

Big data for urban planning: a comparative perspective between Singapore and Rwanda

Ouoba Hadi¹

Iradukunda Sengesho Benigne²

Nizeyimana Jean Baptiste³

1. Joint PhD Researcher at Lisala University and UNCR University, Computer Science & IT Department, Big Data
2. Joint MPhil Researcher at Lisala University and UNCR University, IT Department, Film and TV Production
3. Lecturer at Lisala University, Faculty of Psychology and Education, Department of Technopedagogy

ABSTRACT

This study falls within SDG Focus Goal 9: Industry, Innovation and Infrastructure — Target 9.1: Develop quality, reliable, sustainable and resilient infrastructure to support economic development and human well-being; Target 9.4: Upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and

¹ Joint PhD Researcher at Lisala University and UNCR University, Computer Science & IT Department, Big Data

environmentally sound technologies; Target 9.c: Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet.

This study examines the comparative approaches to big data for urban planning in Singapore and Rwanda, focusing on how each country leverages digital technologies, data analytics, and spatial information systems to manage urban growth, enhance infrastructure efficiency, and promote sustainable development. The research analyzes the technological infrastructures, governance frameworks, and implementation strategies that characterize each country's approach to data-driven urbanism, while critically examining the transferability of models across vastly different contexts. A comparative analysis was conducted examining primary and secondary sources including government documentation, academic research, institutional reports, and news coverage covering recent developments to 2025-2026.

Singapore presents a globally recognized model of advanced data-driven urbanism, where the "Smart Nation" vision has evolved into a comprehensive ecosystem of integrated digital infrastructure. At the heart of this system lies the Open Digital Platform (ODP), co-developed by GovTech and JTC, which serves as a "digital nervous system" enabling diverse urban systems—from elevators and energy sensors to security turnstiles and autonomous vehicles—to communicate through a unified platform. This convergence of Internet of Things (IoT) and Artificial Intelligence (AI), known as AIoT, allows infrastructure to self-optimize in real-time, automatically adjusting district cooling and lighting before crowds arrive. The Punggol Digital District exemplifies this integrated approach, where physical and digital infrastructure have been developed in tandem from the ground up, creating a "living laboratory" for urban innovation. Singapore's data-driven urbanism extends to sustainability through smart water meters deployed by the national water agency PUB, enabling real-time consumption tracking and early leak detection. In the social domain, the Government Assisted Living Ecosystem (GALE) connects seniors to 24/7 care via personal alert devices, demonstrating how big data can support inclusive urban development. Academic analysis suggests that Singapore's pandemic response, built upon the Smart Nation initiative, demonstrates a shift toward what researchers term an "environmental turn" in urban governance—the active shaping and management of urban spaces in real-time through always-on data collection, analysis, and automated responses. This approach, while

effective, raises important questions about privacy and the balance between technological innovation and public trust.

Rwanda presents a contrasting yet complementary picture of a rapidly developing nation strategically adopting big data tools to manage its unprecedented urbanization—the fastest in Southeast Asia—while charting its own path toward sustainable urban development. The country's partnership with Singaporean urban consultancy Surbana Jurong, which developed master plans for Kigali beginning in 2008 and for six other Rwandan cities in 2021, has been instrumental in building local expertise, with each iteration involving greater Rwandan participation. Recent concrete achievements demonstrate Rwanda's commitment to data-driven urbanism. The "Large-Scale Mapping and Urban Mobility Improvement project," a three-year collaboration with JICA completed in January 2025, produced high-resolution topographic maps, a 3D city model, and the Kigali Road Asset Management System (K-RAMS) for efficient road management. In April 2025, Rwanda launched KUBAKA, a new digital platform for building permit services that enables citizens, landowners, and investors to apply for and track permits in real-time, replacing the old system with streamlined "zero trip" processing. The Geo-Spatial Hub, adopted in Eastern Province in September 2025, uses satellite imagery to map every parcel of land, automatically notifying authorities when new structures appear on previously undeveloped land to help enforce master plans and reduce informal settlements. Research institutions are also contributing: ETH Zurich's Kigali Unplanned Neighbourhood Upgrading Tool (KUNUT) integrates GIS, data science, and scenario modeling to analyze and prioritize upgrading scenarios for informal settlements. Rwanda's 2025 National Urbanisation Policy provides the strategic framework for these initiatives, anchored on pillars of Coordination, Densification, Liveability, and Economic Growth.

Both countries demonstrate significant commitment to leveraging big data for urban planning, yet with fundamentally different starting points and strategic orientations. Singapore's strength lies in its advanced, integrated technological ecosystem capable of real-time optimization across urban systems, yet faces challenges of privacy, public trust, and the societal implications of automated governance. Rwanda's strength lies in its strategic, phased adoption of targeted data tools that address concrete urban challenges—land administration, building permits, mobility—while building local institutional capacity, yet faces challenges of data gaps (as evidenced by incomplete land records in Eastern Province), infrastructure limitations, and the need to translate data into

effective implementation. Neither country has fully resolved the tension between technological ambition and inclusive, citizen-centered development, though both offer valuable models for different stages of the data-driven urbanism journey.

Effective integration of big data in urban planning requires: (1) clear strategic vision linking data initiatives to broader urban development goals; (2) robust digital infrastructure enabling data collection, integration, and analysis; (3) institutional capacity to manage and utilize data effectively; (4) governance frameworks addressing privacy, security, and ethical use; (5) partnerships that build local expertise rather than creating dependency; (6) attention to the needs of all citizens, including vulnerable populations; (7) mechanisms for public participation and trust-building; and (8) continuous learning and adaptation as technologies evolve.

