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A CONCEPTUAL MODEL FOR IMPLEMENTING DIGITAL TWIN TECHNOLOGY TO ADDRESS SUSTAINABLE URBANIZATION CHALLENGES IN SMART TASHKENT

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Abstract: This paper proposes a conceptual digital twin model for managing traffic congestion, air pollution, pressure on utility networks, water and energy consumption, construction density, and emergency risks in Tashkent within a unified data environment. The model integrates geographic information systems, Internet of Things sensors, municipal registers, artificial intelligence, and scenario simulation. Its purpose is to test planned measures in a virtual environment before decisions are made, assess their resource and environmental effects, and coordinate municipal services.

Keywords: digital twin, smart city, sustainable urbanization, geographic information system, Internet of Things, artificial intelligence, urban governance, Tashkent.

Relevance of the Problem

Population growth, rising vehicle ownership, and intensive construction are increasing pressure on Tashkent's urban infrastructure. Traffic flows, land use, public transport, air quality, urban heat islands, and electricity and water networks are interdependent, yet the relevant data are produced separately by different public bodies. A decision taken in one sector may therefore create unexpected costs or environmental effects in another. For example, if a new residential complex is assessed only against construction parameters, insufficient road capacity, schools, clinics, water supply, and waste collection may be identified only after the project has advanced.

The Digital Uzbekistan 2030 Strategy, approved by Presidential Decree No. PF-6079, sets objectives for the digital transformation of territories and sectors and for broader data-driven governance [1]. A digital twin can serve as a practical city-level platform for implementing these objectives. It is more than a three-dimensional map: it is a dynamic model that regularly updates the condition of physical assets, calculates their interactions, and tests management scenarios before implementation.

Research Objective and Method

The objective of this research is to develop a phased digital twin model for Tashkent that covers the entire process from data collection to the assessment of management decisions. The study applies systems analysis, functional modelling, and scenario assessment. The model links the social, economic, and environmental indicators of sustainable urbanization within a single decision-making environment.

Conceptual Digital Twin Model

The proposed model consists of five interconnected layers. The first is the city's base spatial model, in which buildings, land parcels, roads, green areas, utility networks, and social facilities are represented in a common coordinate system. The second layer contains dynamic data. Information from traffic detectors, weather stations, air-quality sensors, smart meters, dispatch systems, and citizen requests is received with time stamps.

The third layer integrates data and controls its quality. Common identifiers, a data catalogue, and interagency application programming interfaces are used to detect duplicate or conflicting records. The fourth layer performs analysis and forecasting by modelling traffic flows, the dispersion of air pollution, water pressure, electricity loads, access time to services, and emergency scenarios. The fifth layer provides decision-making interfaces for municipal leaders, dispatchers, planners, and the public.

Layer	Core Components	Management Outcome
Spatial	3D GIS, cadastre, buildings, roads, and networks	View assets and constraints on one map
Data	IoT, registers, dispatch systems, and citizen requests	Monitor city conditions in near real time
Integration	APIs, catalogue, identifiers, and quality controls	Coordinate interagency data
Analytics	AI, forecasting, simulation, and risk models	Assess consequences before decisions
Governance	Dashboards, alerts, and an open portal	Make timely and accountable decisions

Priority Use Cases

In the transport use case, road sections, traffic lights, public transport, and parking facilities are calculated in one model. Before a road, bus route, or signal plan is introduced, its effects on travel time, congestion, and emissions are compared. The environmental use case connects air-quality, wind, green-space, and transport data to identify pollution hotspots and estimate the likely effect of greening measures. The utility use case forecasts water losses, pressure drops, electricity loads, and failure risks.

The urban planning use case assesses a proposed development or reconstruction project against population density, transport demand, solar access, green space, social services, and network capacity. The emergency module calculates evacuation routes and service response times for earthquakes, flooding, fires, or major traffic incidents. Each scenario compares indicators for the current state, the proposed option, and an alternative option.

Implementation Stages and Governance

The first stage should select three pilot areas and clearly defined problems: a congested junction, an area with poor air quality, and a neighbourhood with frequent utility failures. A base 3D GIS, data catalogue, and interagency exchange rules would then be established. In the second stage, sensors and existing information systems would be integrated, and forecasting models for transport and utility networks would be launched. In the third stage, the solution would be expanded across the city and a requirement introduced for major development projects to undergo digital simulation.

A governance council under the city administration should include data owners, sector agencies, the platform operator, and research institutions. The owner, update frequency, and quality indicator must be defined for each dataset. Personal data should be collected only to the minimum extent necessary, aggregated where possible, and protected through role-based access. The cybersecurity architecture should cover segmentation, logging, backup, and operational continuity.

Performance Indicators

Project performance should be measured by urban outcomes rather than by the number of installed sensors. Core indicators may include average travel time on pilot routes, public transport schedule adherence, the time needed to detect and repair network failures, water losses, energy use, pedestrian access to green spaces and social facilities, hours when air-quality limits are exceeded, and the share of investment projects assessed through the model. Baseline values should be measured before each pilot and results published quarterly.

Conclusion

Tashkent's digital twin should function as a mechanism for testing planning and operational decisions in a unified model, rather than as another information system that merely consolidates municipal data. The proposed five-layer model accounts for the links between transport, the environment, utility infrastructure, and construction. Starting with focused pilot areas, using open standards, assigning responsibility for data, and adopting outcome-based indicators will reduce implementation and investment risks. On this basis, a digital twin can make sustainable urbanization part of Tashkent's routine governance practice.

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