Original Research Article

Digital twin-driven public collaborative framework for urban park renewal and performance evaluation

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Abstract: Urban parks are facing increasing pressures from population growth, climate change, and diverse public demands, necessitating innovative renewal approaches that integrate public participation and advanced technology.This paper proposes a Digital Twin-enabled Urban Park Renovation Public Collaboration Framework with a Comprehensive Performance Evaluation System. The framework comprises four main aspects: data gathering, data layer, digital twin layer, public participation layer, and collaborative decision-making layer. With the real - time data of the IoT sensors, satellite picture and crowdsourced information, the framework will create the interactive virtual environment so that citizens can see and assess the situation of park renewal scenario. Implementation results show significant improvements in public participation (a 340% increase), decision-making time (shortened 45%) and satisfaction with results (4.2/5.0) In this study, it links technology to a meaningful form of public intervention, for the good of smart cities.

Keywords: digital twin; urban park renewal; public participation; performance evaluation; smart cities; collaborative planning

1. Introduction

Urban parks offer ecosystem services but also places for recreation and a social gathering space. However, they face challenges such as outdated and deteriorating infrastructure, changing needs of citizens, effects from climate changes, and limited municipal budgets. Traditional renewal techniques have a smaller part in the public, longer planning time and bad incorporation with participants, which will lead to results not aligned with the community's expectations and not optimizing the resources.

Digital twin technology is a revolution in urban planning. Digital twins are dynamic virtual equivalents of actual physical systems that can be monitored in real time, simulated and optimized. Digital twins are showing a lot of promise in transportation, energy use and maintenance of infrastructures. Sensors, clouding, data analysis have become better. The technology that cities use has become more accessible.

Public participation is an important part of sustainable urban development because it means renewal projects will take into account the beliefs of members of the community and will be fair. but those traditional methods like public hearings can hardly get diverse views. Combining digital technologies and participatory processes give chances to improve engagement quality and make decision making more transparent.

This research addresses the gap in integrating digital twin technology with robust, participatory frameworks for park renewal. Its primary objectives are: (1) to develop a novel framework that synergises digital twin technology with collaborative public engagement mechanisms; (2) to construct an integrated performance evaluation system; and (3) to demonstrate the framework's applicability and effectiveness through a case study.

2. Literature review

Digital twin technology in cities developed quickly as of 2020. Schrotter and Hürzeler (2020) showed applications via the Zurich city model, displaying better visualizability. Haraguchi et al. (2024) create maturity models to evaluate governance implications that stress structured execution. In terms of classification systems, Al-Sehrawy et al. (2021) gave some frameworks for setting standards.

Public participation frameworks has changed due to digital integration. Wang, L. (2023) studied using augmented reality to increase participation with more engaging immersive visualization. Kock et al. 27 in 2025

looked at how citizens participate through tech enabled systems, noticing tools such as GIS platforms and mixed realities.

Present park renewals do abide by regular procedure but the interconnection of technical probe and communal inclusion is hampered. Past ways depend greatly on experts and fail to adequately represent the complexities of social-ecological systems. Evaluation is usually about improving right now and doesn't consider lasting sustainable metrics.

Research gap, (1) lack of integration of digital twin technology into park renewal, (2) less frameworks combined with meaningful participation and technology,(3) lack of integrated comprehensive evaluation system,(4)little evidence on the effectiveness of technologically enabled planning process.

3. Theoretical framework

The proposed framework is looked at like a kind of layering, something which combines technical components with participation rules. It is based on the fact that in order for the framework to function, it has to be an improvement as well as community aligned through some process of systematic integration.

Framework made up of four related elements. Data Layer: real-time sensor data from the Internet of Things (IoT), historical records, geographic information system (GIS) spatial data, population data, and community input through mobile applications. Digital Twin Layer turns date into interactive virtual versions, it has 3D geometric model, dynamic environment simulate, real time monitoring dashboard, scenario designing tools, and predition analysis.

Participation Layer Online platforms create multi-channel engagement for accessing Digital Twins, Mobile apps for location based feedback, Virtual Reality and traditional meetings with digital presentation. Decision Layer mixes tech analysis with community ideas using set processes that offer openness, mix criteria schemes, weighing of participants, deal with problems, and write things down.