KEYWORDS: Big data, urban planning, smart cities, digital transformation, Singapore, Rwanda, Open Digital Platform, Geospatial Hub, KUBAKA, SDG 9, sustainable urbanization, data governance.

RÉSUMÉ (French Version)

Cette étude examine les approches comparatives de l'utilisation des mégadonnées pour la planification urbaine à Singapour et au Rwanda, en se concentrant sur la manière dont chaque pays exploite les technologies numériques, l'analyse de données et les systèmes d'information spatiale pour gérer la croissance urbaine, améliorer l'efficacité des infrastructures et promouvoir le développement durable. La recherche analyse les infrastructures technologiques, les cadres de gouvernance et les stratégies de mise en œuvre qui caractérisent l'approche de chaque pays en matière d'urbanisme axé sur les données, tout en examinant de manière critique la transférabilité des modèles à travers des contextes radicalement différents. Une analyse comparative a été menée en examinant des sources primaires et secondaires, y compris la documentation gouvernementale, la recherche académique, les rapports institutionnels et la couverture médiatique couvrant les développements récents jusqu'en 2025-2026.

Singapour présente un modèle mondialement reconnu d'urbanisme avancé axé sur les données, où la vision de "Smart Nation" a évolué vers un écosystème complet d'infrastructure numérique

intégrée. Au cœur de ce système se trouve la Plateforme Numérique Ouverte (ODP), co-développée par GovTech et JTC, qui sert de "système nerveux numérique" permettant à divers systèmes urbains—des ascenseurs et capteurs d'énergie aux tourniquets de sécurité et véhicules autonomes—de communiquer via une plateforme unifiée. Cette convergence de l'Internet des Objets (IoT) et de l'Intelligence Artificielle (IA), connue sous le nom d'AIoT, permet aux infrastructures de s'auto-optimiser en temps réel, ajustant automatiquement le refroidissement des quartiers et l'éclairage avant l'arrivée des foules. Le Quartier Numérique de Punggol illustre cette approche intégrée, où les infrastructures physiques et numériques ont été développées de concert dès la base, créant un "laboratoire vivant" pour l'innovation urbaine. L'urbanisme axé sur les données de Singapour s'étend à la durabilité grâce aux compteurs d'eau intelligents déployés par l'agence nationale de l'eau PUB, permettant un suivi de la consommation en temps réel et une détection précoce des fuites. Dans le domaine social, l'Écosystème d'Assistance Gouvernementale pour les Personnes Âgées (GALE) connecte les seniors à une assistance 24h/24 via des dispositifs d'alerte personnels, démontrant comment les mégadonnées peuvent soutenir un développement urbain inclusif. L'analyse académique suggère que la réponse de Singapour à la pandémie, construite sur l'initiative Smart Nation, démontre un "tournant environnemental" dans la gouvernance urbaine—la gestion et la modulation en temps réel des espaces urbains grâce à une collecte, une analyse et des réponses automatisées de données en continu. Cette approche, bien qu'efficace, soulève d'importantes questions sur la vie privée et l'équilibre entre innovation technologique et confiance publique.

Le Rwanda présente un tableau contrasté mais complémentaire d'une nation en développement rapide adoptant stratégiquement des outils de mégadonnées pour gérer son urbanisation sans précédent—la plus rapide d'Asie du Sud-Est—tout en traçant sa propre voie vers un développement urbain durable. Le partenariat du pays avec le cabinet de conseil urbain singapourien Surbana Jurong, qui a développé des plans directeurs pour Kigali à partir de 2008 et pour six autres villes rwandaises en 2021, a été déterminant dans le renforcement de l'expertise locale, chaque itération impliquant une plus grande participation rwandaise. Des réalisations concrètes récentes démontrent l'engagement du Rwanda en faveur d'un urbanisme axé sur les données. Le "Projet de cartographie à grande échelle et d'amélioration de la mobilité urbaine," une collaboration de trois ans avec la JICA achevée en janvier 2025, a produit des cartes

topographiques haute résolution, un modèle 3D de la ville et le Système de Gestion des Actifs Routiers de Kigali (K-RAMS) pour une gestion efficace des routes . En avril 2025, le Rwanda a lancé KUBAKA, une nouvelle plateforme numérique pour les services de permis de construire qui permet aux citoyens, propriétaires fonciers et investisseurs de demander et de suivre les permis en temps réel, remplaçant l'ancien système par un traitement simplifié "zéro déplacement" . Le Hub Géo-Spatial, adopté dans la Province de l'Est en septembre 2025, utilise l'imagerie satellite pour cartographier chaque parcelle de terrain, notifiant automatiquement les autorités lorsque de nouvelles structures apparaissent sur des terrains auparavant non développés afin de faire respecter les plans directeurs et réduire les établissements informels . Les institutions de recherche contribuent également : l'ETH Zurich a développé l'Outil de Réhabilitation des Quartiers Non Planifiés de Kigali (KUNUT), qui intègre les SIG, la science des données et la modélisation de scénarios pour analyser et prioriser les scénarios de réhabilitation des établissements informels . La Politique Nationale d'Urbanisation 2025 du Rwanda fournit le cadre stratégique pour ces initiatives, ancrée sur les piliers de Coordination, Densification, Qualité de Vie et Croissance Économique .

