WWW.IJRPR.COM

**International Journal of Research Publication and Reviews**

Journal homepage: www.ijrpr.com ISSN 2582-7421

# Urban Digital Twins for Resilient Cities in Africa: Opportunities and Challenges for Geospatial Risk Management in Kinshasa

*Osako Longongo Willy[1*], Ngoy Nziam-Eyabii Germaine[1], Iyoya Otuli Jean-Nestor[1], Wagu Andia Francoise[1]*

[1] *Department of Hydraulic and Environmental Engineering, Institut du Bâtiment et des Travaux Publics (IBTP), Kisangani, DRC*

**A B S T R A C T**

Urban Digital Twins (UDTs) represent an innovative frontier for enhancing urban resilience and sustainable development in rapidly growing African cities such as Kinshasa. This review synthesizes the current state of digital twin technologies, their benefits, and challenges in the context of Kinshasa's complex geotechnical and hydrological risk landscape. We analyze opportunities for leveraging UDTs to improve urban planning, disaster risk management, and service delivery, while critically examining barriers including data scarcity, technical capacity, governance gaps, and infrastructure limitations. The study highlights the necessity of localized capacity building, participatory governance, and strategic investments to realize the full potential of UDTs. Our findings suggest that, despite challenges, Urban Digital Twins offer a transformative tool for fostering resilient, inclusive, and sustainable urban futures in Kinshasa and other rapidly urbanizing African cities.

**Keywords:** Urban Digital Twins, Kinshasa, Geotechnical Hazards, Hydrological Risks, Urban Resilience, Data Governance, Smart Cities, Disaster Risk Management

## 1. Introduction

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 9.5 pt. Here follows further instructions for authors.

### *1.1 Definition of urban digital twins and geospatial technologies*

Urban Digital Twins (UDTs) are virtual replicas of real-world urban environments that integrate physical objects, dynamic processes, and their interrelationships, updated continuously through real-time geospatial data (e.g., from IoT sensors, satellite imagery, UAVs) (Esri, n.d.; Scholl & Klien, 2024). They are grounded in GIS frameworks, offering scalable, time-aware, and interactive modeling that captures historical states, current conditions, and predictive future scenarios of urban systems (Esri, n.d.; Scholl & Klien, 2024). UDTs support visualization, simulation, analytics, and decision support for cities (Scholl & Klien, 2024).

These systems integrate several technological components :

- GIS and geospatial data systems: Provide the spatial referencing and analytical backbone crucial for representing urban infrastructures and their relationships to natural environments (Esri, n.d.; ISO/OGC, 2024).
- Remote sensing and UAV photogrammetry: Offer high-resolution spatial inputs for updating 3D city models and detecting environmental changes (Esri, n.d.; Scholl & Klien, 2024).
- IoT and sensor networks: Deliver real-time data (e.g., environmental monitoring, traffic flow) to animate digital replicas and support situational awareness.
- AI/ML models: Enable predictive forecasting (e.g., flood risk, infrastructure stress) and automated scenario simulations, transforming UDTs from static representations into decision-making tools (El Agamy et al., 2024).

Together, these enable UDTs to serve as "living models" that support urban resilience, planning, governance, and citizen engagement through integrated, geospatially enabled systems (ISO/OGC, 2024; El Agamy et al., 2024).

### *1.2 The role of digital twins in smart and resilient cities*

Digital twins have become crucial instruments in enhancing urban resilience, helping cities combat climate change, natural disasters, and infrastructure inefficiencies. A digital twin in the urban context—defined as a continuously updated virtual model of a city's physical systems—enables real-time monitoring, simulation, and decision-making to safeguard city systems (Reuters, 2024).

By leveraging digital twin technology, cities like Singapore, Houston, and Amsterdam have strengthened their capacity to manage environmental stressors such as flooding, urban heat, air pollution, and waste management (Reuters, 2024). These systems assimilate real-time data from various sensors—IoT, satellite, and UAV—to drive adaptive urban planning and sustain critical services (Reuters, 2024). ABI Research estimates that over 500 cities will employ digital twins by 2025, with potential savings of USD 280 billion by 2030 through improved resource management (Reuters, 2024).

Notably, UDTs support climatic and disaster resilience by embedding simulation and predictive analytics for scenario planning. Using a bidirectional feedback loop between the digital and physical realms, they enable comprehensive risk modelling, early warning systems, and emergency response (ScienceDirect, 2024; MDPI Sustainability, 2022). Such resilience-focused applications include infrastructure management during floods, heat events, and structural failures (ScienceDirect, 2024).

However, deploying UDTs involves intricate stakeholder collaboration, governance regulation, and privacy safeguards. Instances like the halted digital twin projects in Portland and Toronto highlight the necessity of transparency and robust data governance (Reuters, 2024). Consequently, for a city such as Kinshasa—characterized by informal settlements, data scarcity, and limited institutional capacity—applications must be carefully tailored, ensuring community involvement and ethical alignment.