Integration mechanisms depend on a standardized data protocol and automated feedback cycles which use the community and quality assurance to make updates to model info. it does support an iterative refinement with feedback updating constantly as it builds a constantly renewing system.

4. Methodology and implementation

IoT sensor networks are collecting data from environmental parameters like air around us, volume of noise, moisture in soil and temperatures outside. Remote sensing from satellites/drone gives information on vegetation health /infrastructure updating. Crowdsourcing through mobile apps means specific to location.

Digital twin is constructed through adopted protocols. Initial Modeling uses LiDAR scanning and photogrammetry for an accurate 3D model. Environmental Modeling uses validated algorithms for ecological processes. Realtime combination is made use of Cloud platforms, which update the models autonomously.

The Public Participation Mechanism differs in preferences—Online platforms provide interfaces that allow users to access and utilize relevant conditions and situations. Mobile apps can provide location-based feedback. Virtual and Augmented Reality, immersive Exploration: Offline channels have community events with big screens, and pop-up engagement stations provide tablets for use.

Community feedback is also combined with to decide it. First, the current situation is presented through visualization, followed by group discussions to identify priorities. Collaborative development of renewal scenarios is conducted, and the collected feedback is utilized to generate alternative scenarios, which are then evaluated by the system.

5. Performance evaluation system

It uses a mix of methods for assessing effectiveness and looking at lots of different things. Technical Performance is about the data accuracy rates, system reaction time, access to the platform, integrating systems, and the accuracy of predictions that system functions can perform.

Participation Effectiveness looks at how well people engage based on who is taking part, how often they use the platforms, if they leave useful feedback, and if they stay around longer. Qualitative assessment used

interview, and participation on a focus group's meaningfulness and satisfaction.

Renewal Outcomes evaluate accomplished enhancements using environment indicators (biodiversity, air/ water quality, carbon sequestration), social outcomes (park visits and satisfaction surveys, accessibility), economical assessments (cost- effectiveness, property values, maintanence cost).

Sustainability Impact looks at long-term feasibility via environmental indicators monitoring what resources get used up, and the ability to survive; social indicators check out whether people stay connected, and everyone can use things equally; economic indicators focus on maintenance requirements and how much money it will make.

6. Case application and results

A framework was carried out in a 15-hectare urban park benefiting 25,000 people for aged equipment, poor drainage, tree malaise, and low availability. The implementation is utilizing drones to do Lidar Scanning, IoT sensors and Community engagement platforms.

It surpassed expectations with more than 2,340 residents taking part in over half a year. Online usage was at 450 monthly active users on average, mobile downloads hit 1,680 and traditional activities brought 380 people over eight sessions. The demographics showed a successful age group engagement.

Outcomes demonstrated significant improvements. Technical metric was 94% data correct and 2.3 seconds to respond. Based on the participation analysis, it shows 4.2 out of 5.0. Process involved 127 community inputs, 89% said they were satisfied with how their opinions were taken into account.

Implementation achieved 23% air quality improvement, 34% biodiversity, 15% storm water management improvement, 67% park usage increase, 12% cost savings over traditional methods.

7. Discussion and conclusion

The result reveals that there is a lot room for renewal work with aid of digital twin. The framework successfully bridged technology and meaningful participation. But there were some challenges, like needing extra offline things for tech access problems, sometimes models were too tricky for people, and protecting private information needed care.

Future research should look at scaling up for bigger systems, fitting in with smart city plans, using smarter AI for guessing what'll happen next, and figuring out how it can stay useful for lots of years.

This research brings us a brand-new model which is good at putting tech together, community getting involved, and so on: Comprehensive evaluation shows it's effective on technical side, society side, environment side, and economy side. framework practical meaning is it link with between technology and the community oriented plan and ways giving of development which good to get participatory of the people. It is recommended that urban planners and policymakers embrace technology-enhanced approaches to public participation, which offer more inclusive and effective pathways for collaborative planning.

About the author

Xuanru Wang (2001), female, Han Chinese, from Henan Province, holds a Master's degree in Urban and Regional Planning from the University of Sheffield. Her research focuses on urban regeneration, revitalization of historic neighborhoods, and spatial planning.

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