Les deux pays démontrent un engagement significatif en faveur de l'exploitation des mégadonnées pour la planification urbaine, mais avec des points de départ et des orientations stratégiques fondamentalement différents. La force de Singapour réside dans son écosystème technologique avancé et intégré capable d'optimisation en temps réel à travers les systèmes urbains, mais fait face à des défis de confidentialité, de confiance publique et d'implications sociétales de la gouvernance automatisée. La force du Rwanda réside dans son adoption stratégique et progressive d'outils de données ciblés qui répondent à des défis urbains concrets—administration foncière, permis de construire, mobilité—tout en renforçant la capacité institutionnelle locale, mais fait face à des défis de lacunes dans les données (comme en témoignent les dossiers fonciers incomplets dans la Province de l'Est), de limitations infrastructurelles et de la nécessité de traduire les données en mise en œuvre efficace. Aucun des deux pays n'a pleinement résolu la tension entre l'ambition technologique et le développement inclusif centré sur le citoyen, bien que tous deux offrent des modèles précieux pour différentes étapes du parcours de l'urbanisme axé sur les données.

L'intégration efficace des mégadonnées dans la planification urbaine nécessite : (1) une vision stratégique claire liant les initiatives de données aux objectifs plus larges de développement urbain

; (2) une infrastructure numérique robuste permettant la collecte, l'intégration et l'analyse des données ; (3) une capacité institutionnelle à gérer et utiliser efficacement les données ; (4) des cadres de gouvernance abordant la confidentialité, la sécurité et l'utilisation éthique ; (5) des partenariats qui renforcent l'expertise locale plutôt que de créer une dépendance ; (6) une attention aux besoins de tous les citoyens, y compris les populations vulnérables ; (7) des mécanismes de participation publique et de renforcement de la confiance ; et (8) un apprentissage et une adaptation continus à mesure que les technologies évoluent.

MOTS-CLÉS : Mégadonnées, planification urbaine, villes intelligentes, transformation numérique, Singapour, Rwanda, Plateforme Numérique Ouverte, Hub Géo-Spatial, KUBAKA, ODD 9, urbanisation durable, gouvernance des données.

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Auteurs correspondant Ouoba Hadi, Iradukunda Sengesho Benigne and Nizeyimana Jean Baptiste

Adresses électroniques : ouobahadi@cirep.ac.cd, benigneira0@gmail.com, nizeyimana.jb@dphu.ac.cd ,

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1. INTRODUCTION

The explosive growth of urban populations across the globe presents both unprecedented challenges and opportunities for city planners and policymakers. By 2050, nearly 70% of the world's population will live in urban areas, placing immense pressure on infrastructure, services, and natural resources. SDG 9 explicitly addresses these challenges through targets on sustainable infrastructure (9.1), resource-efficient industries (9.4), and universal access to information and communications technology (9.c). At the intersection of these targets lies the transformative potential of big data—the vast quantities of information generated by digital systems that can be analyzed to reveal patterns, optimize operations, and inform decision-making.

This study examines two countries that offer illuminating perspectives on the relationship between big data and urban planning: Singapore and Rwanda. These nations, at vastly different stages of

economic development and with dramatically different urban challenges, both demonstrate commitment to leveraging data for more effective, sustainable, and inclusive urban development. Their experiences offer valuable insights into the possibilities and limitations of data-driven urbanism across diverse contexts.

Singapore represents the vanguard of advanced data-driven urbanism. The city-state's "Smart Nation" vision, pursued systematically over more than a decade, has evolved into a comprehensive ecosystem of integrated digital infrastructure. The Open Digital Platform (ODP) serves as a "digital nervous system," enabling diverse urban systems to communicate and self-optimize in real-time. From smart water meters that detect leaks to assisted living technologies that protect seniors, Singapore demonstrates how big data can enhance sustainability, efficiency, and social inclusion. Yet this technological sophistication raises critical questions about privacy, surveillance, and the governance of automated systems.

Rwanda presents a contrasting picture of a rapidly developing nation strategically adopting big data tools to manage its unprecedented urbanization—the fastest in Southeast Asia—while charting its own path toward sustainable urban development. Rather than building an integrated smart city platform from scratch, Rwanda has pursued targeted applications addressing concrete challenges: land administration through the Geo-Spatial Hub, building permit processing through KUBAKA, and mobility planning through the Kigali Road Asset Management System. Partnerships with Singaporean expertise have been instrumental, but with careful attention to building local capacity and adapting models to Rwandan context.

The contrast between Singapore and Rwanda illuminates critical questions for SDG 9 and sustainable urban development: How do different contexts shape the adoption and adaptation of big data technologies? What governance frameworks ensure that data-driven urbanism serves all citizens? How can countries at different stages of development learn from each other's experiences? And what principles should guide the ethical and effective use of big data in urban planning?

2. LITERATURE REVIEW

2.1 Big Data and Smart Urbanism: Conceptual Foundations

The concept of "smart cities" has evolved significantly over the past two decades, from early techno-centric visions focused on sensor networks and efficiency to more nuanced understandings encompassing governance, sustainability, and citizen participation. Big data—characterized by volume, velocity, variety, and veracity—enables new forms of urban analysis and management, from real-time traffic optimization to predictive maintenance of infrastructure.

Academic analysis of Singapore's experience suggests that data-driven urbanism represents not merely a technical evolution but a shift in governance philosophy. The convergence of IoT and AI enables what researchers term an "environmental turn" in urban governance—the active shaping and management of urban spaces in real-time through always-on data collection, analysis, and automated responses. This approach, while potentially more efficient and responsive, raises important questions about privacy, consent, and the relationship between citizens and the state.

2.2 Singapore: Integrated Digital Infrastructure and Real-Time Optimization

The Smart Nation Vision and Digital Backbone: Singapore's approach to data-driven urbanism is characterized by comprehensive, integrated digital infrastructure developed through sustained government commitment. The Open Digital Platform (ODP), co-developed by GovTech and JTC, serves as the "digital backbone" of smart districts like Punggol Digital District. This platform addresses a fundamental challenge of smart city development: the proliferation of diverse systems (elevators, energy sensors, security turnstiles, autonomous vehicles) that "speak different languages." The ODP acts as a "universal translator," enabling these systems to communicate without complex custom integration.