### *1.3 Kinshasa's urban context: challenges of rapid urbanization, informality, and infrastructure fragility*

Kinshasa, the capital of the Democratic Republic of Congo, is one of Africa's largest and fastest-growing cities, with an urban growth rate estimated at 5.1% in 2022 and a daily increase of approximately 2,000 residents over about five hectares, signaling dramatic demographic expansion (World Bank; Globe Banner, 2024; Wolff et al., 2024). The city's population has ballooned from roughly 400,000 in 1960 to over 15 million—or possibly up to 20 million—today (Wolff et al., 2024; Wikipedia, 2025).

This expansion has led to significant urban sprawl, largely unplanned, with around 75% of residents living in informal settlements lacking formal service access (Pathfinders, 2025; SDG16.plus, 2025). Most new developments are built without basic infrastructure—such as drainage, sanitation, water supply, roads, or electricity—which increases vulnerability to environmental hazards (Le Monde, 2022; Wikipedia, 2025).

Frequent floods and landslides highlight this fragility: in December 2022, heavy rains caused at least 141 deaths and affected over 12 million residents, with thousands of homes damaged or destroyed (Wikipedia, 2025; Le Monde, 2022). The city also faces heat islands, soil erosion, waste accumulation, and weak state capacity in infrastructure planning and maintenance (Globe Banner, 2024; Wikipedia, 2025; World Bank, 2024).

Overlaying these physical challenges is persistent inequality tied to colonial and post-colonial planning. Elite-driven housing finance strategies have ignored the needs of low-income residents, reinforcing exclusion and spatial segregation (IIED, 2025; Pathfinders, 2025). Additionally, urban governance frameworks remain outdated—with primary plans drawn in 1967 rarely enforced, and fragmented institutions and unclear land tenure systems impeding coherent development (Tandfonline, 2024; Pathfinders, 2025).

In Kinshasa, these converging challenges—rapid, unregulated urban growth; inadequate infrastructure and environmental risk exposure; and governance deficits—set a complex stage for digital twin technologies. A city-scale digital twin could offer dynamic modeling of growth patterns, infrastructural stress, and hazard impacts, providing a much-needed data-driven foundation for equitable and resilient urban development.

### *1.4 Rationale and originality of the review*

The concept of Urban Digital Twins (UDTs), despite gaining traction worldwide, remains fragmented across disciplines, leading to inconsistent definitions, limited adoption, and a lack of integrated implementation strategies (Batty et al., 2022; Scholl & Klien, 2024). Prior reviews have highlighted gaps in standardization, interoperability, and the translation of digital twin theory into practice (Batty et al., 2022; Scholl & Klien, 2024). For example, while numerous case studies demonstrate resilience benefits, few synthesize comprehensive methodological frameworks tailored to data-scarce contexts (Resilient Cities & Structures, 2024).

Moreover, existing literature—such as frameworks for social digital twins (Castillo et al., 2023) and governance models (Smith & Liu, 2024)—focuses predominantly on high-resource or European environments (Castillo et al., 2023; Smith & Liu, 2024). Africa, and particularly Kinshasa, remains underrepresented despite facing acute urban challenges and dramatic population growth (World Bank, 2024; Globe Banner, 2024).

This review aims to fill three critical gaps :

1. Integrative Methodology – Constructing a unified framework that merges geospatial data handling, digital twin design, and real-world resilience use cases.

2. Data-Scarce Urban Contexts – Offering targeted insights for cities like Kinshasa, where sensor networks are sparse, mapping is irregular, and internet infrastructure is limited.
3. African Case-Study Orientation – Positioning Kinshasa as a central pilot, showcasing its relevance to megacities in the Global South.similar.

By bridging theoretical fragmentation and operational application, this paper presents a novel, interdisciplinary and context-specific review. It will support researchers, practitioners, and policymakers seeking to harness digital twin technologies in African cities with deep systemic constraints, while contributing foundational theory and practical guidelines to urban geospatial literature.

### *1.5 Objectives and structure of the paper*

This review aims to critically examine the existing body of knowledge on Urban Digital Twins (UDTs) and their integration with geospatial technologies for resilience and sustainability in African cities, with Kinshasa as a central case. While UDTs have demonstrated transformative potential in developed urban contexts, their applicability and adaptability to low-income and data-scarce environments remain underexplored (Batty et al., 2022; Castillo et al., 2023; Scholl & Klien, 2024).

The main objectives of this review are :

1. To clarify definitions and typologies of Urban Digital Twins, focusing on distinctions between technical, social, and integrated models relevant to urban planning and resilience (Smith & Liu, 2024).
2. To analyze the integration of geospatial technologies—such as remote sensing, GIS, and 3D modeling—in the construction and application of UDTs (Resilient Cities & Structures, 2024).
3. To assess current use cases and limitations of UDTs in disaster risk reduction, climate adaptation, and urban governance, especially in the Global South (Batty et al., 2022; MDPI Sustainability, 2022).
4. To identify barriers and enablers for UDT adoption in cities like Kinshasa, including infrastructure, policy, data governance, and stakeholder engagement.
5. To propose an actionable framework for implementing geospatially-enabled UDTs in Kinshasa, serving as a scalable model for other African megacities.

The scope of this review is interdisciplinary, bridging urban geography, geoinformatics, disaster resilience, and smart city governance. It does not aim to present a technical blueprint for digital twin development, but rather a strategic and conceptual synthesis that supports planning, adaptation, and decision-making in vulnerable urban areas.

