

The protection of the historical and cultural heritage of the ancient city of Suzhou

An activated digital twin approach

Tao Yang; Jing Li; MengYao Li; YangBin Miu; Ying Tian; Ling Guo Sun

Abstract: To achieve the protection and revitalization of cultural heritage, in line with President Xi Jinping's call for "making more cultural relics and heritage come alive and fostering a strong social atmosphere for inheriting Chinese civilization," digital twins are increasingly becoming new tools and platforms to realize this goal. Based on the construction practices of the Suzhou CIM+ Ancient City Protection and Renewal Platform, this paper reviews the practical challenges, theoretical foundations, and digital twin technology bases of Suzhou's ancient city protection and renewal. It innovatively proposes a digital twin framework for Suzhou's ancient city, using scenarios such as digital recreation, value identification, scenario simulation, and comprehensive governance as drivers. The technical drivers include a spatial coding system, distributed architecture, real-time response simulation, and flexible human-computer interaction. These innovations aim to resolve the contradictions between the protection and revitalized development of the ancient city, promoting its sustainable development. The paper also looks forward to the digital revival of traditional construction methods, the digital evolution of traditional lifestyles, and the digital enhancement of traditional cultural values in Suzhou's ancient city. Through these practices and summaries, it provides a solid methodological foundation for achieving broader, deeper, and higher-standard protection and revitalization of urban historical and cultural heritage in the future.

Keywords: Cultural Heritage; Digital Twin Scenarios; Ancient City Protection and Revitalization; Digital Technology Drivers

CLC Number: TU984 Literature Symbol Code A

DOI 10.16361/j.upf.202401010

Article No. 1000-3363(2024)01- 0082- 09

About the Author

Yang Tao is an associate professor at the School of Architecture, Tsinghua University, and a yangtao128@tsinghua.edu.cn deputy director of the Technology Innovation Center for Smart Human Settlements and Spatial Planning and Governance of the Ministry of Natural Resources

Li Jing is a senior architect at the Planning and Design Company of the Chinese Academy of Planning and Planning (Beijing).

Li Mengyao is a planner and corresponding author of the Planning and Design Company of the Chinese Academy of Planning and Planning (Beijing), mengyao-119@163.com

Miao Yangbing is a senior planner and director of the China Academy of Urban Planning and Design

Tian Ying is a Ph.D. candidate in the School of Architecture of Tsinghua University and a planner of the Planning and Design Company of the Chinese Academy of Planning and Planning (Beijing).

Sun Lingguo is the director of the Suzhou Spatial Planning Think Tank Platform

* National Key R&D Program of China "Theory and Methods of Urban Renewal Design" (No.: 2022YFC3800301)

Since the 18th Party Congress, General Secretary Xi Jinping has repeatedly emphasized the importance of cultural self-confidence to the development of the Chinese nation, proposing that “cultural self-confidence is a more basic, broader and deeper self-confidence, and a more fundamental, deeper and more enduring force.”^[1] The “14th Five-Year Plan” issued in March 2021 also proposes to “promote the creative transformation and innovative development of Chinese outstanding traditional culture, and strengthen the scientific and technological innovation of cultural relics. The “Fourteenth Five-Year Plan” issued in March 2021 also proposes to “promote the creative transformation and innovative development of outstanding traditional Chinese culture, and strengthen the scientific and technological innovation of cultural relics”.¹ The “Opinions on Promoting the Implementation of the National Cultural Digitization Strategy” issued in May 2022 makes it clear that by 2035, the physical distribution and logical connection will be completed, fast link, efficient search, comprehensive sharing, key integration of the national cultural big data system, Chinese culture panoramic presentation, Chinese culture digitization results shared by all . The process of renewal and development of ancient cities and towns is often caught in the contradiction between protection and development, and leads to some misunderstandings, such as: demolition and reconstruction leading to the destruction of the original historical and cultural heritage; new construction projects that do not conform to the traditional historical style and urban texture; injection of new cultural tourism and commerce, but lack of consideration for the indigenous people, lack of improvement of housing conditions, infrastructure, public space, etc., and a low sense of well-being and experience for residents [3.3]. The residents' sense of well-being and experience is low ^[3-4]. Based on the case of the preservation and renewal of the ancient city of Suzhou, the technical and methodological framework of digital twin is proposed in order to explore a new digital path for the preservation and revitalization of the city's historical and cultural heritage in an attempt to promote the organic fusion of China's excellent traditional cultural values and emerging cultural lifestyles.

1 Research background

1.1 New Developments in Conservation and Renewal Theory

The conservation and renewal of urban historical and cultural heritage has a certain theoretical foundation and practice. The protection of historical and cultural heritage began in the 19th century, and has experienced an evolution from tangible to intangible, from monolithic to holistic, from single strategy to hierarchical classification ^[5-7], which is typified by the theory of organic regeneration and the theory of sustainable conservation, with the former focusing on systematic protection of the originality and wholeness of historical and cultural heritage and continuation of the historical texture ^[8-9], and the latter introducing the principle of sustainability into the field of urban heritage protection, no longer sticking to the debate of “authenticity”, but paying more attention to the long-term significance of historical and cultural heritage for the relevant stakeholders ^[10-9]. The former focuses on the systematic protection of the authenticity and integrity of historical and cultural heritage and the continuation of the historical texture^[8-9] , while the latter introduces the principle of sustainability into the field of urban heritage preservation, which is no longer confined to the “authenticity” debate, but pays more attention to the long-term significance of the historical and cultural heritage for the relevant stakeholders^[10-11] . Outside the framework of “conservation”, some scholars^[12-13] have also combined historical and cultural heritage with the field of sociology, exploring the ways of

heritage renewal and utilization. For example, by combining the theory of urban catalysts, material traditional factory renovation, historical building repair, community micro-park construction, sculpture, windows and doors, carvings, etc., or non-material thematic activities, festivals and publicity, etc., are used as catalysts implanted in the process of renewal of the ancient city, and these catalysts from the urban environment are utilized to promote urban change and produce a “chain reaction”. “Chain reaction”, with small-scale, progressive renewal to drive the overall renewal of the surrounding environment revitalization and sustainable development. The scene theory proposed by Clark, a professor at the University of Chicago, is from the perspective of producers and workers to the perspective of consumers, and incorporates cultural connotations on the basis of traditional physical space, proposing that the scene mainly consists of five elements, including community space, convenient cultural and living facilities, diversified activities, crowds, and common cultural values, etc. ^[14-15], and the combination of elements in the scene has a driving effect on the formation of socio-economic phenomena and the The combination of elements in the scenario has a driving effect on the formation of socio-economic phenomena and the sustainable development of the city.

The essence of a scene is to construct a consumption pattern that brings together people, places, things and objects. Combined with the foundation of progressive preservation and regeneration, using small and micro-scale spaces such as buildings and plots of land as the focus point, and further shaping the scene through the creative combination of multiple elements, it can trigger new demands and applications of greater value, and promote holistic preservation and sustainable development. However, the definition of different cultural values and scenes in the traditional scene theory is based on the case studies of western big cities, and its categorization is not completely suitable for the current protection and renewal of China's historical and cultural cities, and the results of scene shaping of some old street scenic spots and cultural attractions in China are often unsatisfactory. And whether it is catalyst theory or scene theory, the realization mechanism behind it is still very complicated, and currently lacks the objective evaluation of the realization of the effect after application. The use of digital technology can save investment and construction costs, the scene applied in the digital space to find the catalyst, and test the value of the catalyst, through the interaction of digital and physical, and then go to the real investment in the construction and protection, and the digital space of the proceeds of the physical space for the construction of the construction of the physical space and the operation of the formation of the virtual and real cycle of the digital and physical economy.