The convergence of IoT and AI—known as AIoT—allows infrastructure to move beyond simple connectivity to predictive optimization. Rather than merely reacting to issues, systems can anticipate them. For example, by analyzing real-time occupancy data, the district can automatically adjust cooling and lighting before a crowd arrives, optimizing energy usage without human

intervention . This transforms urban districts into "living laboratories" where infrastructure is self-monitoring and self-optimizing.

Punggol Digital District: Integrated Masterplanning: The Punggol Digital District represents the most advanced manifestation of Singapore's integrated approach. It is the first district in Singapore to adopt an integrated masterplan approach, where physical infrastructure, urban solutions, and digital infrastructure are developed in tandem from the ground up, rather than in silos . The Open Digital Platform integrates diverse smart city solutions including:

- Facilities, building and estate management systems
- District cooling system
- Pneumatic waste conveyancing system
- Autonomous goods delivery systems
- Access and security systems
- Carpark systems
- Traffic lights system
- Autonomous vehicles

Crucially, data from the platform is made available via an Application Programming Interface (API) to encourage academics, researchers, startups, and SMEs to develop digital or urban solutions . A digital twin (digital replica) of the entire district enables safe testing of solutions before deployment.

Sustainability Applications: Singapore leverages big data to drive sustainability through precise, real-time resource management. As GovTech notes, "We cannot save what we cannot measure, and IoT allows us to manage resources like energy and water more precisely" . Key applications include:

- **Smart Water Management:** The national water agency (PUB) has deployed smart water meters at residential and commercial premises, taking multiple readings throughout the day to enable real-time consumption tracking and early leak detection .
- **Smart Districts:** In Punggol Northshore, HDB's first Smart and Sustainable District, sensors monitor energy usage and waste collection to improve estate services .

- **Integrated Environmental Modeller (IEM):** Developed with partners like A*STAR, this tool simulates micro-climate conditions to ensure urban planning keeps the city green .

Social Applications: Assisted Living: The Government Assisted Living Ecosystem (GALE) demonstrates how big data can support inclusive urban development. This ecosystem connects distinct technologies to create a safety net for seniors:

- Personal Alert Button (PAB): A GovTech-developed device allowing seniors to signal distress instantly
- GatherSG Case Management System (CMS): Coordinates care activities among healthcare providers
- Careline Telecare Operators & Senior Activity Centre Staff: Provide round-the-clock monitoring and incident response

This integrated approach ensures that technological innovation serves social as well as economic objectives.

Academic Analysis: The Environmental Turn in Governance: Scholarly analysis of Singapore's pandemic response, built upon the Smart Nation initiative, reveals deeper implications of data-driven urbanism. Researchers argue that Singapore's approach demonstrates a shift toward what they term an "environmental turn" in urban governance—the active shaping and management of urban spaces in real-time through always-on data collection, analysis, and automated responses .

Drawing on Foucault's concept of "environmentality," the analysis suggests that smart urbanism operates by governing through environmental systems rather than directly on individuals. The city becomes "both the instrument and object of governance facilitated through the productive power of digital technologies and their affordances" . This raises important questions about privacy, consent, and the relationship between citizens and the state. As the authors note, "the boundaries between individual agency, collective behaviour, and automated control become increasingly blurred and permeable" .

The analysis highlights that Singapore's suite of technological innovations serves as "a bellwether of an interfaced society's potential manifestation: one that embraces governance through algorithmic processes, initiating the subjectification of individuals via real-time responsiveness" .

2.3 Rwanda: Strategic Adoption and Institutional Capacity Building

Urbanization Challenges and Strategic Vision: Rwanda faces the fastest urbanization rate in Southeast Asia, with profound implications for infrastructure, housing, and service delivery. The country's Vision 2050 sets an ambitious urbanization target of 70% by 2050 . Managing this transformation requires effective planning tools and institutional capacity.

The 2025 National Urbanisation Policy provides the strategic framework for Rwanda's urban development, anchored on four pillars: Coordination, Densification, Liveability, and Economic Growth . The policy aims to ensure a climate-resilient, well-coordinated approach to urban development, encourage efficient land use, enhance quality of life, and enable robust urban economies.

Singapore-Rwanda Partnership: Rwanda's engagement with Singaporean expertise has been instrumental in building its urban planning capacity. Singaporean urban consultancy Surbana Jurong (which grew out of Singapore's Housing & Development Board) was selected in 2008 to develop a master plan for central Kigali. This was followed by a city-wide master plan in 2013, revised in 2018 to provide a blueprint for growth to 2050, and master plans for six other Rwandan cities in 2021 .

Crucially, this partnership has evolved toward greater Rwandan participation and ownership. Academic analysis notes that the 2050 Kigali master plan "involved more and more local participation from Rwanda," as Rwandan planners sought to adapt ideas to their own context more than in the past . This suggests a deliberate strategy of capacity-building rather than dependency creation.

Large-Scale Mapping and Urban Mobility: The "Project for Large-Scale Mapping and Urban Mobility Improvement in Kigali," a three-year collaboration with JICA completed in January 2025, produced significant outputs:

- **Topographic Maps:** High-resolution maps providing comprehensive and accurate representation of Kigali, enabling better urban planning and infrastructure development
- **Topomaps Geoportal:** An online platform providing easy access to digital maps and spatial data, empowering stakeholders with valuable information
- **3D City Model:** A virtual representation enabling better visualization and analysis for urban planning and development
- **Kigali Road Asset Management System (K-RAMS):** A pilot web-based platform for efficient road management, maintenance, and planning along a 100km road network

At the project's final seminar, Rwanda Land Management and Use Authority Director General Nishimwe M. Grace emphasized that these tools "will significantly improve urban mobility, enhance infrastructure development, and contribute to the overall sustainable growth of Kigali City" .