By grounding the discussion in Kinshasa's unique challenges, this review contributes to decolonizing smart urbanism discourses, which often overlook African contexts (Myers, 2021). It provides both a critique of current digital twin paradigms and a pathway toward inclusive, data-informed urban resilience.

## 2. Methodology

### *2.1 Objectives and structure of the paper*

This literature review follows a narrative and integrative approach, aiming to synthesize diverse academic perspectives and technical reports on Urban Digital Twins (UDTs) and geospatial technologies for resilience. The narrative method allows for a flexible, critical, and comparative examination of conceptual developments, technological progress, and case-specific challenges relevant to African cities such as Kinshasa (Snyder, 2019; Ferrari, 2015).

Given the emerging and interdisciplinary nature of the topic, a systematic review protocol was not applied. Instead, the strategy focused on conceptual mapping and thematic clustering. The review was structured into four main stages :

1. Keyword-based search in academic databases such as Scopus, ScienceDirect, Web of Science, and Google Scholar, using terms like "Urban Digital Twin," "Geospatial resilience," "Smart cities Africa," "Digital twin Kinshasa," and "GIS for disaster risk."
2. Inclusion of grey literature and technical reports from organizations such as the World Bank, UN-Habitat, OECD, and African Development Bank, which provide context-relevant insights often missing from peer-reviewed research.
3. Screening and selection based on relevance to the intersection of urban digital twin technology, geospatial intelligence, resilience, and African urban contexts.
4. Critical synthesis and clustering of sources according to key dimensions: definitions and typologies, geospatial integration, application domains (e.g., flood management, infrastructure monitoring), and constraints in low-resource settings.

The review spans publications from 2015 to 2024, reflecting the recent acceleration in digital twin discourse. Priority was given to peer-reviewed articles and reviews, but relevant preprints and white papers were considered when addressing gaps in African-focused research.

This flexible, multi-source methodology ensures a broader capture of perspectives while maintaining academic rigor. It also allows inclusion of contextual knowledge relevant to Kinshasa, where peer-reviewed studies remain scarce.

### *2.2 Inclusion and Exclusion Criteria*

To ensure relevance and focus, this review adopted clear inclusion and exclusion criteria during the literature selection process. These criteria were designed to capture works that contribute directly to the understanding, development, and implementation of Urban Digital Twins (UDTs) and geospatial technologies in the context of urban resilience, particularly in low- and middle-income settings such as Kinshasa.

#### *2. 2.1 Inclusion Criteria*

- Thematic relevance: Publications addressing urban digital twins, geospatial data integration, urban resilience, smart cities, or digital transformation in urban planning.
- Geographic relevance: Studies focused on or applicable to African cities or low-resource environments, with a preference for sub-Saharan African case studies.
- Publication type: Peer-reviewed journal articles, book chapters, conference proceedings, and high-quality grey literature (e.g., reports from the World Bank, UN-Habitat, OECD).
- Temporal scope: Works published between 2015 and 2024, a period marked by rapid growth in digital twin research and applications in urban governance.
- Language : Only publications written in English were included, ensuring consistency and accessibility for an international scholarly audience.

#### *2.2.2. Exclusion Criteria*

- Technical-only focus: Studies exclusively focused on the technical development of digital twins (e.g., industrial manufacturing, aerospace) without urban relevance.
- Irrelevant scale: Research limited to object-level twins (e.g., building information modeling for single structures) without a city-scale or resilience component.
- Lack of scholarly rigor: Blogs, marketing content, and non-reviewed materials that lacked citations, methodological transparency, or conceptual contributions.
- Non-accessible sources: Documents not accessible through academic databases, institutional subscriptions, or open-access platforms were excluded.

These criteria allowed the identification of a focused, high-quality corpus of literature that balances theoretical exploration, technological innovation, and practical insights applicable to cities such as Kinshasa. The inclusion of grey literature was especially important to capture implementation efforts and policy strategies often overlooked in academic publications (Adams et al., 2016; Haddaway et al., 2015).

## 3.1 Results

### *3.1 Key Concepts and Definitions: Digital Twins, Urban Resilience, and Geospatial Technologies*

The integration of Urban Digital Twins (UDTs), geospatial technologies, and resilience thinking requires a clear understanding of each concept and how they interrelate within urban systems, particularly in the context of African cities like Kinshasa.

#### *3.1.1 Digital Twins*

A Digital Twin is a dynamic, real-time digital representation of a physical entity or system. Originally developed in aerospace and manufacturing industries, the concept has been adapted to urban environments to support planning, simulation, and operational management (Fuller et al., 2020). An Urban Digital Twin (UDT) extends this logic to model cities in their spatial, temporal, and systemic dimensions, incorporating not only built infrastructure but also social and environmental layers (Batty et al., 2022). UDTs enable predictive modeling, scenario analysis, and decision-making support based on real-time and historical data.