1.2 Fundamentals of Digital Twin Technology

The concept of digital twin was initially proposed by Prof. Grieves at the Product Lifecycle Management course at the University of Michigan in 2003, with early applications in the military industry. Currently, there is no unified understanding of digital twin, which is mainly considered to include dimensions such as physical entities, virtual entities, connections between virtual and real, and data and services^[16-18]. Digital twins are used to visualize complex physical systems that are difficult to model by constructing digital mirrors of the physical entities in the virtual information space, which in turn provides a reference for the control and optimization of the complex physical systems^[19]. With the development of emerging technologies such as big data, cloud computing, Internet of Things (IoT), virtual/augmented/mixed reality, artificial intelligence, etc., digital twin technology has begun to penetrate in the urban field, and the concept of digital twin city has appeared, i.e., the concept of constructing the mapping and interaction between

the real city and the digital city to realize the process of complete correspondence, fusion, and evolution between the physical world and the digital world, as well as to drive the intelligentization of the city^[20]. With the development of digital twin technology, the digital construction method of historical and cultural heritage has been innovated, and there are new paths for protection and revitalization. The use of 3D modeling technology provides samples for the restoration and rehabilitation of historical buildings and historical neighborhoods^[21-22], which is used for cultural relics to build databases and archives, and heritage rescue and protection, while establishing the digital image of physical cultural heritage, and combining cloud platforms and interactive experience methods such as AR and VR to create digital museums, which can realize on-line cloud tours and three-dimensional immersive tours, and promote the dissemination and inheritance of culture. At the same time, spatial big data technology is used to store spatial location information, protection planning information and historical information of cultural heritage to support the analysis work in the protection and renewal of historic districts and historic urban areas, including the investigation of the status quo of historic districts, planning and design, management and control, and value assessment, as well as the analysis of spatial form and spatial social form, morphological structure, and spatial structure of historic districts based on the spatial syntax.

It also analyzes the spatial form of historic districts based on spatial syntax, and analyzes the relationship and reasonableness of the spatial form of historic districts with the spatial social form, morphological structure, and land use layout^[23].

In addition, City Intelligent/Information Modeling (CIM) technology is conducive to the integrated management and application of cultural heritage information by integrating BIM, GIS, IoT and other technologies, spatially locating non-vector data such as cultural heritage protection information and historical information, and fusing them with 3D data such as refined historical models. Integrated management and application, through real-time dynamic data acquisition, transmission, processing, analysis, modeling, combined with real-time dynamic data to achieve cultural relics environment monitoring, monitoring and analysis of pedestrian and vehicular traffic, analysis of the current situation of the neighborhood environment, etc., monitoring and premonitoring the state of the tangible cultural heritage Alert, and combined with simulation models and AI for the prediction of emergencies and solution simulation^[24-26].

From previous research and practice, it can be found that the application of digital twin technology in the protection and revitalization of historical and cultural heritage has been transformed from pure data collection, 3D modeling, and visualization display to comprehensive decision-making and analysis support^[27], which can not only grasp the real and complete information, but also help to give greater play to the cultural value, cultural promotion and dissemination, and manifest and pass on the cultural self-confidence. However, there are still implementation difficulties for ancient cities. First, the high threshold of digital modeling. Although there are a variety of high-precision surveying and mapping and three-dimensional modeling technology, but the ancient city in the old house is more, build can truly reflect the entity of the ancient city micro-detail, ancient building components, historical buildings, the internal structure of the high-precision model requires a large investment, at present such technology has not yet been applied on a large scale, and is often only for the individual important cultural heritage units, historical buildings, three-dimensional point cloud modeling, indoor high-precision modeling and so on. The construction of digital twin cities is costly and long,

and it is difficult to guarantee the sustainability of the project by purely relying on government investment.

Purely relying on government investment is difficult to ensure continuous data updates and operation and maintenance. Secondly, digital applications are to be explored. The current application of digital technology is focused on digital cultural tourism and digital archives of historical heritage, but the mining of cultural heritage data, the fusion of physical models and semantic information is still relatively lacking^[28], and has not yet established the feedback and guidance of the virtual to the real, the lack of auxiliary decision-making mechanisms for the revitalization of the ancient city, urban renewal, etc., and the lack of effective paths of public participation in the dissemination and transmission of culture. Technology does not solve all the problems, in practice, how to better use the digital twin technology to protect, revitalize and reproduce the historical and cultural heritage, to achieve the revival of the ancient city of Suzhou and the sustainable development of the culture is the need to further think about the content.

1.3 Challenges for the conservation and renewal of the ancient city of Suzhou

As one of the first batch of famous historical and cultural cities in China, Suzhou, with a history of 2500 years, has hundreds of cultural relics protection units, numerous tangible and intangible cultural heritages, and a unique and relatively intact urban texture with a double checkerboard pattern on land and water, has been adhering to the general policy of protection-oriented for many years. For the protection of the historical and cultural heritage of the ancient city of Suzhou, it is not only the protection of the heritage itself, but also its revitalization and utilization, giving full play to the value of the cultural heritage, and giving comprehensive consideration to the economic development of the ancient city and the protection of people's livelihood^[29]. At present, Suzhou still has some practical difficulties under the dual requirements of protection and renewal.

On the one hand, the development space of the overall pattern of ancient city protection is limited. The ancient city strictly implements the historical and cultural protection plan, there are many cultural heritage units and protected buildings, the quality of houses varies, the ownership types of private houses, public houses under direct management, mixed ownership and other houses are complicated, and the population of residents is mixed, and the years of government-led small-scale gradual "micro-renewal" experience has been able to strengthen the protection, but has failed to stimulate the renewal and economic development for a long time. It is difficult to realize sustainability by relying only on the government's continuous investment and construction.

On the other hand, it is difficult to converge and integrate data from multiple sources under the background of refined governance. Finding the development direction of ancient city protection and renewal and revitalization requires comprehensive and accurate data, but now the data are often scattered in different departments, different enterprises, population, culture and other non-vector data is still a lack of accurate location, land, land and other spatial units are not unified with each other cross, in the demand for refined governance lack of micro-scale data such as housing, households, and other data, various types of data urgently need a unified standard for the integration of the standardization of the fusion^[30].

The above problems lead to information asymmetry among all parties, and it is difficult for multiple subjects to negotiate and make decisions. Investors need to know which buildings or intangible cultural heritages to protect, so that they can avoid damaging cultural heritages in the

process of renewal, and at the same time can utilize the planning of cultural scenarios to promote economic benefits; builders need to know which traditional or advanced technologies are applicable to the ancient city of Suzhou, so that they can choose the appropriate technologies to repair or renew the buildings in accordance with the actual architectural conditions; protectors or the government need to know where the appropriate investors and technologies are available, and where they can use the technologies to repair or renew the buildings. Where there are suitable investors and technologies to control and guide the conservation and renewal of the ancient city; Consumers or the public want to know what cultural scenes are worth experiencing in the ancient city. Therefore, in general, the ancient city of Suzhou needs to explore how to use digital twin technology to effectively mobilize the resources of all social parties under the overall framework of protection, promote the matching of resources for investment, construction, cultural protection, and consumer experience, and promote the negotiation and common governance of multiple subjects, so as to promote the sustainable development of the ancient city.

