Journal of World Architecture, 2025, Volume 9, Issue 4
https://ojs.bbwpublisher.com/index.php/JWA
Online ISSN: 2208-3499
Print ISSN: 2208-3480

Analysis of GIS Technology Application in Urban Planning from the Perspective of Smart Cities

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Abstract: The world is being swept by the wave of smart cities, and Geographic Information System (GIS) technology plays a key role in it. This article explores the application status and development trend of GIS technology in urban planning from the perspective of smart cities. By sorting out the application value of GIS in urban strategic layout, multi system collaboration, and precise services, it explains the necessity of promoting the transformation of planning towards intelligence. We have summarized and organized the practical points of GIS in areas such as overall planning, underground space, landscape, and transportation, including spatial simulation, 3D management, ecological integration, and dynamic optimization. Looking ahead to the future, the cross integration of GIS with artificial intelligence, 3D modeling, carbon neutrality monitoring, data collaboration, and other technologies will drive planning towards a new stage of development that is more intelligent, refined, open, and green. With the empowerment of GIS, we aim to create sustainable cities that are resilient, low-carbon, and inclusive, making urban life better.

Keywords: Smart city; Urban planning; GIS

Online publication: 4th September 2025

1. Introduction

Cities, the crystallization of human civilization, are undergoing a transformation from tradition to wisdom. In this transformation, the application of GIS technology has attracted much attention. GIS, as the core support of digital cities, is profoundly reshaping the concepts and methods of urban planning. On the one hand, the construction of smart cities has put forward new requirements for multi-source data fusion, real-time perception, and accurate analysis, and GIS has become a powerful tool to crack the "urban disease". On the other hand, the internal and external environment of cities is constantly changing, and GIS provides spatial and temporal thinking for planning and decision-making, helping to promote the resilient development of cities. Standing at the forefront of smart cities, examining the application landscape of GIS in urban planning is of great significance for promoting innovation in planning theory and practice.

2. The necessity of applying GIS technology in urban planning from the perspective of smart cities

2.1. Strategic planning drives resource allocation

The construction of smart cities requires consideration of different dimensions such as economy, society, and ecology, and requires balancing the relationship between population and resources, environmental capacity, and infrastructure, which poses higher demands on macro-level decision-making in cities. GIS technology can provide necessary spatial thinking and analytical tools for strategic planning. Firstly, the GIS platform can integrate multiple sources of data, such as land, planning, environmental protection and more [1], to construct a "map" of urban development, visually presenting the background of resources and environment, allowing decision-makers to examine urban issues from a global perspective, and laying the spatial foundation for top-level design. Secondly, GIS spatial analysis can simulate the impact of different policy scenarios on urban systems, optimize resource allocation plans, and avoid blind decision-making. In addition, major national strategies have put forward new requirements for urban development, and GIS plays a key role in identifying land development boundaries, monitoring carbon emission hotspots, and helping cities implement goals and tasks such as land conservation and intensive use, green and low-carbon development [2].

2.2. System collaboration achieves fine governance

A smart city is an organic whole that operates in coordination with multiple systems, involving many fields such as energy, transportation, and water management. Breaking down the "information silos" between departments and achieving interconnectivity among multiple systems requires the traction and pivotal role of spatial data. GIS can provide a unified spatial reference framework for cross departmental collaboration. On the one hand, each department can aggregate and overlay their own facility data [3], such as underground pipelines, streetlight poles and so on. At the same electronic map to achieve integrated management and comprehensive utilization of spatial data. On the other hand, GIS can be integrated with real-time monitoring systems such as the Internet of Things to dynamically collect operational status data of urban components, and combined with spatial analysis models to timely detect facility faults and hidden dangers, achieving refined management. In addition, urban development is constantly changing, and static planning is difficult to adapt to the new situation. GIS can integrate remote sensing, big data and other technologies to dynamically perceive changes in urban texture and simulate future development scenarios, providing scientific basis for planning adjustment and improvement [4].