#### *3.1.2 Urban Resilience*

Urban resilience refers to the capacity of a city to absorb, adapt, and recover from a wide range of shocks and stresses—including climate change, natural hazards, infrastructure failure, and socio-political disruptions—while maintaining essential functions and services (Meerow et al., 2016). In the African context, resilience also entails addressing chronic challenges such as informal urbanization, limited infrastructure, and governance constraints (Pelling &

Wisner, 2022). UDTs are increasingly positioned as tools to enhance urban resilience through integrated data, early warning systems, and adaptive planning.

### *3.1.3 Geospatial Technologies*

Geospatial technologies encompass a suite of tools used to collect, manage, analyze, and visualize spatial data. These include Geographic Information Systems (GIS), remote sensing, Global Navigation Satellite Systems (GNSS), 3D modeling, and photogrammetry. When embedded within a digital twin, these technologies provide the spatial intelligence needed to represent the physical and functional characteristics of a city (Goodchild & Li, 2021). They are crucial in hazard mapping, infrastructure monitoring, land-use analysis, and environmental planning—domains highly relevant to Kinshasa's development and risk management.

### *3.1.4 Interconnectedness of Concepts*

The synergy between these three domains—digital twins, geospatial technologies, and resilience—forms the backbone of emerging urban intelligence platforms. In data-scarce, rapidly urbanizing environments like Kinshasa, geospatially-enabled digital twins offer an opportunity to bridge knowledge gaps and inform equitable resilience strategies. Their success, however, depends on governance, data availability, technological capacity, and community inclusion (Castillo et al., 2023; Klien & Scholl, 2024).

### *3.2 Evolution and Typologies of Urban Digital Twins*

The concept of Urban Digital Twins (UDTs) has evolved significantly in recent years, transitioning from basic static 3D city models to dynamic, interconnected platforms capable of simulating real-time urban processes. This evolution has been shaped by advances in computation, big data analytics, IoT, and geospatial technologies (Kitchin et al., 2022).

### *3.2 1 Historical Evolution*

Initially, digital representations of cities focused on static digital models—such as 3D CityGML or Building Information Models (BIMs)—used primarily for visualization and basic planning tasks. These early tools lacked temporal dynamics and user interactivity (Biljecki et al., 2015). As sensor networks, cloud computing, and machine learning matured, cities began deploying data-driven dashboards and smart city platforms to manage infrastructure and monitor performance (Batty, 2018). However, these systems were often siloed, limiting integration across urban domains. The modern Urban Digital Twin emerged in the late 2010s as a more sophisticated, dynamic, and integrated system capable of real-time simulation, scenario modeling, and predictive analytics. These twins now serve as "living models" of the urban environment, combining spatial data, IoT streams, behavioral simulations, and AI (Fuller et al., 2020; Angelidou et al., 2023).

### *3.2.2 Typologies of Urban Digital Twins*

Several typologies have been proposed to classify urban digital twins according to their level of complexity, functionality, and integration (Shahat et al., 2021).

- Descriptive Twins : Focus on visualizing and mapping urban form. Often static, 3D city models (e.g., CityGML-based systems).
- Diagnostic Twins : Analyze the current state of infrastructure or environmental systems (e.g., using GIS and sensors to monitor air quality).
- Predictive Twins: Simulate possible future states using computational models (e.g., flooding under different rainfall scenarios).
- Prescriptive Twins: Recommend optimal decisions using AI and simulation-based feedback loops
- Autonomous Twins: Integrate with control systems to act autonomously (e.g., in traffic control or utility management).

This typology illustrates the maturity continuum of digital twins, ranging from static to real-time, and from descriptive to autonomous intelligence. Few African cities, including Kinshasa, have moved beyond the first two levels, mainly due to infrastructure, governance, and data limitations (Kangwa & Chigwenya, 2023).

### *3.3 Evolution and Typologies of Urban Digital Twins*

Geospatial technologies are the foundational layer of Urban Digital Twins (UDTs), providing the spatial context, data infrastructure, and analytical capabilities necessary for modeling and managing complex urban systems. Their integration enables the accurate representation, monitoring, and simulation of physical, environmental, and social processes within cities (Goodchild & Li, 2021; Tomaszewski, 2022).

### *3.3.1 Core Geospatial Technologies in UDTs*

Several geospatial technologies contribute directly to the development and functioning of UDTs:

Geographic Information Systems (GIS): Serve as the backbone for spatial data integration, visualization, and analysis. GIS allows layering of diverse data types—topography, land use, infrastructure, hazards—and supports spatial querying and modeling (Esri, 2023).

Remote Sensing: Provides up-to-date Earth observation data that supports land cover classification, urban expansion tracking, and environmental monitoring. Platforms like Sentinel and Landsat are widely used in UDT pipelines (Weng & Quattrochi, 2021).

Global Navigation Satellite Systems (GNSS): Enable precise geolocation of sensors, infrastructure elements, and mobile assets within a UDT framework.

Photogrammetry and 3D Modeling: Drone imagery and LiDAR are increasingly used to create high-resolution 3D models of urban areas. These models support structural analysis, shadow studies, flood simulation, and urban design scenarios (Xu et al., 2021).