2 Scene-driven Digital Twin of Suzhou Ancient City

The digital twin scenario has a driving effect on the overall construction of the digital twin of the ancient city of Suzhou, thus consolidating the cornerstone of the digital twin architecture of the ancient city. First of all, the scene itself provides a reference system for data collection or machine learning to drive the reorganization of data with scene requirements and build parameter links between different models. Second, the fusion of data or model iteration constitutes the learning process of multi-layer scenarios. Around the realization of the scenarios, different models work together through customized combinations to form the interaction between business and data, simulate the functional operation of spatial scenarios from different dimensions, and promote the construction of digital twin scenarios. Finally, the digital twin through this learning process, the real world of people, places, things, things abstracted into the digital world of knowledge, and in the real spatial scene can be reproduced to accelerate the iteration of knowledge, breeding the wisdom of human-computer interaction, and through the process of repeated verification, iteration, to build up a multilevel, multi-precision, multi-modal complex scene system through the process of repeated verification and iteration^[31]. Therefore, constructing data based on scenes, mining value based on data, and deducing simulation based on value support various macro and micro decisions, constructing the whole process of protecting, renewing, revitalizing, and utilizing the ancient city from awareness to identification, from decision-making to governance, and finally realizing the closed loop of overall sustainable development of the twinned ancient city.

2.1 Digital Twin Architecture of the Ancient City of Suzhou

The current conservation and renewal of the ancient city of Suzhou needs to build a whole scene, incorporating all kinds of historical and cultural elements, people, and social environments in the ancient city, reflecting the originality of the material form of the ancient city through digital elements, and emphasizing the holistic conservation of the ancient city, and at the same time, it also needs new triggers as catalysts to activate the value of the ancient city through the interaction of the full-scene twins of the social, economic, and cultural aspects. Suzhou City is promoting the construction of digital Suzhou, and has basically built the basic platform of Suzhou City Information Model (CIM)^[32], and is exploring the digital twin demonstration application of the ancient city with the pilot of the historical city area of 19.2 km² (Fig. 1). General Secretary Xi

Jinping visited the ancient city of Suzhou on July 6, 2023, and said, “Suzhou has done a good job in combining tradition and modernity, not only with historical and cultural heritage, but also with high-tech innovation and high-quality development, which represents the direction of future development”^[33]. Combining the above theoretical and technological foundations, this paper proposes the use of digital twin technology to build a “digital twin scene”, with the goal of full-time and space-time sharing, full-cycle common governance, and full-domain twin interaction, to build a digital twin system for the ancient city of Suzhou, and to unleash the unique cultural value of the ancient city under the dual-driven of scene and technology to realize the protection and revitalization of the historical and cultural heritage. Protection and revitalization of historical cultural heritage.

Different from the scene defined by the traditional scene theory, the digital twin scene refers to the reproduction and reflection of the real scene on the digital interface on the one hand, and on the other hand, it is the new scene generated from the simulation of the real scene during the feedback process of the digital environment to the real scene, and then feedback to the real scene to optimize the real scene in a cyclic process. The traditional scene theory raises the “space” from the purely physical level to the social level, while the “space” in the digital twin city further rises from the real level to the virtual level, reflecting the physical space, social, economic, and cultural life of the city in a digital and abstract way, forming a digital twin city. economy, cultural life, etc., forming a digital twin scene.

For the ancient city of Suzhou, such a digital twin scene not only reflects the entity of the ancient city, highlights the urban texture of the ancient city, but also embodies the cultural values embedded in the ancient city, and at the same time provides a brand new perspective to build a smarter space of the ancient city after integrating the sensing, interacting, and feedback capabilities. Just as the elements in scene theory are organically related to each other^[34], digital twin scenes can also be newly decoupled and reconstructed through the combination of digital elements^[35].

Combining digital twin technology and traditional scene theory to build a new “digital twin scene” can not only make up for the weakness of the technology itself in reflecting the local cultural needs and cultural values, but also build the corresponding business line data based on the scene combing, and through the unified spatial unit system to open up the data of the business line, discovering new problems from the combination of different data elements; using the digital twin scene to build a new digital twin scene can also decouple and reconstruct the scene through the combination of digital elements^[35]. The distributed architecture supports the efficient convergence, convenient access and comprehensive sharing of historical and cultural heritage dispersed all over the world at the digital level; based on the real-time monitoring data of IOT sensing, big data and machine learning technologies are used to further explore the inner laws and operation rules of the scene, realize the scientific simulation of the real city, and promote the integrated decision-making and governance of the digital twin city; through the human-computer interaction and scene reorganization, we can also build the data of corresponding business lines based on the scene combing. human-computer interaction methods and scene reengineering to promote the formation of new cultural characteristics and values, thus realizing the evolution of the traditional life model and the enhancement of cultural values, and realizing the overall sustainable development goals. See Figure 2.



Fig.1 The architecture of the digital twins of the ancient city of Suzhou

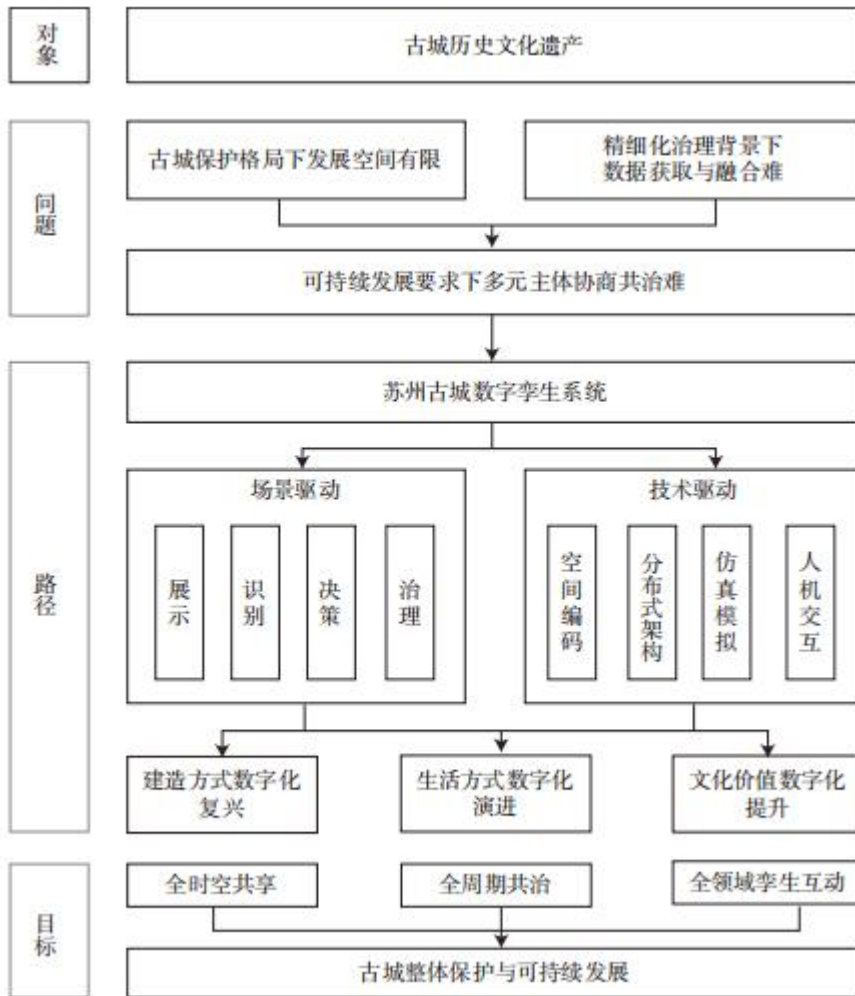


Fig.2 The process of urban historic and cultural heritage protection and revitalization based on digital twins scenarios

2.2 Digital reproduction of physical ancient city protection

Integrate multi-dimensional spatial and temporal data, construct the digital base plate of the ancient city, combine the historical drawings, current situation model, urban design model and other three-dimensional models and socio-economic attribute data to realize the digital reproduction of the ancient city's past, present, and future scenes and the reconstruction of cultural values. The digital template includes two aspects. On the one hand, it starts from the material form and protects all kinds of physical elements of the ancient city, such as houses, buildings, courtyards, cultural relics protection units, ancient trees, ancient bridges, ancient wells, river and water systems, streets and roads, etc., through digital modeling. According to the needs of different spatial scales, different precision models will be involved, for example: high-precision tilt photography model is the closest to the real status quo of the ancient city (Fig. 3), which can realize the overview of the current situation of a wide range of larger scales, intuitively see the characteristics of the ancient city's landscape, and strengthen the overall view corridor, the building height control; monolithic architectural model, layered sub-family model can show the architectural morphology, elevation, and related attribute information. Component-level models, such as BIM models, can reflect the details of the interiors and components of the ancient

buildings; artificial fine models rendered by the game engine (Figure 4) can give users an immersive feeling, which is beneficial to cultural experience and publicity.