2.3. Scene implementation improves service quality

The construction of smart cities should focus on the people and provide precise and inclusive public services, which poses new challenges to the government's governance capacity. The spatial analysis and modeling functions at the micro scale of GIS provide strong support for promoting service implementation. Firstly, GIS can analyze the spatiotemporal behavioral characteristics of residents' travel and consumption [5], optimize the location selection and service supply of community level public service facilities, and enable more services to run and fewer people to run errands. Secondly, GIS 3D pipeline modeling can coordinate the relationship between aboveground and underground spaces, guide municipal infrastructure construction, improve engineering quality, and reduce construction risks. Once again, GIS can create immersive virtual reality scenes, allowing planning and design schemes to go beyond the drawings and solicit public opinions in a more intuitive and interactive way, enhancing the transparency and sense of identity of planning. In short, GIS provides a rich toolbox for the scenario-based application of smart cities, which helps to achieve the service tenet of "everything around the people, everything for the people” [6].

3. Key points of GIS technology application in urban planning from the perspective of smart cities

3.1. Urban master plan

The overall urban planning is a guiding document for overall urban development, and the introduction of GIS technology injects new vitality into the planning process. In terms of multi scenario simulation, GIS platform can integrate multidimensional data such as population, economy, land, transportation, and more. To construct urban digital twin models covering multiple systems of nature, society, and economy. Planners can set different policy scenarios in the digital space, such as industrial structure adjustment, population growth patterns, infrastructure layout and simulate various possible paths of urban future development, and use GIS spatial analysis tools to evaluate the impact of each plan on economic growth, environmental quality and social equity. Through comprehensive analysis, the optimal planning strategy can be selected to improve the scientific and forward-looking nature of planning [7]. In terms of land intensive use assessment, GIS can accurately depict the urban “three life space” pattern, identify permanent basic farmland, ecological protection red lines, and urban development boundaries, and establish a “three zone and three lines” control system. On this basis, GIS can comprehensively evaluate the location conditions, resource endowments, and environmental capacity of each plot, calculate development intensity, identify inefficient land use, propose differentiated land use optimization strategies, maximize land resource conservation, and promote high-quality urban development. At the same time, GIS is also a powerful tool for planning implementation supervision, which can timely detect illegal land use behavior and ensure the implementation of planning [8].

3.2. Underground space planning

Underground space is an important resource for alleviating urban land scarcity and optimizing above ground spatial layout, but its planning and construction involve complex factors such as geology and pipelines, which require higher requirements for information technology. The integration of GIS and BIM technology can break through the limitations of traditional two-dimensional planning and achieve refined management of the entire lifecycle of underground space. During the planning and design phase, GIS can construct a three-dimensional geological model and integrate data such as underground pipelines and buildings into a unified spatial reference frame, forming a digital twin of underground space. This facilitates the optimization of pipeline layout in three-dimensional scenes, identifies spatial conflicts in advance, and reduces design iterations. Based on the 3D pipeline model, planners can carry out vertical pipeline design, net distance analysis and forth, capable to improve pipeline utilization efficiency. In the operation and maintenance management stage, GIS can integrate IoT monitoring data, real-time control the temperature, humidity, stress and other state parameters in the pipeline gallery, and use big data analysis technology to construct pipeline health diagnosis and fault warning models, timely discover hidden dangers such as leakage, fracture and deformation to achieve visual and intelligent operation and maintenance of pipeline facilities, extend service life, and reduce safety risks. In addition, GIS can also simulate emergency evacuation in underground spaces, optimize disaster prevention and shelter routes, and enhance urban safety resilience [9].

3.3. Urban landscape planning

Urban landscape carries people's expectations for a better life and is also an important indicator of the level of urban ecological civilization. GIS technology, with its powerful spatial analysis and visualization capabilities, provides strong support for creating livable urban landscapes. At the macro level, GIS can outline the situation of regional ecological background, identify the spatial arrangement pattern of natural elements such as mountains, waters, forests, fields, lakes, and grasses, and evaluate their ecosystem service functions, such as water conservation and biodiversity maintenance. Based on this, the layout of regional ecological corridors can be optimized to maintain urban ecological security [10]. Taking the construction plan of the ecological corridor in the Inner Mongolia section of the Yellow River Basin as an example, Xiaocao Digital conducted precise analysis of the ecosystem through GIS and remote sensing technology. The study found that 54% of the low safety level areas were located within the 10 km riparian zone outside the embankment of the Yellow River main stream. The ecological corridor space was scientifically defined as 10km outside the embankment of the Yellow River main stream and 2 km on both sides of the primary tributaries, forming a continuous, open, stable, and self-sustaining green landscape system. At the meso level, GIS can measure the spatial structure and connectivity level of urban green spaces, identify issues such as green space fragmentation and landscape segmentation, and simulate and optimize green space layout, develop ecological restoration plans, and build an "urban green lung". GIS can also evaluate the level of green spaces in recreational services and allocate open spaces such as parks and green spaces reasonably. At the micro level, GIS can integrate technologies such as 3D modeling and environmental simulation to create an immersive landscape visualization platform, allowing planners to experience the landscape effects of different plant configurations and small piece placements in a virtual context, and select the optimal design solution [11].