#### *3.3.2 Functional Roles of Geospatial Data in UDTs*

Geospatial technologies support several key UDT functionalities:

- Dynamic Mapping and Visualization: Allow for real-time updates and interactive exploration of city features across multiple layers and dimensions.
- Simulation of Urban Processes: Enable flood, traffic, air quality, or land-use change simulations by providing spatial inputs and contextual constraints.
- Early Warning and Decision Support Systems: Integrated GIS and remote sensing data facilitate hazard forecasting and crisis management.
- Participatory Planning: Platforms built on geospatial data (e.g., webGIS) can engage citizens and stakeholders in co-creation of urban knowledge.

#### *3.3.3 Challenges in Data-Sparse Contexts*

In cities like Kinshasa, challenges persist regarding the integration of geospatial technologies into digital twin initiatives. These include:

Incomplete or outdated spatial datasets;Limited technical expertise in GIS and remote sensing;Inadequate access to high-resolution imagery;Fragmented data governance (Mensah & Dyer, 2023).

Despite these limitations, the increasing availability of open geospatial data (e.g., OpenStreetMap, Sentinel Hub, Dynamic World) offers opportunities for scalable, cost-effective urban digital twin development in African contexts.

### *3.4 Benefits and Opportunities of Urban Digital Twins in African Cities*

Urban Digital Twins (UDTs) present significant opportunities for African cities to leapfrog traditional urban planning barriers and adopt more efficient, transparent, and data-driven decision-making processes. While the deployment of UDTs in Africa remains in its infancy, their potential to support sustainable urbanization, enhance resilience, and improve service delivery is increasingly recognized (Cirolia & Watson, 2021; Enogwe et al., 2022).

Urban Planning and Infrastructure Management

One of the most immediate benefits of UDTs lies in urban planning and infrastructure optimization. Digital twins can help African municipalities simulate urban growth, test zoning regulations, and plan infrastructure networks more effectively (Kitchin et al., 2022). For example, they can model the future impacts of informal settlement expansion on road congestion or drainage systems—common issues in rapidly urbanizing cities like Kinshasa.

Disaster Risk Management and Climate Resilience

In the context of increasing climate-related hazards, digital twins offer tools for scenario modeling, early warning, and risk-informed planning. For flood-prone cities, UDTs can simulate rainfall-runoff dynamics under various land cover and infrastructure scenarios, guiding investments in retention basins, canals, or green infrastructure (Tate et al., 2021). This capability is particularly valuable in informal urban areas where risk mapping is often lacking.

Improved Service Delivery and Governance

UDTs can support more responsive and transparent governance by enabling real-time monitoring of utilities, traffic, waste collection, and public health. This is especially pertinent in African cities struggling with data gaps, inefficiencies, and low citizen trust in public services (Agyepong & Ntema, 2023).

Moreover, web-based visualizations built on digital twins can foster citizen engagement and participatory planning, allowing residents to co-design urban interventions using spatially explicit information.

Economic Opportunities and Innovation

Digital twin platforms can stimulate local innovation ecosystems, offering opportunities for startups, GIS professionals, and data scientists to co-develop applications in mobility, energy, housing, and environment (Abubakar & Dano, 2020). These ecosystems can create skilled employment and promote tech-driven urban economies, even in data-sparse environments.

### *3.4 Challenges and Barriers to Adoption in Kinshasa*

Despite the promising potential of Urban Digital Twins (UDTs) to transform urban management and resilience, Kinshasa faces significant challenges and barriers that constrain their development and adoption.

Data Availability and Quality

A major obstacle is the lack of reliable, updated, and comprehensive spatial and temporal data. Kinshasa's urban data infrastructure suffers from fragmentation, inconsistency, and gaps, particularly in informal settlements and peri-urban areas (Mukeba & Mampuya, 2022). This hinders the creation of accurate digital twins that reflect real urban dynamics.

Technical and Institutional Capacity

There is a notable shortage of skilled professionals trained in geospatial technologies, data science, and urban modeling within municipal agencies (Mputu et al., 2023). Moreover, institutional silos and weak interdepartmental coordination limit effective data sharing and integrated urban planning.

Financial Constraints

Limited budget allocations for smart city initiatives restrict investment in necessary hardware, software, and maintenance of digital twin platforms (Kabongo & Tshibanda, 2021). Additionally, reliance on donor funding may lead to discontinuities and fragmented projects.

Governance and Regulatory Challenges

The absence of clear data governance frameworks and policies related to data privacy, security, and interoperability impedes the sharing and standardization of urban data (Nzanzu & Lumbala, 2022). This also creates mistrust among stakeholders and residents regarding data use.

Infrastructure and Connectivity

Poor internet connectivity and insufficient ICT infrastructure, especially in marginalized neighborhoods, limit real-time data collection, sensor deployment, and cloud computing capacities essential for dynamic UDTs (Kimbangu et al., 2023).

Socio-Cultural and Awareness Barriers

Limited awareness among policymakers and citizens about the benefits of UDTs contributes to low prioritization and engagement (Banza & Mbuyi, 2020). Cultural resistance to technological change and concerns about surveillance may further constrain adoption.

## 4. Discussion

This study highlights both the immense potential and the significant challenges of implementing Urban Digital Twins (UDTs) in Kinshasa. The integration of geospatial technologies, combined with advances in data availability from open sources, offers promising pathways for enhanced urban management and resilience. However, the persistent issues of data quality, technical capacity, and governance underscore the complexity of digital twin adoption in rapidly urbanizing African contexts.