On the other hand, the digital baseboard scene is also the embodiment of social and economic activities and cultural values of the old city, the old streets and old houses in the old city are the landing point of people's life memories, and from a sustainable point of view, the protection of historical and cultural heritage can not be separated from the attention to the people and the inheritance of cultural values, including the living environment, the way of life and the production, and the traditional customs that are closely related to the lives of the people, which are also important parts of the protection and inheritance of culture. These are also important parts of cultural protection and inheritance. Through the convergence and integration of space and related facilities, population, transportation and other socio-economic data, we can realize the full-cycle, full-service, full-factor and full-data baseboard of the ancient city, and digitally reproduce the core essence of the protection of historical and cultural heritage in a comprehensive manner.



Fig.3 The three-dimensional view of Suzhou Ancient City



Fig.4 The high resolution of a selected garden in Suzhou Ancient City

2.3 Value Identification for Physical Old Town Revitalization

Scene values can be recognized and measured. In the digital twin of the ancient city, multiple spatial scenes are often descriptively parsed by different indicators, which are transformed into a system of quantitative indicators that abstractly correspond to the spatial scenes themselves. These indicators may come directly from the deep learning of the data, or from the deep mining of the model calculation results.

Based on the digital substrate, we start from different dimensions, different elements and different indexes, construct digital twin "recognition" scenes from ecological, social, economic and cultural dimensions, abstract and reorganize the digital elements and the relationship between the elements, construct an assessment model, assess and value mine the ancient city, and form a unique digital portrait of the ancient city, reflecting the reality of the city. The assessment and value mining of the ancient city will form a unique digital portrait of the ancient city, reflecting the operation law of the real scene, the value of the historical and cultural heritage of the ancient city, and the hidden problems in the development of the ancient city. On this basis, it can identify areas that need to strengthen historical and cultural protection and control, land plots that can be micro-renewed or areas with greater renewal potential (Fig. 5), and provide refined data and scientific analysis results with fine-grained data for government departments and investment and implementation bodies, and at the same time, help to clarify the amount of population, buildings and resources involved in the renewal project of the ancient city, and assist the corresponding bodies in making more accurate decision-making judgments. At the same time, it is conducive to clarifying the population, buildings and resources involved in the ancient city renewal projects, assisting the corresponding subjects to make more accurate decision-making judgments, and promoting the implementation of the subsequent ancient city protection and revitalization renewal at project level.



Fig.5 The assessment of development potential for each plot: the CIM+ regeneration for Suzhou Ancient City

2.4 Deductive Decision Making of Digital Twin for Ancient City

On the basis of “identifying” the value of the scene, combining the dual needs of protection and renewal, treating the ancient city as an organic whole, combining the overall planning for the protection and renewal development of the ancient city with the business process of the renewal of the ancient city, simulating the digital decision-making scenarios with the characteristics and needs of the local society through the digital twin technology, providing functions such as assisting in project siting, planning conditions, design control and impact assessment, and assisting in the whole life cycle of the planning and construction management of the ancient city. It provides functions such as assisting in project site selection, planning conditions, design scheme control and impact assessment, assisting in the whole life cycle of the planning and construction management of the old city, constructing a platform for the consultation of multiple subjects in the renewal of the old city, and exploring the innovation of the old city protection and renewal mode in a three-dimensional digitalized and intelligentized way.

For example, in the planning and site selection of the ancient city renewal project, the spatial block model can be automatically simulated by adjusting different indicators to prejudge the effect of the project implementation, and combined with the requirements for the protection of historical and cultural cities, it can be linked with the 3D status quo model to view the overall spatial morphology and landscape condition of the city; through the system algorithms, it can prejudge the social impacts of the population to be moved and resettled, the impacts of the traffic flow, and the demand for public service facilities and the cost of demolition and reconstruction, the scale of reconstruction and the cost of the reconstruction. Through the system algorithm, quantitative estimation of the economic impacts such as the cost of demolition and reconstruction, the scale of reconstruction, the total amount of financing, etc. is carried out to balance the comprehensive interests of different participants such as residents, government, investors, and so on, in the process of renewal. For example, at a more microscopic scale, online simulation can be carried out for the management of street facades, repair of old houses and demolition of unauthorized building works by adjusting the color of building facades and

replacing roofs online, reflecting the participation of multiple subjects, shaping digital twin scenarios in line with the laws of reality and business rules, and assisting in the formulation of regeneration policies and decision-making by combining different forms of human-computer interactions such as informatization platforms and cell phone apps.

2.5 Comprehensive Management of Digital Twins in Ancient Cities

Apply digital twin technology to urban operation, urban management, social governance, emergency management and other fields to realize full subject mapping, full element perception and full scene empowerment. The use of Internet of Things, edge computing, cloud computing and other technologies, combined with the visualization of all kinds of elements in the virtual space, the original invisible underground corridors in the ancient city, underground pipelines, as well as major traffic routes, major municipal infrastructure and other urban lifeline projects to accurately monitor, in the ancient city of the digital twin of the full scope of the real scene to reflect the operation of the situation; combined with simulation simulation technology, to achieve the traffic flow, crowd activity, Combined with simulation technology, it can realize the simulation of traffic flow, crowd activities, natural disasters, epidemic spread, etc., and provide intelligent prediction services for traffic congestion management, crowd evacuation in scenic spots, and precise prevention and control of epidemics.

Combining the current situation, planning data, and above and below ground data in the digital twin platform, it provides the basic baseboard support for multi-departmental and multi-expert meetings to give the planning and design conditions of the project, which facilitates the government to refine the project management and control requirements, implement the planning conditions, and formulate the refined management requirements for the protection and renewal of the ancient city (Figure 7); combining with the public participation, it provides the public with more convenient digital public services; and continuously enriches the digital twin scenarios to facilitate the management of traffic congestion, crowd evacuation at scenic spots, and precise control of epidemics. The digital twin scenarios are constantly enriched to promote smarter protection and more scientific governance of the ancient city, to promote the closed-loop operation of the integration of urban planning, construction, management and operation of the ancient city, and to show the high-level wisdom of the digital twin city.



Fig.6 The location selection decision: the CIM+ regeneration for Suzhou Ancient City



Fig.7 The negotiation for planning permit specifications: the CIM+ regeneration for Suzhou Ancient City

3 Technology-Driven Digital Twin of Suzhou's Ancient City

3.1 Entity and spatial coding system

Starting from the demand of digital twin scenarios, we sort out the smallest spatial unit of the digital twin of the ancient city of Suzhou as a building, and establish the association relationship and different types of spatial entities covering different levels of spatial units, such as buildings, land, parcels, grids, neighborhoods, streets, districts, counties, cities, and so on, so as to open up the relationship between the business of different domains and the data, to satisfy the demand for three-dimensional data attribute mounting and the application scenarios of the integration of the two-dimensional and three-dimensional, and establish a unique “identity card” code for each spatial unit and spatial entity. It establishes a unique “ID” code for each spatial unit and spatial entity. See Figure 8.