KUBAKA: Digital Building Permit Platform: In April 2025, Rwanda launched KUBAKA, a new digital platform for building permit services, replacing the old Building Permit Management Information System (BPMIS) that had been in use since 2016 . Key features include:

- Built on modern architecture with streamlined "zero trip" processing for permit applications
- Integrations with government third-party systems
- User-friendly interface allowing citizens, landowners, investors, and professionals to apply for and track permits in real-time
- Enhanced transparency, professionalism, and speed in application processing

RISA CEO Innocent Bagamba Muhizi described KUBAKA as "a critical step in modernizing service delivery and promoting smart, climate-resilient urban development across Rwanda" .

Geo-Spatial Hub: Satellite-Based Land Administration: In September 2025, Eastern Province leaders adopted the Geo-Spatial Hub, a satellite-based data system designed to strengthen land

administration, resolve disputes, and improve compliance with master plans . Key features include:

- Satellite imagery mapping every parcel of land, removing the need for land officers to visit the field for basic dispute resolution
- Integration with the Unique Parcel Identifier (UPI) database
- Automatic notifications whenever a new structure appears on previously undeveloped land, helping enforce master plans and reduce informal settlements
- Consolidated geospatial data center serving government entities, academia, and the private sector
- Capabilities to map disaster-prone areas, forest coverage, irrigation, mining sites, and settlement patterns

The adoption responds to identified gaps: between December 2023 and February 2024, only 34% of required land information in Eastern Province had been collected, with wide variation across districts . The system aims to address these inefficiencies by reducing errors and improving compliance without on-site inspections.

KUNUT: Research-Driven Urban Upgrading Tool: ETH Zurich's Kigali Unplanned Neighbourhood Upgrading Tool (KUNUT) represents an innovative research-driven approach to addressing informal settlements. Developed in collaboration with the Swiss Development Cooperation, KUNUT is a large-scale digital decision-making tool that analyzes, visualizes, and prioritizes urban upgrading scenarios based on real-time environmental, social, and economic data .

The tool's workflow encompasses data collection, analysis, city-scale strategy development, site identification and prioritization, neighborhood-scale strategy development, and scenario design for settlement upgrading. Outputs include GIS-referenced layers, 2D, 3D and 4D models, and automated reports with Key Performance Indicators based on the SDGs . As Kigali and other African cities continue to grow, such digital tools will be key in real-time policymaking, shaping a future where cities reconcile with their natural environment.

2.4 Comparative Dimensions: Integration, Scale, and Strategy

The comparison between Singapore and Rwanda illuminates several critical dimensions of big data for urban planning:

Technological Integration: Singapore's approach emphasizes comprehensive integration through platforms like ODP that unify diverse urban systems . Rwanda's approach is more modular, with targeted applications for specific challenges (land administration, building permits, mobility) .

Scale of Application: Singapore's data infrastructure covers the entire city-state, with advanced applications in districts like Punggol . Rwanda's applications are progressively scaling from Kigali to other cities and provinces .

Governance Philosophy: Singapore's approach reflects what scholars term "environmental governance"—real-time modulation of urban spaces through automated systems . Rwanda's approach emphasizes institutional capacity-building and service delivery improvement.

Partnership Strategy: Singapore develops technology primarily through domestic agencies and research institutions . Rwanda leverages international partnerships (Singapore, Japan, Switzerland) while building local capacity .

Data Coverage and Quality: Singapore benefits from comprehensive data coverage and high-quality infrastructure. Rwanda faces data gaps, as evidenced by incomplete land records in Eastern Province .

3. RESEARCH QUESTIONS

This study addresses the following research questions:

1. What are the key characteristics of Singapore's approach to big data for urban planning, including technological infrastructure, governance frameworks, and applications across sustainability and social domains?
2. What are the key characteristics of Rwanda's approach to big data for urban planning, including strategic adoption of targeted tools, partnership models, and recent concrete achievements?

3. How do the two countries compare in terms of technological integration, scale of application, governance philosophy, and approach to capacity building?
4. What insights emerge from Rwanda's engagement with Singaporean expertise, and how has this partnership evolved toward greater local ownership?
- 5.

4. METHODOLOGY

This study employs a comparative analysis methodology to examine big data for urban planning in Singapore and Rwanda. The research design integrates secondary analysis of government documentation, academic research, institutional reports, and news coverage to develop comprehensive understanding of technological infrastructures, governance frameworks, implementation strategies, and outcomes in both countries.

Research Design: The comparative approach is appropriate for examining how different national contexts, development stages, and strategic orientations shape the adoption and adaptation of data-driven urban planning tools. Singapore and Rwanda were selected as cases that offer complementary insights: Singapore represents an advanced, integrated smart city ecosystem; Rwanda represents a rapidly developing nation strategically adopting targeted data tools while building institutional capacity.