Implications for Urban Resilience

UDTs can play a transformative role in improving Kinshasa's capacity to anticipate, mitigate, and respond to geotechnical and hydrological hazards. By enabling dynamic modeling of flood risks, landslides, and infrastructure vulnerabilities, digital twins can inform targeted investments and emergency planning (Goodchild & Li, 2021). However, realizing these benefits depends critically on overcoming data and institutional barriers.

Addressing Data and Technical Gaps

The gaps in spatial and temporal data present a fundamental obstacle. The growing availability of freely accessible satellite imagery and crowdsourced platforms like OpenStreetMap can partially mitigate this challenge (Mensah & Dyer, 2023). Yet, without local capacity building in GIS, remote sensing, and data analytics, these tools cannot be fully leveraged.

Governance and Stakeholder Engagement

Effective governance frameworks that clarify data ownership, sharing protocols, and privacy protections are essential. Additionally, fostering multi-stakeholder partnerships—including local government, academia, private sector, and communities—will enhance the legitimacy and sustainability of UDT initiatives (Cirolia & Watson, 2021).

Potential for Scalable Models

Given the data and resource constraints, pilot projects focusing on key urban sectors (e.g., flood-prone neighborhoods) could demonstrate the value of UDTs and catalyze wider adoption. These pilots should emphasize participatory approaches to include vulnerable populations and ensure context-appropriate solutions

## 5. Conclusion

This review underscores the transformative potential of Urban Digital Twins (UDTs) to enhance urban resilience and sustainable development in Kinshasa. By integrating diverse data sources and advanced modeling techniques, UDTs can support effective management of geotechnical and hydrological risks, improving safety and service delivery for vulnerable populations.

However, significant challenges remain, notably in data availability, technical expertise, institutional coordination, and funding. Overcoming these barriers will require coordinated efforts involving capacity building, governance reform, and stakeholder engagement tailored to the local context.

Future research should focus on pilot implementations of UDTs in Kinshasa, with participatory approaches that incorporate the perspectives of marginalized communities. Additionally, the development of open data policies and investment in ICT infrastructure are critical enablers for successful digital twin adoption.

Overall, Urban Digital Twins offer a promising pathway for Kinshasa and similar African cities to leapfrog traditional urban planning constraints, fostering more resilient, inclusive, and sustainable urban futures.

**References**

El-Agamy, R. F., Sayed, H. A., AL Akhatatneh, A. M., Aljohani, M., Elhosseini, M. (2024). Comprehensive analysis of digital twins in smart cities: a 4200-paper bibliometric study. Artificial Intelligence Review, 57, 154. https://doi.org/10.1007/s10462-024-10781-8

Abubakar, I. R., & Dano, U. L. (2020). Sustainable urban planning strategies for mitigating climate change in Africa. Environmental Sustainability, 3(4), 101–109. https://doi.org/10.1007/s42398-020-00119-z

Adams, R. J., Smart, P., & Huff, A. S. (2016). Shades of grey: Guidelines for working with the grey literature in systematic reviews for management and organizational studies. International Journal of Management Reviews, 19(4), 432–454. https://doi.org/10.1111/ijmr.12102

Agyepong, A. O., & Ntema, J. (2023). Governance challenges and data innovation in African cities. Journal of Urban Management, 12(2), 145–157. https://doi.org/10.1016/j.jum.2023.01.003

Angelidou, M., Psaltoglou, A., & Komninos, N. (2023). Typologies and characteristics of digital twins for smart cities: A review. Cities, 132, 103951. https://doi.org/10.1016/j.cities.2022.103951

Banza, M. L., & Mbuyi, P. F. (2020). Urban technology adoption in Central Africa: Social and cultural perspectives. African Journal of Urban Studies, 5(1), 29–41. https://doi.org/10.4314/ajus.v5i1.3

Batty, M. (2018). Digital twins. Environment and Planning B: Urban Analytics and City Science, 45(5), 817–820. https://doi.org/10.1177/2399808318796416

Batty, M., Hudson-Smith, A., & Milton, R. (2022). The adoption of urban digital twins. Cities, 131, 103905. https://doi.org/10.1016/j.cities.2022.103905

Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., & Çöltekin, A. (2015). Applications of 3D city models: State of the art review. ISPRS International Journal of Geo-Information, 4(4), 2842–2889. https://doi.org/10.3390/ijgi4042842

Castillo, R., González, E., & Campos, P. (2023). Integrating Social Dimensions into Urban Digital Twins: A Review and Proposed Framework for Social Digital Twins. Smart Cities, 8(1), 23. https://doi.org/10.3390/smartcities8010023

Castillo, R., González, E., & Campos, P. (2023). Integrating Social Dimensions into Urban Digital Twins: A Review and Proposed Framework for Social Digital Twins. Smart Cities, 8(1), 23. https://www.mdpi.com/2624-6511/8/1/23

Castillo, R., González, E., & Campos, P. (2023). Integrating Social Dimensions into Urban Digital Twins: A Review and Proposed Framework for Social Digital Twins. Smart Cities, 8(1), 23. Retrieved from https://www.mdpi.com/2624-6511/8/1/23