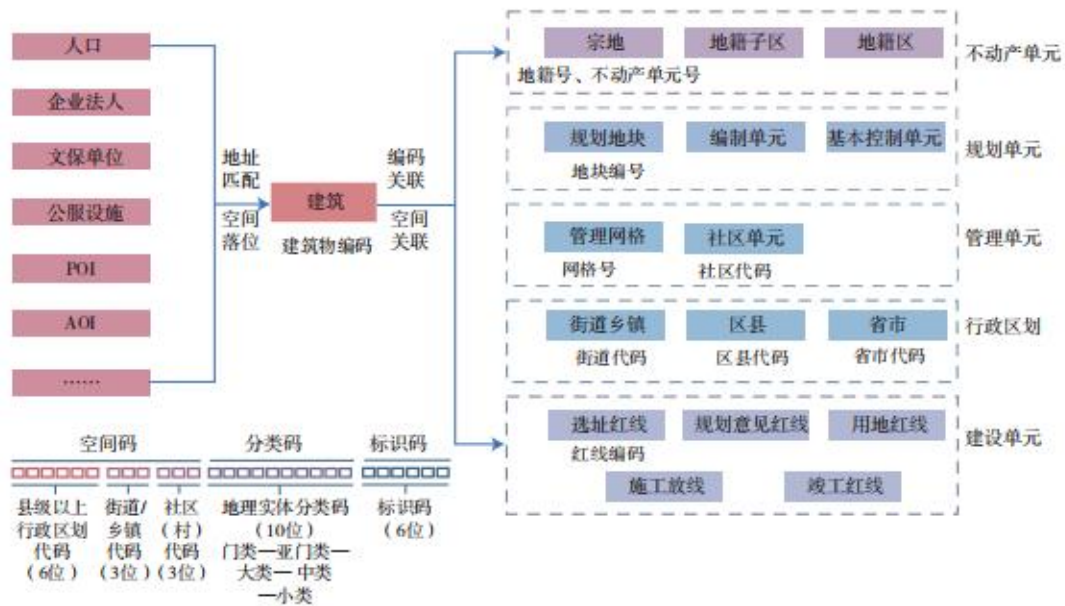


Fig.8 The system for spatial coding: the standard for the digital twins of Suzhou

Based on the spatial coding to establish the anchor point of the virtual-reality mapping of the digital twin of the ancient city, it realizes the management of each ancient tree, ancient bridge, ancient house, etc., integrates the related data and realizes the data coherence of the buildings, plots, planning plots, communities, and neighborhoods, and the various restrictions on the protection of history and culture, the advantageous conditions, and the other related status quo data, etc., can be united into a “block” based on the same spatial unit. “The code itself is also a built-in algorithm.

The code itself is also a built-in algorithm, which constructs a “metric” for spatial identification and transaction. While strengthening the management of digital elements of historical and cultural heritage, it provides a basis for updating research and comprehensive governance of the ancient city, facilitating the query and sharing of information related to any cultural element, any land parcel, and any spatial scope, and realizing the following in the future. In the future, data sharing and data transaction can be realized with “block” as the unit.

3.2 Distributed architecture system connecting grassroots to the rest of the world

In traditional information systems, distributed architecture is the use of high-speed computer networks to connect physically dispersed units to form a logically unified whole[36], which can effectively solve the problem of high concurrency and provide scalability and high availability. The digital twin of the ancient city draws on the idea of distributed architecture to create a distributed architecture system that is efficiently and quickly accessed by users, connecting the grassroots level with the rest of the world to strengthen the cultural dissemination of the ancient city and cultural exchanges with the rest of the world, and to realize the adaptive use of historical and cultural heritage.

On the one hand, different types of historical and cultural protection objects are converged in the digital twin of the ancient city in the form of digital elements, including national, provincial and municipal cultural relics protection units and historical buildings, immovable cultural relics that have not yet been approved as protection units, intangible cultural heritages and so on, which are further refined in the different spatial scales of the ancient city, neighborhoods, blocks,

parcels, and buildings and transformed into a digital architecture in the protection and updating of the ancient city. These digital elements will be further refined and displayed in different spatial scales of the ancient city, blocks, neighborhoods, plots, buildings, etc., and will be transformed into the control requirements of the corresponding spatial units in the protection and renewal of the ancient city, so as to realize refined historical and cultural protection and spatial governance. On the other hand, in the future, outside the ancient city of Suzhou, the historical and cultural resources of different regions, cities and countries can also build their own historical and cultural distributed data nodes with the same hierarchical structure, and the nodes around the world will be interconnected through a high-speed computer network to build the digital twin system of the ancient city of Suzhou in the way of “crowdfunding” to promote the digital twin of cultural resources and to promote the digital twin of cultural resources and to promote the digital twin of cultural resources. Through the “crowdfunding” way to build the digital twin system together, it will promote the efficient convergence of digital twin cultural resources, open to the public all over the world with the support of high concurrent access, so that the public can experience the multi-cultural characteristics in the digital twin scene, strengthen the protection, inheritance and development of cultural heritage resources, and promote the global historical and cultural exchanges and the prosperity of culture and art.

3.3 Real-time Response Simulation Based on Trusted Big Data and AI

The more important technology in the construction of digital twin city is algorithm and simulation, through real-time simulation based on credible big data and AI such as IOT perception in the digital twin world, it can solve the simulation and decision-making of various complex scenarios that can not be realized through simulation in the real world. In the protection of ancient cities, through the three-dimensional scanning and modeling of historical and cultural heritage, and according to the real points of access to the IOT perception monitoring data, it is convenient for users to perceive all kinds of real-time dynamic data of the heritage in real time, and through the system to set up the corresponding thresholds, to strengthen the dynamic protection of the heritage and monitoring and early warning, and to discover the changes in the cultural heritage in a timely manner and to deal with the crises.

In terms of revitalizing and utilizing the ancient city, real-time crowd monitoring data from various scenic spots within the city can be integrated into the digital twin space, combined with demographic information such as age, gender, and origin. By planning corresponding offline activities or supporting commercial facilities in areas with high foot traffic, the vitality of the ancient city can be enhanced. In terms of safety emergency response in the ancient city, by finely modeling the underground pipelines, buildings, roads, facilities and other small pieces in the ancient city, and installing corresponding monitoring or alarm devices at different points, reliable AI learning can be used to warn of dangerous situations in advance when dangerous goods or sources are discovered in the ancient city, or to simulate and recommend emergency plans in a timely manner when dangerous situations occur, so as to achieve the best emergency response effect.

3.4 Flexible human-computer interaction for ancient city protection

Another important technology in the construction of digital twin cities is interaction and control. As a space mapped in real time with the real world, the digital twin space can achieve corresponding effects by controlling objects in the virtual space, and then provide support for corresponding decisions in the real world. This technology is especially important in the

protection and revitalization of ancient cities. In the aspect of cultural protection, when planning and approving the renewal project in the historical and cultural district, by placing the program in the real scene for comparison and viewing, the user can be placed in the first-person perspective on the road around the program or in a specific location to have a real feeling of the program, to see whether the program is coordinated with the surrounding architectural style, whether it will block some important landmarks, whether it affects the view corridors, etc., while supporting the development of a virtual space to achieve the corresponding effect, and thus provide support for the corresponding decision-making in the real world. It also supports online material change, color change and component change to assist the review of the planning scheme through flexible human-computer interaction, so as to maximize the protection of the style and texture of the ancient city.