3.4. Urban transportation planning

Transportation is the artery of urban economic and social development, as well as a key factor influencing residents' quality of life. GIS technology has been widely applied in the field of transportation planning, providing decision-making ideas for alleviating urban congestion and creating a green transportation system. In terms of transportation demand analysis, GIS can integrate multiple sources of transportation big data, such as video surveillance data, vehicle GPS data, IC card swiping data and so on. To determine the traffic status of roads real-time and combine machine learning algorithms to consider factors such as holidays and major events, estimate future transportation demand, and dynamically change traffic control methods, such as signal timing settings, tidal lanes, and more in order to alleviate local road congestion. In terms of planning for slow-moving systems, GIS can evaluate the spatial distribution and service quality of existing pedestrian and bicycle lanes, identify breakpoints and congestion points in the slow-moving network, simulate and optimize traffic paths, provide strategies such as adding non-motorized lanes and improving supporting facilities, create a coherent and comfortable pedestrian and cycling space, and promote green travel [12]. In terms of optimizing the public transportation network, GIS can explore the spatiotemporal distribution characteristics of residents' travel "starting and ending points", identify peak passenger flow areas, and consider the degree of adaptation to land use. It can implement simulation optimization of conventional public transportation and rail transit routes, improve the coverage area and transfer convenience of public transportation, and ultimately achieve the goal of creating a "public transportation metropolis". For example, at the 2022 Winter Olympics, the intelligent transportation planning system developed using GIS and big data played a crucial role. By simulating different traffic control schemes in advance and simulating different traffic operation situations during the event, it improved the level of transportation organization strategies and ensured smooth traffic operation during the event.

4. The development trend of GIS technology application in urban planning from the perspective of smart cities

4.1. AI + GIS technology fusion drives intelligent decision-making

The deep integration of artificial intelligence and GIS is reshaping the technological paradigm of urban planning. In terms of data collection, AI enabled remote sensing image interpretation can quickly and accurately extract land use status, and combined with machine learning algorithms, achieve automatic detection and early warning of land use changes, greatly improving planning and supervision efficiency. In terms of data analysis, the combination of knowledge graph and GIS can deeply explore the complex relationships between driving factors of urban development, reveal the internal mechanisms of urban evolution, and intelligently generate planning indicator systems based on logical reasoning, optimize urban functional layout, and avoid empirical decision-making. In terms of data simulation, the integration of multi-agent models and GIS can set behavioral rules for different groups in digital twin cities, simulate the emerging characteristics of traffic flow and pedestrian flow in complex road networks, and optimize urban infrastructure configuration through parameter tuning, making city operations smoother. In addition, the rise of the concept of metaverse has opened up new imaginative space for planning and development. The deep integration of GIS with virtual reality, human-computer interaction and other technologies will bring about a new mode of immersive and experiential planning and design.

4.2. Deepening the application of 3D GIS and building an integrated system

With the advancement of surveying and mapping technologies such as LiDAR and oblique photography, urban 3D modeling is becoming increasingly sophisticated, empowering and enhancing planning and management. In terms of underground space governance, 3D GIS can finely depict the spatial location and attribute characteristics of underground pipelines, break through the limitations of traditional 2D planes, and achieve integrated management of the entire process of pipeline comprehensive planning, vertical design, and net distance analysis, effectively avoiding chaos such as repeated excavation and spatial conflicts. In terms of above ground building control, the integration of 3D GIS with BIM, CIM and other technologies can achieve seamless connection from overall planning to detailed construction planning and building design. Planners can accurately control the volume, height, setback and landscape corridor of buildings in three-dimensional scenes, and dynamically simulate the construction effect to enhance the seriousness and authority of planning [13]. In terms of low altitude management, the emergence of new formats such as drones and "flying" taxis pose new challenges to urban low altitude order. 3D GIS can simulate air traffic corridors, optimize route organization, and monitor aircraft status in real-time, effectively avoiding air congestion and safety hazards.