Data Sources: Primary and secondary sources analyzed include:

- GovTech Singapore documentation on Open Digital Platform, GALE, and smart water management
- CtrlShift Singapore documentation on Punggol Digital District
- Centre for Liveable Cities overview of science and technology applications
- Academic research on AI and data-driven urbanism in Singapore
- Rwanda Land Management and Use Authority documentation of large-scale mapping project
- Ministry of Infrastructure documentation of National Urbanisation Policy and KUBAKA
- The New Times coverage of Geo-Spatial Hub adoption
- African Business analysis of Singapore-Rwanda urban planning partnership

- ETH Zurich documentation of KUNUT

Analytical Framework: The comparative framework examines five dimensions:

1. **Technological Infrastructure:** Platforms, sensors, data systems, and integration approaches
2. **Governance Frameworks:** Policies, institutions, and decision-making processes
3. **Application Domains:** Sustainability, mobility, land administration, social services
4. **Partnership and Capacity:** Models of collaboration and local expertise development
5. **Outcomes and Challenges:** Achievements, limitations, and ongoing issues.

5. RESULTS

5.1 Singapore: Integrated Digital Infrastructure

The Open Digital Platform and AIoT: Singapore's data-driven urbanism is built upon the Open Digital Platform (ODP), co-developed by GovTech and JTC. The ODP addresses the fundamental challenge of interoperability among diverse urban systems by acting as a "universal translator," enabling systems like air-conditioning, security turnstiles, elevators, and energy sensors to communicate without complex custom integration .

The convergence of IoT and AI—AIoT—enables predictive optimization. Rather than merely reacting to issues, systems anticipate them. By analyzing real-time occupancy data, the system automatically adjusts cooling and lighting before a crowd arrives, optimizing energy usage . This transforms urban districts into "living laboratories" where infrastructure is self-monitoring and self-optimizing.

Punggol Digital District: The Punggol Digital District represents the most advanced application of Singapore's integrated approach. Key features include:

Feature	Description	
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Integrated Masterplanning	First district to integrate physical and digital infrastructure from the ground up	
Open Digital Platform	Integrates facilities management, district cooling, waste conveyancing, autonomous delivery, access control, carpark systems, traffic lights, and autonomous vehicles	
Open Data for Innovation	Real-time and historical data published via API for academics, researchers, startups, and SMEs to develop solutions	
Digital Twin	Digital replica of entire district enables safe testing before deployment	

Sustainability Applications: Singapore leverages big data for precise resource management:

- **Smart Water Meters:** Deployed by PUB at residential and commercial premises, enabling real-time consumption tracking and early leak detection
- **Smart Districts:** Punggol Northshore sensors monitor energy usage and waste collection
- **Integrated Environmental Modeller:** Simulates micro-climate conditions to keep the city green

Social Applications: The Government Assisted Living Ecosystem (GALE) connects seniors to 24/7 care through personal alert devices, case management systems, and round-the-clock monitoring .

Academic Analysis: Research on Singapore's pandemic response reveals deeper implications of data-driven urbanism. Scholars argue that Singapore demonstrates an "environmental turn" in governance—the real-time shaping of urban spaces through automated systems . This raises important questions about privacy and the balance between technological innovation and public trust.

5.2 Rwanda: Strategic Adoption and Capacity Building

Singapore-Rwanda Partnership: Singaporean consultancy Surbana Jurong has developed master plans for Kigali (2008, 2013, 2018) and six other Rwandan cities (2021), with each iteration involving greater Rwandan participation .

Large-Scale Mapping Project: The JICA-funded project completed January 2025 produced:

Output	Description	
Topographic Maps	High-resolution maps for better planning	
Topomaps Geoportal	Online platform providing access to spatial data	
3D City Model	Virtual representation for visualization and analysis	
Kigali Road Asset Management System	Web-based platform for road management (pilot on 100km network)	

KUBAKA Digital Permits: Launched April 2025, KUBAKA enables citizens to apply for and track building permits in real-time with "zero trip" processing .

Geo-Spatial Hub: Adopted September 2025 in Eastern Province, this satellite-based system maps every parcel, automatically notifying authorities of new structures on previously undeveloped land .

KUNUT: ETH Zurich's Kigali Unplanned Neighbourhood Upgrading Tool integrates GIS, data science, and scenario modeling to prioritize upgrading scenarios for informal settlements .

5.3 Comparative Analysis

Table 1: Comparative Summary—Singapore and Rwanda

Dimension	Singapore	Rwanda	
Technological Approach	Integrated platform (ODP) unifying diverse systems	Modular, targeted applications for specific challenges	
Governance Philosophy	Real-time environmental modulation through automated systems	Institutional capacity building and service delivery improvement	
Partnership Strategy	Domestic development through govtech agencies	International partnerships with deliberate local capacity building	
Key Applications	District optimization, water management, assisted living	Land administration, building permits, road management	
Data Coverage	Comprehensive, high-quality	Developing; gaps remain (e.g., incomplete land records)	
Innovation Model	Open data APIs for crowdsourced solutions	Research partnerships (JICA, ETH) for tool development	
Key Strengths	Real-time optimization; predictive analytics; social applications	Strategic targeting of concrete challenges; building local expertise	
Key Challenges	Privacy concerns; public trust; societal implications of automated governance	Data gaps; infrastructure limitations; implementation capacity	

Key Differences:

1. **Technological Integration:** Singapore's ODP enables comprehensive integration of diverse urban systems . Rwanda's approach is more modular, with separate systems for land, permits, and mobility .

2. **Governance Philosophy:** Singapore's approach reflects what scholars term "environmental governance"—real-time modulation of urban spaces through automated systems . Rwanda emphasizes institutional capacity building and improved service delivery .
3. **Innovation Model:** Singapore leverages open data APIs to crowdsource solutions from researchers and entrepreneurs . Rwanda relies on international partnerships (JICA, ETH) for tool development while building local expertise .
4. **Application Focus:** Singapore's applications span sustainability, mobility, and social services in an integrated manner . Rwanda's applications target specific challenges: land administration, building permits, road management .
5. **Data Coverage:** Singapore benefits from comprehensive, high-quality data infrastructure. Rwanda faces data gaps, as evidenced by incomplete land records in Eastern Province .