In terms of the cultural revitalization and inheritance of the ancient city, through the fine modeling of the protected building and the collection and connection of original data, a virtual digital museum is built, so that the user can really see every component of the protected building, every detailed texture, and even the cultural allusions and historical data behind it in the digital space, and adopt the form of flexible human-computer interaction through multi-terminal application, friendly interactive interface, simple and smooth operation. Through multi-terminal application, friendly interactive interface and simple and smooth operation experience, users can feel the charm of historical and cultural heritage in a more real way without the limitation of time and place, and restore the cultural originality of historical and cultural heritage in the way of dialogue between “human and scene”, so as to realize the enhancement and inheritance of cultural heritage value.

4 Future Prospects of Digital Twinning in the Ancient City of Suzhou

4.1 Digital revitalization of the traditional construction method of the ancient city

Currently, there are two main renewal methods in the ancient city of Suzhou, one is the repair of protected buildings, and the other is the alteration, expansion or reconstruction of ordinary buildings. Digital twin technology facilitates more accurate and scientific repair and restoration of various types of protected buildings, and strengthens the review and management of new buildings to meet the scenarios of fine management and multi-professional synergy for the protection of the ancient city.

For historical and cultural protection buildings, digital twin technology can record and restore the most real and detailed data of the current building, analyze and simulate the ancient construction materials, digitally record the components while also recording the construction techniques of ancient buildings, such as intangible cultural heritage, and reproduce the ancient construction process, so as to simulate the construction process of the historical building in the digital twin space, and can also be combined with 3D technology to improve the management of new buildings. The construction process can also be combined with 3D printing, modular construction and other technologies to reproduce and produce precious components, providing valuable assets for the repair and restoration of historical buildings in the future. Secondly, the effects of different restoration schemes can be simulated online by means of digital simulation to assist in determining the scheme that best matches the real-life scenario of the ancient city. In addition, low-carbon technologies can also be combined to explore the renewal and transformation of old buildings, improve energy efficiency through energy-saving renovation, energy consumption monitoring, automatic regulation, etc., to create low-carbon and zero-

carbon buildings, and realize the combination of new and old construction technologies.

4.2 Digital Evolution of Traditional Life Patterns in Ancient Cities

With a history of 2,500 years, the ancient city of Suzhou still maintains the double checkerboard pattern of “parallel land and water, neighboring rivers and streets” and the unique style of “small bridges and flowing water, whitewashed walls and tiles”. Nowadays, when the tangible cultural heritage is still well preserved, digital twin technology can better realize the digital evolution of the traditional life pattern, so that the ancient city can really “look like the history of 2,500 years outside, and walk inside to experience 2035”.

Digital twin technology for the traditional mode of life in the ancient city there are two main changes. One is to enhance the life experience of people in the real world through digital twins in various industries, such as the combination of digital creativity and the “slow” lifestyle of small bridges and water gardens in the ancient city, where people can digitally connect to a convenient life in the digital twin ancient city, including online performance, online classroom, telecommuting, smart hospitals, smart supermarkets, etc. In the real world, digital twins can also be used in the real world. People in the digital twin can digitally make convenient life connections, including online performances, online classes, telecommuting, smart hospitals, smart supermarkets, etc., while in the physical ancient city, they can still experience an ecologically livable and pleasant built environment; another example is the combination of Internet of Things (IoT) sensing, edge computing, and automated driving technology, which will promote the application of unmanned vehicles and other new types of transportation in the future to improve the efficiency of transportation operations, further save road space, return the streets to the people, and provide more slow-moving and changeable activity space. The other is through the construction of a digital world that is a twin replica of the real world, so that people can experience digital life scenes in the digital space, for example, to create a unique digital image of an individual, to experience shopping, entertainment and other types of life scenes in the digital ancient city, but also to participate in the virtual world in the wisdom of the crowds activities, simulated experience of the ancient city's planning, design and updating and transformation, and operation of their own digital assets, and some of the good content and Some good contents and models can also be moved to the real world for reproduction, to enhance the sense of access and happiness of the people in reality.

4.3 Digital enhancement of the traditional cultural value of the ancient city

The digital reproduction of the cultural heritage of the ancient city through digital twin technology can promote the transformation of relevant “cultural resources” into “cultural assets” and comprehensively enhance the cultural value of the ancient city. The value of historical and cultural heritage consists of two dimensions: the value of the cultural heritage itself and the value of the industry chain derived from the cultural heritage.

On the one hand, the use of cultural heritage to promote the development of regional characteristics of cultural industries, cultural heritage to give birth to the brand, the brand to drive the industry, through the industry to feed the cultural heritage of the way to increase the income of the residents, activate the internal development of power, and promote the development of regional characteristics of the industry^[37], for example, the Sky City 2077 project in Suzhou is to explore the deconstruction and reconstruction of the elements of the historical and cultural elements of Suzhou, through the immersive experience of scenes, virtual reality socialization and other ways, to enhance the cultural value of the ancient city. virtual reality

socialization, etc.

Through immersive scene experience, virtual reality socialization, etc., the historical, present and past Suzhou is displayed in digital form, which in turn drives local cultural consumption and urban development.

On the other hand, the digital twin of the ancient city can also provide a display and trading scene for various digital elements of historical and cultural heritage in the ancient city. In the future, historical and cultural heritage can be retained forever in the meta-universe, and it can also transcend the real space, and through the meta-universe, it can reorganize all kinds of tangible and intangible historical and cultural heritage into a brand-new civilization community in the virtual space, so that it can enhance the sense of experience of the digital twin and open up relevant cultural creation and development for people from all over the world. The digital twin scene can enhance the experience of the digital twin scene, and launch relevant cultural creation and economic trading activities for people all over the world, and carry out digital trading of cultural derivatives of cultural heritage. Through digitalization, the craftsmanship, materials, technology, cultural connotations, stories and lifestyles of cultural relics or ancient buildings will be disseminated and consumed on a larger scale, which will, in turn, enhance the protection of cultural relics and ancient buildings, promote the emergence of new business creativity, promote the consumption and transaction scenarios in the physical world, and expand the scope of influence of the historical and cultural heritage from the local and Chinese to the global environment, so as to achieve the digital enhancement of the traditional cultural value of the ancient city. digital enhancement of the traditional cultural value of the ancient city.

5 Conclusion

Digital twin technology is a new tool for the preservation and revitalization of historical and cultural heritage, as well as a means to make life better. The needs of life provide innovative ideas and application scenarios for the technology, and the simulation and experimentation of the technology in the digital twin scenario of the ancient city will, in turn, promote the development of the related emerging technology industry in reality, and be applied in real life to create new life experiences and lifestyles. In this paper, by combing the problems in the process of protection and renewal of the ancient city of Suzhou, combining its current situation and development needs, we creatively propose to use digital twin technology to build a “digital twin scene”, build a digital twin system for the ancient city of Suzhou, and explore the construction mode of the ancient city of Suzhou with digital twin driven by both scene and technology, so as to solve the contradictions in the process of protection and renewal of the ancient city of Suzhou, and to release the new life experiences and lifestyles in the real life. It will solve the contradictions in the process of protection and renewal of the ancient city of Suzhou, release the unique cultural value of the ancient city, promote the protection, utilization and inheritance of the historical and cultural heritage, and realize the holistic protection and sustainable development of the ancient city, as well as exploring the application of the digital twin of the ancient city of Suzhou in the future digital economy, digital life and digital culture, so as to realize the full-time and spatial sharing, the full-cycle common governance, and the full-field interaction of the twins. On the basis of the digital twin, the traditional cultural values and emerging cultural lifestyles are continuously integrated, the living culture can be continuously iterated, and the quality connotation of the ancient city can be eternal.