4.3. Carbon neutrality monitoring creates green planning tools

The "dual carbon" goal injects strong impetus into the green transformation of urban planning, and GIS, as an important tool for carbon emission accounting, will help generate and optimize low-carbon urban planning schemes. In terms of carbon emission monitoring, GIS can integrate multi-source data such as energy monitoring systems and atmospheric environment sensing networks, and embed carbon emission accounting models to build a carbon emission spatiotemporal big data platform covering key areas such as industry, construction, and transportation. By using machine learning algorithms to mine historical data, it is possible to achieve carbon emission warning by region and industry, identify high carbon blocks, and guide the formulation of differentiated emission reduction policies. In terms of carbon sequestration potential assessment, GIS remote sensing monitoring can accurately identify key parameters such as vegetation type and coverage, and combine carbon sequestration models to evaluate the carbon sequestration capacity of different ecosystems such as forests, wetlands, and grasslands, optimize carbon sequestration spatial layout, and maximize regional carbon neutrality potential [14]. In the planning of near zero carbon communities, GIS can integrate building energy consumption models to analyze the energy demand of communities under different orientations and spacing layouts, and optimize energy-saving renovation strategies for existing communities. For newly built communities, GIS can perform parametric simulations of multiple factors such as building volume, rooftop photovoltaics, and energy storage facilities, generating design combinations with near zero carbon emissions, providing solutions for achieving community level carbon neutrality.

5. Policy standards drive collaborative governance of data

With the intensive introduction of new smart city policies at the national and local levels, the construction of urban spatiotemporal big data platforms is in full swing, and the GIS data exchange and sharing mechanism is becoming increasingly perfect. In terms of top-level design, local governments take the lead in formulating data submission standards and management norms, clarifying the data submission responsibilities of departments such as natural resources, planning, housing and construction, ecological environment, emergency management, and other related departments, breaking down data barriers, and achieving cross departmental data "one map" management.

A unified spatiotemporal framework allows data to run more and people to run less errands. In terms of data opening, on the premise of protecting privacy and national security, the government actively explores the market-oriented allocation path of data resources, encourages market entities such as Internet platforms, operators, scientific research institutions to participate in data sharing and opening, makes good use of social data resources, and cultivates new momentum of the digital economy. In terms of data application, the combination of GIS and blockchain technology can achieve secure storage and traceability of data throughout the planning process, and plug the loopholes in the transfer of benefits in the approval field. The rise of low code GIS platforms will promote rapid iteration of planning industry applications. Planners can easily develop personalized applications without complex programming foundations, shortening the innovation cycle of applications. With the deepening of the construction of digital twin cities, GIS will become an important platform for multi professional collaboration and multi departmental linkage, helping to create an integrated urban digital management paradigm that covers the entire cycle, all elements, and all processes [15].

6. Conclusion

Smart cities open a window for innovative thinking in urban planning, and the application of GIS technology has moved from being a "timely aid" to being a "icing on the cake". From macro decision-making to micro implementation, from static planning to dynamic governance, GIS provides strong support for the full cycle, full factor, and full process management of urban development. In the future, with the accelerated penetration of new technologies such as artificial intelligence, big data, cloud computing, and blockchain, GIS will be deeply integrated with multiple disciplines, continuously expanding its application boundaries and promoting the formation of a new paradigm of intelligent planning that is self-aware, self-analyzing, self-deciding, and self-executing. In the era of digital twins, planning will move from blueprint depiction to real-time simulation, from expert opinions to public participation, and from government leadership to multi-party collaboration. Under the guidance of the dual carbon target, the plan will shift from focusing on economic indicators to emphasizing ecological civilization, and from extensive growth to green intensification.

Disclosure statement

The author declares no conflict of interest

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