and equitable urban–rural integration.

6. Sustainability and Governance Implications

This section discusses the implications of the proposed digital twin–enabled urban–rural governance framework from three perspectives: environmental sustainability, governance transformation, and socio-economic coordination. It further highlights the contribution of the study to sustainable development goals (SDGs) and long-term regional resilience.

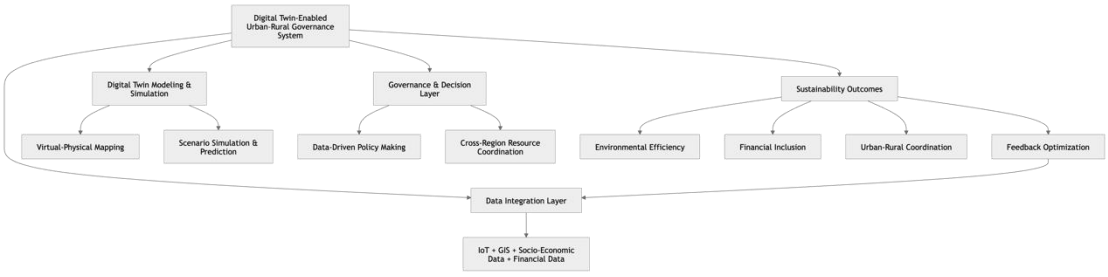

Figure 2. Simplified Framework of Digital Twin-Enabled Urban–Rural Sustainability and Governance System

6.1 Environmental Sustainability Implications

The application of digital twin technology in urban–rural economic systems provides significant potential for enhancing environmental sustainability through improved monitoring, simulation, and optimization of resource use.

First, the integration of multi-source data (e.g., remote sensing, IoT sensors, and geographic information systems) enables real-time monitoring of land use patterns, energy consumption, and ecological conditions. This facilitates the identification of environmental inefficiencies and supports evidence-based ecological management.

Second, digital twin–based simulation systems allow policymakers to evaluate the environmental impact of alternative development scenarios prior to implementation. For instance, infrastructure expansion, industrial relocation, or agricultural restructuring can be assessed in terms of their potential carbon emissions, land degradation, and resource consumption.

Third, the proposed framework contributes to resource efficiency by optimizing the allocation of water, land, and energy resources across urban and rural areas. This reduces redundancy and improves the overall ecological carrying capacity of regional systems.

Overall, the integration of digital twin technology promotes a shift from reactive environmental management to proactive and predictive ecological governance.

6.2 Governance Transformation for Sustainability

From a governance perspective, the digital twin–enabled framework facilitates a transition from fragmented and hierarchical administrative structures toward integrated, platform-based governance systems.

Traditional urban–rural governance is often constrained by information asymmetry, departmental silos, and delayed decision-making. The proposed framework addresses these limitations by enabling real-time data sharing and cross-sector coordination within a unified digital environment.

In particular, the “digital thread” mechanism ensures continuous information flow across planning, implementation, monitoring, and feedback stages of governance. This improves transparency, accountability, and policy responsiveness.

Moreover, governance processes become more adaptive and scenario-driven. Decision-makers can test alternative policy options in a virtual environment, allowing for ex ante evaluation of governance outcomes. This enhances policy precision and reduces the risks associated with trial-and-error policymaking.

As a result, the governance system evolves toward a more flexible, data-driven, and participatory model that supports long-term sustainability objectives.

6.3 Socio-Economic Sustainability and Financial Inclusion

The proposed digital twin framework also contributes to socio-economic sustainability by improving financial inclusion and optimizing resource allocation mechanisms across urban and rural regions.

In rural areas, limited access to financial services has traditionally constrained economic development. By leveraging digital twin systems, financial institutions can obtain more accurate and real-time assessments of credit risk, economic activity, and asset conditions. This reduces information asymmetry and enhances the efficiency of credit allocation.

Furthermore, the integration of financial technology with digital twin platforms supports the development of inclusive financial products tailored to the needs of small enterprises, agricultural producers, and rural households. This improves capital accessibility and promotes balanced regional development.

In addition, intelligent resource allocation mechanisms enhance labor mobility and industrial matching between urban and rural economies, thereby reducing structural unemployment and improving overall economic resilience.

6.4 Contribution to Sustainable Development Goals (SDGs)

The proposed framework contributes to multiple United Nations Sustainable Development Goals (SDGs), particularly:

- **SDG 8 (Decent Work and Economic Growth):** by improving resource efficiency and promoting inclusive financial systems;
- **SDG 9 (Industry, Innovation, and Infrastructure):** through the integration of digital twin infrastructure in governance systems;
- **SDG 10 (Reduced Inequalities):** by narrowing the urban–rural development gap through optimized resource allocation;
- **SDG 11 (Sustainable Cities and Communities):** by enhancing coordinated urban–rural planning and governance;
- **SDG 12 (Responsible Consumption and Production):** through improved resource efficiency and environmental monitoring.