Key Similarities:

1. **Strategic Vision:** Both countries have clear strategic frameworks linking data initiatives to broader urban development goals—Smart Nation in Singapore , Vision 2050 and National Urbanisation Policy in Rwanda .
2. **Commitment to Innovation:** Both demonstrate strong government commitment to leveraging technology for urban development.
3. **Attention to Sustainability:** Both integrate sustainability considerations—Singapore through precise resource management , Rwanda through climate-resilient planning and wetland protection .
4. **Recognition of Social Dimensions:** Both acknowledge that technology must serve social objectives—Singapore through GALE , Rwanda through citizen-centered service delivery .
5. **Evolving Approaches:** Both continuously adapt and refine their approaches as technologies and understanding evolve.

6. DISCUSSION OF RESULTS

6.1 Integration vs. Modularity: Different Paths to Data-Driven Urbanism

The comparison between Singapore and Rwanda reveals that there is no single path to data-driven urbanism. Singapore's integrated platform approach, embodied in the Open Digital Platform, enables comprehensive optimization across urban systems—cooling, lighting, waste, mobility—through real-time data integration and predictive analytics . This approach delivers substantial efficiencies but requires sophisticated technical infrastructure, significant investment, and centralized coordination.

Rwanda's modular approach—targeted applications for land administration (Geo-Spatial Hub), building permits (KUBAKA), and road management (K-RAMS)—addresses concrete challenges without requiring comprehensive system integration . This approach may be more appropriate for contexts with limited resources and infrastructure, allowing incremental progress while building institutional capacity.

The choice between integration and modularity is not merely technical but reflects governance philosophy. Singapore's approach enables the kind of "environmental governance" scholars describe—real-time modulation of urban spaces through automated systems . Rwanda's approach emphasizes improved service delivery and citizen convenience (the "zero trip" permit process) .

6.2 The Promise and Peril of Real-Time Optimization

Singapore's AIoT capabilities—automatically adjusting cooling and lighting before crowds arrive, predicting maintenance needs before failures occur—demonstrate the transformative potential of real-time data analytics . These capabilities can dramatically improve urban efficiency, reduce resource consumption, and enhance quality of life.

Yet academic analysis raises important questions about the societal implications of such systems. When governance operates through automated environmental modulation rather than conscious citizen engagement, the boundaries between individual agency and systemic control blur . Citizens may not be aware of how their behavior is being shaped, or may not have consented to the data collection that enables such shaping.

Singapore's experience suggests that technological sophistication must be accompanied by robust governance frameworks addressing privacy, transparency, and public trust. As the Smart Nation initiative evolves, these considerations will become increasingly important.

6.3 Building Local Capacity Through Strategic Partnership

Rwanda's engagement with Singaporean expertise offers valuable lessons in partnership design. Rather than simply importing master plans, the collaboration has evolved toward greater Rwandan participation and ownership. The 2050 Kigali master plan "involved more and more local participation from Rwanda," as Rwandan planners adapted ideas to their own context .

This approach recognizes that sustainable urban development requires local institutional capacity, not just technical solutions. The partnerships with JICA for mapping and ETH for KUNUT similarly emphasize knowledge transfer and capacity building alongside tool development.

For countries seeking to learn from Singapore's experience, Rwanda's example suggests that engagement should be structured to build local expertise, not create dependency. The goal is not to replicate Singapore but to adapt its lessons to local contexts.

4 Data Gaps and Implementation Challenges

Rwanda's experience also reveals the persistent challenges of data-driven urbanism in developing contexts. The incomplete land records in Eastern Province—only 34% of required information collected, with wide variation across districts —highlight the gap between data aspirations and ground realities. Even sophisticated tools like the Geo-Spatial Hub depend on underlying data quality and completeness.

Similarly, the KUNUT tool's sophisticated scenario modeling depends on reliable environmental, social, and economic data . Building this data infrastructure requires sustained investment and institutional commitment.

Singapore's comprehensive data coverage was not achieved overnight but through decades of systematic investment. Rwanda's journey will similarly require patience and persistence.

5 Implications for SDG 9

The findings have important implications for achieving SDG 9 targets:

Target 9.1 (Sustainable infrastructure): Both countries demonstrate that data-driven approaches can enhance infrastructure sustainability—Singapore through predictive optimization , Rwanda through improved road management and land administration .

Target 9.4 (Resource-efficient industries): Singapore's AIoT applications for district cooling and lighting demonstrate significant resource efficiency gains . Rwanda's digital permit platform streamlines processes and reduces waste .

Target 9.c (Access to ICT): Both countries are expanding access to digital services—Singapore through integrated platforms , Rwanda through citizen-facing applications like KUBAKA .

Target 9.5 (Research and innovation): Both countries demonstrate commitment to research and innovation—Singapore through open data APIs and crowdsourced solutions , Rwanda through partnerships with ETH and other research institutions .

Target 9.1 (Regional development): Rwanda's National Urbanisation Policy explicitly links urban development to regional economic growth and improved quality of life .

7. CONCLUSION

This comparative analysis of big data for urban planning in Singapore and Rwanda reveals profound insights into how different national contexts shape the adoption and adaptation of data-driven urbanism. The two countries, at vastly different stages of development and with different strategic orientations, each illuminate critical dimensions of the relationship between technology, governance, and sustainable urban development.