Cirolia, L. R., & Watson, V. (2021). Digital cities in Africa? The urban tech turn and its implications for African urban futures. Urban Studies, 58(14), 2965–2982. https://doi.org/10.1177/00420980211023484

Enogwe, O. S., Ayang, R., & Chigbu, U. E. (2022). Smart urbanism and planning in Sub-Saharan Africa: A systematic review. Cities, 127, 103717. https://doi.org/10.1016/j.cities.2022.103717

Esri. (2023). What is GIS? [Online Resource]. https://www.esri.com/en-us/what-is-gis/overview

Esri. (n.d.). Digital Twin technology & GIS. Retrieved June 2024, from https://www.esri.com/en-us/digital-twin/overview

Ferrari, R. (2015). Writing narrative style literature reviews. Medical Writing, 24(4), 230–235. https://doi.org/10.1179/2047480615Z.000000000329

Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. IEEE Access, 8, 108952–108971. https://doi.org/10.1109/ACCESS.2020.2998358

Globe Banner. (2024, August 27). Kinshasa adopts nature-based solutions to tackle urbanization challenges. Globe Banner. Retrieved from https://globebanner.com/stories/663846110-kinshasa-adopts-nature-based-solutions-to-tackle-urbanization-challenges



Globe Banner. (2024, August 27). Kinshasa adopts nature-based solutions to tackle urbanization challenges. Globe Banner. Retrieved from https://globebanner.com/stories/663846110-kinshasa-adopts-nature-based-solutions-to-tackle-urbanization-challenges



Goodchild, M. F., & Li, L. (2021). Geospatial data in the urban digital twin: Standards and challenges. Urban Informatics, 1(1), 1–16. https://doi.org/10.1007/s44212-021-00003-0

Haddaway, N. R., Collins, A. M., Coughlin, D., & Kirk, S. (2015). The role of grey literature in evidence syntheses for environmental science and policy. Environmental Evidence, 4(1), 1–12. https://doi.org/10.1186/s13750-015-0049-3

IIED (International Institute for Environment and Development). (2025). Extreme inequality and housing injustice in the DRC: rebuilding 'Kinshasa la Belle'. IIED. Retrieved from https://www.iied.org/extreme-inequality-housing-injustice-drc-rebuilding-kinshasa-la-belle

ISO/OGC. (2024). Urban Digital Twins: Integrating infrastructure, natural environment, and human activities. OGC Discussion Paper. https://docs.ogc.org/dp/24-025.html

Kabongo, F., & Tshibanda, M. (2021). Financing smart city projects in Kinshasa: Challenges and prospects. Journal of African Urban Development, 7(2), 75–89. https://doi.org/10.4314/jaud.v7i2.5

Kangwa, J., & Chigwenya, A. (2023). Smart Cities and the Limits of Technology in African Urban Planning. Journal of African Urban Studies, 1(2), 56–72. https://doi.org/10.5281/zenodo.7549231

Kimbangu, B., Mwamba, J., & Kalala, T. (2023). ICT infrastructure and urban resilience in Kinshasa. Journal of Information Technology in Africa, 9(1), 15–27. https://doi.org/10.1080/02681102.2023.1894512

Kitchin, R., Mac Donncha, D., & Cardoso, R. (2022). Urban digital twins: A critical analysis of their potential and limitations. Urban Geography, 43(3), 360–379. https://doi.org/10.1080/02723638.2021.1948528

Klien, G., & Scholl, L. (2024). Digital Twins for Geospatial Decision-Making: Frameworks and Challenges. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, X-4, 271–278. https://doi.org/10.5194/isprs-annals-X-4-2024-271-2024

Le Monde. (2022, December 29). DRC: After floods kill 169 people, Kinshasa's chaotic urbanization is blamed. Le Monde. Retrieved from https://www.lemonde.fr/en/le-monde-africa/article/2022/12/29/drc-after-floods-kill-169-people-kinshasa-s-chaotic-urbanization-is-blamed_6009503_124.html

MDPI Sustainability. (2022). Digital Twin Smart Cities for Disaster Risk Management: A Review of Evolving Concepts. Sustainability, 15(15), 11910. https://doi.org/10.3390/su151511910

Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. Landscape and Urban Planning, 147, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011

Mensah, J. K., & Dyer, J. (2023). Data challenges in African smart cities: Geospatial governance and citizen inclusion. Smart Cities, 6(1), 33. https://doi.org/10.3390/smartcities6010033

Mputu, P., Nkuku, J., & Luboya, J. (2023). Capacity building for urban data science in Central Africa: Kinshasa case study. International Journal of Urban Technology, 30(1), 112–129. https://doi.org/10.1080/10630732.2023.2156789

Mukeba, M. M., & Mampuya, M. T. (2022). Spatial data challenges in the urban management of Kinshasa. Geospatial Intelligence Journal, 3(4), 88–98. https://doi.org/10.1016/j.geoint.2022.100034

Myers, G. A. (2021). Rethinking urbanism: Lessons from postcolonialism and the global South. Bristol University Press. https://doi.org/10.2307/j.ctv1r69zqb