By aligning technological innovation with sustainability objectives, the proposed framework provides a systematic pathway toward long-term regional balance and inclusive development.

In summary, the digital twin–enabled urban–rural governance framework offers a comprehensive approach to advancing sustainability across environmental, governance, and socio-economic dimensions. It enables the transition from static and fragmented management to dynamic, integrated, and data-driven governance systems. The framework not only improves resource efficiency and policy effectiveness but also supports inclusive development and ecological resilience, thereby contributing to the broader agenda of sustainable regional transformation.

7. Conclusion

This study demonstrates that Digital Twin technology serves as a powerful engine driving the reform of urban–rural economic systems, with its application potential and practical value becoming increasingly evident. By constructing comprehensive virtual mappings and simulation environments that encompass

the entire urban–rural spectrum, this technology significantly enhances the foresight, scientific rigor, and coordination of reform-related decision-making. It provides critical support for dismantling institutional barriers, optimizing factor allocation, and fostering new drivers of urban–rural development.

Empirical and practical evidence suggests that digital twin–enabled reform is catalyzing a profound transformation in governance models, shifting them toward greater precision, dynamism, and intelligence. This transformation has effectively promoted high-quality urban–rural integration and strengthened the overall efficiency and resilience of economic systems.

Looking ahead, with the continuous evolution of technology and the deepening of application scenarios, digital twin technology is expected to reshape urban–rural relationships and economic institutions across broader domains and at deeper levels. It is poised to become an indispensable digital foundation for achieving the goal of common prosperity, ushering in a new stage of intelligent and coordinated urban–rural development.

Statements and Declarations

(a) Funding: This research received no external funding.

(b) Conflicts of Interest: The authors declare no conflict of interest.

(c) Acknowledgments: The author(s) declare that there are no acknowledgments.

References

Ahmad, N., Fatima, I., Alam, M. et al. (2025). Digital twin model design for smart village[M]//Digital Twins for Smart Cities and Villages. *Elsevier*, 127-148.

Dellaly, M., Skander-Mustapha, S., & Slama-Belkhodja, I. (2024). A digital twin model-based approach to cost optimization of residential community microgrids. *Global Energy Interconnection*, *7*(1), 82-93.

Huang, Z. (2025). *A Digital Twin Model for Comprehensive Development in Backward Areas*.

Liu, F., Wang, D., Liu, C. H. et al. (2025). Data-driven coordination and optimization of the digital economy and urban–rural integration. *Energy Economics*, 108959.

Omrany, H., Mehdipour, A., Oteng, D. et al. (2025). The uptake of urban digital twins in the built environment: A pathway to resilient and sustainable cities. *Computational Urban Science*, *5*(1), 20.

Panga, N. K. R., Bobba, J., Bolla, R. L. et al. (2025). *Revolutionizing Urban Development in Smart Cities with Advanced Digital Twins: Integrating IoT, Multi-Model Simulations, and Geospatial Analytics[M]//Computational Tools for Sustainable Industrial Transformation* (pp. 155-185). Singapore: Springer Nature Singapore.

Sharma, S. N., & Dehalwar, K. (2026). Urban spatial digital twin in sustainability spur economic growth in transit-oriented development-based development[M]//Tenable engineering for a sustainable future. *Elsevier*, 257-300.

Supianto, A. A., Nasar, W., Aspen, D. M. et al. (2024). An urban digital twin framework for reference and planning. *IEEE Access*, *12*, 152444-152465.

Wang, Y., Yue, Q., Lu, X. et al. (2024). Digital twin approach for enhancing urban resilience: A cycle between virtual space and the real world. *Resilient Cities and Structures*, *3*(2), 34-45.

Xiao, M., Chen, L., Feng, H. et al. (2024). Sustainable and robust route planning scheme for smart city public transport based on multi-objective optimization: Digital twin model. *Sustainable energy technologies and assessment*s, *65*, 103787.

Xu, J., & Gong, J. (2023). Novel sustainable urban management framework based on solar energy and digital twin. *Solar Energy*, *262*, 111861.

Xu, W., & Liu, S. (2024). Novel economic models for advancing urban energy management and transition: Simulation of urban energy system in digital twin. *Sustainable Cities and Society*, 101, 105154.

Ye, X., Du, J., Han, Y. et al. (2023). Developing human-centered urban digital twins for community infrastructure resilience: A research agenda. *Journal of Planning Literature*, *38*(2), 187-199.