However, the digital twin technology is still in the early stage, the visualization ability is

much larger than the simulation and interoperability ability, and the visualization ability of localization still needs to be improved. Therefore, the process of digital twinning for the ancient city of Suzhou will be gradual and iterative. First, the knowledge of various industries based on the protection and renewal of the ancient city needs to be transformed into simulation models in order to realize the breakthrough of cross-disciplinary collaborative modeling innovation in the future; second, the accumulation of perceptual data based on the ancient city needs to be pulled according to the effective application scenarios, so as to continuously update the data in the process of use and maintain the vitality of the digital twin platform of the ancient city; third, the creative innovation of the ancient city needs to embrace generative digital technologies (e.g. generative big modeling) in a timely manner. Thirdly, the creative innovation of the ancient city needs to embrace the generative digital technology (such as generative big model) in time to create new economic, living, cultural and management modes of the ancient city as much as possible, so that the traditional objects and culture of the ancient city can be creatively continued and promoted in the daily life of the people.

References

[1] 中华人民共和国国民经济和社会发展第十四个五年规划和 2035 年远景目标纲要 [EB/OL].

新华社 . http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm, 2021-03-13

The Outline of the 14th Five-Year Plan for National Economic and Social Development and Long-Term Goals for 2035 [EB/OL]. Xinhua News Agency. http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm, 2021-03-13.

[2] 中共中央办公厅 国务院办公厅印发《关于推进实施国家文化数字化战略的意见》

[EB/OL]. 新华社 . http://www.gov.cn/zhengce/2022-05/22/content_5691759.htm, 2022-05-22

The General Office of the Central Committee of the Communist Party of China and the General Office of the State Council Issue the "Opinions on Promoting the Implementation of the National Cultural Digitization Strategy" [EB/OL]. Xinhua News Agency. http://www.gov.cn/zhengce/2022-05/22/content_5691759.htm, 2022-05-22.

[3] 张松 . 城市生活遗产保护传承机制建设的理念及路径:上海历史风貌保护实践的经验和

挑战[J]. 城市规划学刊, 2021(6): 100- 108.

Zhang Song. Concepts and Approaches to the Mechanism Construction for the Protection and Inheritance of Urban Living Heritage: Experiences and Challenges from Shanghai's Historical Urban Fabric Protection Practices [J]. Urban Planning Forum, 2021(6): 100-108.

[4] 张松, 张广汉, 张杰, 等 .“新时代中国特色 历史城市的价值认识及保护要义”学术笔谈会[J].

城市规划学刊, 2018(1): 1-9.

Zhang Song, Zhang Guanghan, Zhang Jie, et al. Academic Symposium on the Value Recognition

and Protection Essentials of Historical Cities in the New Era with Chinese Characteristics [J]. Urban Planning Forum, 2018(1): 1-9.

[5] 兰伟杰, 胡敏, 赵中枢. 历史文化名城保护制度的回顾、特征与展望[J]. 城市规划学刊, 2019(2): 30-35.

Lan Weijie, Hu Min, Zhao Zhongshu. Review, Characteristics, and Prospects of the Protection System for Historic and Cultural Cities [J]. Urban Planning Forum, 2019(2): 30-35.

[6] 常青, 阮仪三, 张松, 等. “文化遗产与历史保护”学术笔谈[J]. 城市规划学刊, 2019 (S1): 105-108.

Chang Qing, Ruan Yisan, Zhang Song, et al. Academic Symposium on Cultural Inheritance and Historical Protection [J]. Urban Planning Forum, 2019(S1): 105-108.

[7] 党安荣, 梁媛媛, 陈麦尼, 等. 历史文化名城保护的信息技术方法研究进展与趋势 [J]. 中国名城, 2021, 35(4): 33-37.

Dang Anrong, Liang Yuanyuan, Chen Maoni, et al. Research Progress and Trends in Information Technology Methods for the Protection of Historic and Cultural Cities [J]. China Famous Cities, 2021, 35(4): 33-37.

[8] 陈蔚, 胡斌. 我国历史文化遗产保护理论体系的框架性研究[J]. 室内设计, 2012, 27 (5): 35-38.

Chen Wei, Hu Bin. Framework Study on the Theoretical System of Historical and Cultural Heritage Protection in China [J]. Interior Design, 2012, 27(5): 35-38.

[9] 黄勇, 石亚灵. 国内外历史街区保护更新规划与实践评述及启示[J]. 规划师, 2015, 31(4): 98-104.

Huang Yong, Shi Yaling. Review and Implications of Domestic and International Practices in the Protection and Renewal Planning of Historic Districts [J]. Planners, 2015, 31(4): 98-104.

[10] 屠李, 张超荣, 赵鹏军. 走向可持续性保护: 城市遗产保护的理论与实践 [C]//新常态: 传承与变革——2015 中国城市规划年会论文集 (08 城市文化). 2015.

Tu Li, Zhang Chaorong, Zhao Pengjun. Towards Sustainable Protection: Theoretical Evolution and Planning Response in Urban Heritage Conservation [C]//New Normal: Inheritance and Transformation — Proceedings of the 2015 China Urban Planning Annual Conference (08 Urban Culture). 2015.

[11] 刘辉龙. 基于“有机更新”理论的北京南锣鼓巷历史文化保护区的提升策略[J]. 中国文化遗产, 2018(4): 85-92.

Liu Huilong. Strategies for Enhancing the Nanguo Drum Alley Historical and Cultural Protection Zone Based on the Theory of "Organic Renewal" [J]. Chinese Cultural Heritage, 2018(4): 85-92.

[12] 朱佳奇, 夏健, 刘露. 基于“城市触媒”理论的历史文化街区保护更新研究: 以苏州古城 15

号街坊为例[J]. 苏州科技大学学报(工程技术版), 2020, 33(2): 45-50.

Zhu Jiaqi, Xia Jian, Liu Lu. Research on the Protection and Renewal of Historical and Cultural Districts Based on the Theory of "Urban Catalyst": A Case Study of Block 15 in Suzhou Ancient City [J]. Journal of Suzhou University of Science and Technology (Engineering Technology Edition), 2020, 33(2): 45-50.

[13] 秦海东, 胡李平. 基于城市触媒效应的传统商业街区微更新策略[J]. 规划师, 2019, 35(S1): 81-86.

Qin Haidong, Hu Liping. Micro-Renewal Strategies for Traditional Commercial Districts Based on the Urban Catalyst Effect [J]. Planners, 2019, 35(S1): 81-86.

[14] 李和平, 靳泓, Terry N. Clark, 等. 场景理论及其在我国历史城镇保护与更新中的应用[J]. 城市规划学刊, 2022(3): 102-110.

Li Heping, Jin Hong, Terry N. Clark, et al. Place Theory and Its Application in the Protection and Renewal of Historical Towns in China [J]. Urban Planning Forum, 2022(3): 102-110.

[15] 吴军, 夏建中, 特里·克拉克. 场景理论与城市发展: 芝加哥学派城市研究新理论范式 [J]. 中国名城, 2013(12): 8-14.

Wu Jun, Xia Jianzhong, Terry Clark. Place Theory and Urban Development: A New Theoretical Paradigm of Urban Studies from the Chicago School [J]. China Famous Cities, 2013(12): 8-14.

[16] GLAESSGEN E, STARGEL D. The digital twin paradigm for future NASA and U. S. Air Force vehicles[C]//Proceedings of the 53rd AIAA/ ASME/ ASCE/ AHS/ ASC Structures, Structural Dynamics and Materials Conference. Honolulu, USA: AIAA, 2012.

[17] TAO Fei, ZHANG Meng, LIU Yu, et al. Digital twin driven prognostics and health management for complex equipment[J]. CIRP Annals-Manufacturing Technology, 2018, 67 (1):169-172.

[18] 陶飞, 刘蔚然, 张萌, 等. 数字孪生五维模型及十大领域应用[J]. 计算机集成制造系统, 2019, 25(1): 1-18.