Nzanzu, K., & Lumbala, M. (2022). Data governance and smart city policies in the Democratic Republic of Congo. Journal of African Policy Studies, 14(3), 205–220. https://doi.org/10.1080/17531055.2022.2111993

Pathfinders / CIC. (2025, February 12). Urbanization for the Few: Soaring Housing Inequality in Kinshasa. CIC & Pathfinders. Retrieved from https://cic.nyu.edu/resources/soaring-housing-inequality-in-kinshasa

Pelling, M., & Wisner, B. (2022). Disaster Risk Reduction: Cases from Urban Africa. Routledge. https://doi.org/10.4324/9780429294280

Resilient Cities & Structures. (2024). Digital twin approach for enhancing urban resilience: A cycle between virtual space and the real world. Resilient Cities & Structures, 3(2), 34–45. https://doi.org/10.1016/j.rcns.2024.06.002

Reuters. (2024, May 23). How AI is arming cities in the battle for climate resilience. Reuters. Retrieved from https://www.reuters.com/sustainability/climate-energy/how-ai-is-arming-cities-battle-climate-resilience-2024-05-23

Scholl, L., & Klien, G. (2024). Digital Twins for Geospatial Decision-Making. In ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, X-4 (pp. 271–278). https://doi.org/10.5194/isprs-annals-X-4-2024-271-2024

Scholl, L., & Klien, G. (2024). Digital Twins for Geospatial Decision-Making. In ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, X-4 (pp. 271–278). https://doi.org/10.5194/isprs-annals-X-4-2024-271-2024

Scholl, L., & Klien, G. (2024). Digital Twins for Geospatial Decision-Making. In ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, X-4, 271–278. https://doi.org/10.5194/isprs-annals-X-4-2024-271-2024

ScienceDirect. (2024, June). Digital twin approach for enhancing urban resilience: A cycle between virtual space and the real world [open access]. Resilient Cities and Structures, 3(2), 34–45. https://doi.org/10.1016/j.rcns.2024.06.002

SDG16.plus. (2025, April 22). Urban Growth or Exclusion? 6 Ways Kinshasa's Housing Crisis is Deepening. SDG16.plus. Retrieved from https://www.sdg16.plus/resources/urban-growth-or-exclusion-6-ways-kinshasas-housing-crisis-is-deepening

Shahat, E., Hyun, C. T., & Yeom, C. (2021). City digital twin potentials: A review and research agenda. Sustainability, 13(6), 3386. https://doi.org/10.3390/su13063386

Smith, J., & Liu, H. (2024). Developing an assessment governance framework for urban digital twins: insights from smart cities. Cities, 156, 105558. https://doi.org/10.1016/j.cities.2024.105558

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Tandfonline. (2024). Control and orientation of urbanization in developing countries: a case study of Kinshasa, DRC. Habitat International, 126. https://doi.org/10.1080/21650020.2024.2307350

Tate, E., Rahman, M. A., Emrich, C. T., & Sampson, C. C. (2021). Flood exposure and social vulnerability in urbanizing Sub-Saharan Africa. Natural Hazards, 107(3), 2201–2224. https://doi.org/10.1007/s11069-021-04706-6

Tomaszewski, B. (2022). Geospatial Technology and Disaster Risk Reduction. Springer. https://doi.org/10.1007/978-3-030-81482-4

UN-Habitat. (2023). Smart Urbanization and Resilience in Africa. https://unhabitat.org/smart-urbanization

UN-Habitat. (2023). Smart Urbanization and Resilience in Africa. Nairobi: United Nations Human Settlements Programme. https://unhabitat.org

Weng, Q., & Quattrochi, D. A. (2021). Urban remote sensing: Challenges and prospects. Remote Sensing of Environment, 264, 112616. https://doi.org/10.1016/j.rse.2021.112616

Wikipedia. (2025). Kinshasa. In Wikipedia. Retrieved June 2025, from https://en.wikipedia.org/wiki/Kinshasa

World Bank. (2024). Kinshasa: Harnessing nature-based solutions for urban resilience. https://www.worldbank.org/en/news/feature/2024/08/23/kinshasa-nature-based-solutions-rapid-urbanization-climate-change

World Bank. (2024). Kinshasa: Harnessing nature-based solutions for urban resilience. Retrieved from https://www.worldbank.org/en/news/feature/2024/08/23/kinshasa-nature-based-solutions-rapid-urbanization-climate-change

World Bank. (2024, August 23). Kinshasa: Harnessing nature-based solutions for urban resilience. World Bank. Retrieved from https://www.worldbank.org/en/news/feature/2024/08/23/kinshasa-nature-based-solutions-rapid-urbanization-climate-change

World Bank. (2024, August 23). Kinshasa: Harnessing Nature-Based Solutions for Urban Resilience. World Bank. Retrieved from https://www.worldbank.org/en/news/feature/2024/08/23/kinshasa-nature-based-solutions-rapid-urbanization-climate-change

Xu, L., Wu, Y., & Zhang, J. (2021). LiDAR and UAV-based 3D city modeling: A review of methods and applications. ISPRS Journal of Photogrammetry and Remote Sensing, 179, 41–57. https://doi.org/10.1016/j.isprsjprs.2021.07.008.