Tao Fei, Liu Weiran, Zhang Meng, et al. A Five-Dimensional Model of Digital Twin and Its Applications in Ten Fields [J]. Computer Integrated Manufacturing Systems, 2019, 25(1): 1-18.

[19] 杨林瑶, 陈思远, 王晓, 等. 数字孪生与平行系统: 发展现状、对比及展望[J]. 自动化学报, 2019, 45(11): 2001-2031.

Yang Linyao, Chen Siyuan, Wang Xiao, et al. Digital Twin and Parallel Systems: Current Developments, Comparisons, and Prospects [J]. Acta Automatica Sinica, 2019, 45(11): 2001-2031.

[20] 党安荣, 王飞飞, 曲葳, 等. 城市信息模型 (CIM) 赋能新型智慧城市发展综述[J]. 中国名城, 2022, 36(1): 40-45.

Dang Anrong, Wang Feifei, Qu Wei, et al. Overview of the Empowerment of New Smart City

Development by Urban Information Modeling (CIM) [J]. China Famous Cities, 2022, 36(1): 40-45.

[21] 杨昕. 数字技术在历史建筑保护与修复中的应用研究[J]. 中国房地产, 2021(21): 74-79.

Yang Xin. Research on the Application of Digital Technology in the Protection and Restoration of Historical Buildings [J]. China Real Estate, 2021(21): 74-79.

[22] 周庆, 吕扬, 李兵. 多时态三维技术在历史文化街区保护中的应用: 以北京石景山区模式口文保区修缮整治为例[J]. 北京测绘, 2018, 32(1): 84-88.

Zhou Qing, Lyu Yang, Li Bing. Application of Multi-Temporal 3D Technology in the Protection of Historical and Cultural Districts: A Case Study of the Cultural Heritage Protection Area in Modekou, Shijingshan District, Beijing [J]. Beijing Surveying and Mapping, 2018, 32(1): 84-88.

[23] 陈仲光, 徐建刚, 蒋海兵. 基于空间句法的历史街区多尺度空间分析研究: 以福州三坊七巷历史街区为例[J]. 城市规划, 2009 (8): 92-96.

Chen Zhuguang, Xu Jiangan, Jiang Haibing. Research on Multi-Scale Spatial Analysis of Historical Districts Based on Space Syntax: A Case Study of Sanfang Qixiang Historical District in Fuzhou [J]. Urban Planning, 2009(8): 92-96.

[24] 秦晓珠, 张兴旺. 数字孪生技术在物质文化遗产数字化建设中的应用[J]. 情报资料工作, 2018(2): 103-111.

Qin Xiaozhu, Zhang Xingwang. Application of Digital Twin Technology in the Digital Construction of Material Cultural Heritage [J]. Intelligence and Information Work, 2018(2): 103-111.

[25] 吴志强, 甘惟, 臧伟, 等. 城市智能模型 (CIM)的概念及发展[J]. 城市规划, 2021, 45(4): 106-113.

Wu Qiang, Gan Wei, Zang Wei, et al. Concept and Development of Urban Intelligent Modeling (CIM) [J]. Urban Planning, 2021, 45(4): 106-113.

[26] 吴志强, 甘惟, 刘朝晖, 等. AI城市: 理论与模型架构[J]. 城市规划学刊, 2022(5): 17-23.

Wu Qiang, Gan Wei, Liu Zhaohui, et al. AI City: Theory and Model Architecture [J]. Urban Planning Forum, 2022(5): 17-23.

[27] 吴志强, 王坚, 李德仁, 等. 智慧城市热潮下的“冷”思考学术笔谈[J]. 城市规划学刊, 2022(2): 1-11.

Wu Qiang, Wang Jian, Li Deren, et al. Academic Symposium on "Cold" Thinking in the Wave of Smart Cities [J]. Urban Planning Forum, 2022(2): 1-11.

[28] 张智, 党安荣, 侯妙乐, 等. 长城文化遗产保护与利用的信息技术方法框架构建[J]. 遥感学报, 2021, 25(12): 2339-2350.

Zhang Zhi, Dang Anrong, Hou Miaole, et al. Framework Construction of Information Technology Methods for the Protection and Utilization of the Great Wall Cultural Heritage [J]. Journal of

Remote Sensing, 2021, 25(12): 2339-2350.

[29] 王承华, 张进帅, 姜劲松. 微更新视角下的历史文化街区保护与更新: 苏州平江历史文化街区城市设计 [J]. 城市规划学刊, 2017(6): 96-104.

Wang Chenghua, Zhang Jinshuai, Jiang Jinsong. Protection and Renewal of Historical and Cultural Districts from a Micro-Renewal Perspective: Urban Design of Pingjiang Historical and Cultural District in Suzhou [J]. Urban Planning Forum, 2017(6): 96-104.

[30] 杨俊宴. 从数字设计到数字管控: 第四代城市设计范型的威海探索 [J]. 城市规划学刊, 2020(2): 109-118.

Yang Junyan. From Digital Design to Digital Management: Exploration of the Fourth Generation of Urban Design in Weihai [J]. Urban Planning Forum, 2020(2): 109-118.

[31] 杨俊宴, 程洋, 邵典. 从静态蓝图到动态智能规则: 城市设计数字化管理平台理论初探 [J]. 城市规划学刊, 2018(2): 65-74.

Yang Junyan, Cheng Yang, Shao Dian. From Static Blueprint to Dynamic Intelligent Rules: Initial Exploration of the Theoretical Framework for Digital Management Platforms in Urban Design [J]. Urban Planning Forum, 2018(2): 65-74.

[32] 杨滔, 李晶, 张月朋, 等. 城市信息模型 (CIM) 平台顶层设计的理论与方法探讨: 以苏州为例 [J]. 城市发展研究, 2022, 29(7): 24-29.

Yang Tao, Li Jing, Zhang Yuepeng, et al. Theoretical and Methodological Exploration of the Top-Level Design of Urban Information Modeling (CIM) Platform: A Case Study of Suzhou [J]. Urban Development Research, 2022, 29(7): 24-29.

[33] 把握好现代化进程中传统与现代的关系 [EB/OL]. 人民日报. http://paper.people.com.cn/rmrb/html/2023-09/11/nw.D110000renmrb_20230911_1-09.htm, 2023-09-11.
Grasping the Relationship Between Tradition and Modernity in the Process of Modernization [EB/OL]. People's Daily. http://paper.people.com.cn/rmrb/html/2023-09/11/nw.D110000renmrb_20230911_1-09.htm, 2023-09-11.

[34] 吴军. 城市社会学研究前沿: 场景理论述评 [J]. 社会学评论, 2014, 2(2): 90-95.

Wu Jun. Research Frontiers in Urban Sociology: A Review of Place Theory [J]. Social Science Review, 2014, 2(2): 90-95.

[35] 温雯, 戴俊骋. 场景理论的范式转型及其中国实践 [J]. 山东大学学报(哲学社会科学版), 2021(1): 44-53.

Wen Wen, Dai Juncheng. Paradigm Transformation of Place Theory and Its Chinese Practice [J]. Journal of Shandong University (Philosophy and Social Sciences Edition), 2021(1): 44-53.

[36] 李明. 浅谈分布式数据库在组织机构代码系统中的应用 [J]. 山东纺织经济, 2007(4): 2.

Li Ming. A Brief Discussion on the Application of Distributed Databases in the Organizational Code System [J]. Shandong Textile Economy, 2007(4): 2.

[37] 黄永林, 李媛媛. 文化强国战略背景下的 中国文化遗产保护与利用[J]. 理论月刊, 2022(3): 68-78.

Huang Yonglin, Li Yuanyuan. Protection and Utilization of China's Cultural Heritage under the Background of the Cultural Powerhouse Strategy [J]. Theoretical Monthly, 2022(3): 68-78.