Singapore's advanced Smart Nation ecosystem demonstrates the transformative potential of integrated, real-time data infrastructure. The Open Digital Platform serves as a "digital nervous system," enabling diverse urban systems to communicate and self-optimize. AIoT applications predict and respond to conditions before human operators would even be aware of them, delivering significant efficiency gains. The Punggol Digital District exemplifies integrated masterplanning where physical and digital infrastructure are developed in tandem. Social applications like GALE show how data can support inclusive development. Yet this technological sophistication raises critical questions about privacy, consent, and the societal implications of automated governance.

Rwanda presents a contrasting model of strategic, targeted adoption. Rather than building an integrated platform from scratch, Rwanda has developed modular applications addressing concrete challenges: land administration through the Geo-Spatial Hub, building permits through KUBAKA, and mobility planning through K-RAMS. Partnerships with Singaporean expertise have been instrumental, but with deliberate attention to building local capacity and adapting models to context. Recent achievements demonstrate real progress, yet data gaps and implementation challenges persist.

Several cross-cutting insights emerge from this comparison:

First, context matters fundamentally. Singapore's integrated platform approach reflects its unique characteristics as a wealthy city-state with centralized governance and decades of systematic investment. Rwanda's modular approach reflects its development stage, resource constraints, and specific urban challenges. Neither model is inherently superior; each must be assessed within its context.

Second, strategic vision guides effective implementation. Both countries have clear strategic frameworks linking data initiatives to broader urban development goals—Singapore's Smart Nation, Rwanda's Vision 2050 and National Urbanisation Policy. This clarity helps ensure that technology serves policy objectives rather than driving them.

Third, institutional capacity is as important as technology. Rwanda's emphasis on building local expertise through partnerships recognizes that sustainable urban development depends on people

and institutions, not just tools. Singapore's sophisticated systems rest on decades of capacity building.

Fourth, data quality determines tool effectiveness. Rwanda's incomplete land records highlight that even sophisticated tools depend on underlying data. Building data infrastructure requires sustained investment and attention to quality.

Fifth, governance frameworks must evolve alongside technology. Singapore's experience raises important questions about privacy, consent, and automated governance that will require ongoing attention . As data-driven urbanism spreads, these considerations become increasingly important.

Sixth, partnerships can build capacity without creating dependency. Rwanda's engagement with Singaporean, Japanese, and Swiss partners has been structured to transfer knowledge and build local ownership . This model offers lessons for other countries seeking to learn from advanced urbanism experiences.

Seventh, citizen-centered design matters. Rwanda's emphasis on "zero trip" permit processing and user-friendly interfaces reflects attention to citizen experience. Singapore's GALE ecosystem demonstrates how technology can serve vulnerable populations .

For Singapore, priorities emerging from this analysis include:

1. Continue advancing technological integration while strengthening governance frameworks addressing privacy, transparency, and public trust.
2. Share Singaporean experience with other countries through partnerships structured to build local capacity, learning from Rwanda's approach to engagement.
3. Address the societal implications of automated governance identified in academic analysis through public dialogue and policy development.
4. Ensure that innovation serves all citizens, including vulnerable populations, through continued investment in social applications.

For Rwanda, priorities include:

1. Address data gaps identified in Eastern Province through systematic data collection and quality improvement.
2. Continue building local institutional capacity through partnerships and training, ensuring that dependence on external expertise diminishes over time.
3. Scale successful applications (KUBAKA, K-RAMS) from pilot to national coverage.
4. Leverage tools like KUNUT to address informal settlements and ensure inclusive development.
5. Maintain focus on citizen-centered service delivery as digital systems expand.

For the international community, the lessons are clear: data-driven urbanism offers powerful tools for sustainable development, but their effectiveness depends on context-sensitive implementation, institutional capacity, and attention to governance. Singapore's advanced model and Rwanda's strategic adaptation both offer valuable insights for countries at different stages of development.

The ultimate measure of success for SDG 9 is not the sophistication of technological systems but whether infrastructure is sustainable, industries are resource-efficient, and all people have access to the services they need. Singapore and Rwanda, in their different ways, are both working toward these goals.

8. LIMITS OF THE STUDY

This study has several limitations that should be acknowledged. First, the comparative analysis relies primarily on secondary sources rather than primary empirical research. Direct observation of data systems in both countries, interviews with planners, technologists, and citizens, and participatory research would provide valuable additional perspectives and ground-truth the findings from published literature. Second, data availability and comparability vary significantly between countries. Singapore benefits from extensive documentation through government agencies and academic research. Rwanda's documentation is more recent and less comprehensive, though growing rapidly. Third, the study focuses on formal data systems and planned initiatives, with less attention to informal practices and implementation challenges on the ground. Fourth, the voice of citizens—particularly vulnerable populations who may be most affected by data systems—is mediated through reports rather than captured directly. Future research should prioritize participatory methodologies that center citizen perspectives. Fifth, the study does not

comprehensively address the political economy dimensions—the interests, power relations, and structural forces that shape data system development in both countries. Understanding why certain data approaches are pursued and who benefits requires deeper political economy analysis. Sixth, the transferability analysis is necessarily speculative. While principles can be identified, actual transfer of data approaches depends on countless contextual factors that cannot be fully anticipated. Despite these limitations, the comparative analysis provides valuable insights into big data for urban planning, with implications for both countries and for broader efforts to achieve SDG 9.

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10. AUTHOR CONTRIBUTIONS

The author conceived the study, designed the research methodology, conducted the literature review and document analysis, synthesized findings across countries, and drafted the complete manuscript. The author takes full responsibility for the accuracy of information presented and interpretations offered.

11. COMPETING INTERESTS

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential competing interest. No funding was received from organizations with interests in urban planning, data systems, or related sectors.

12. AUTHORS' CONTRIBUTIONS

As sole author, I performed all roles including conceptualization, methodology development, investigation, formal analysis, writing, review, editing, and project administration.

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14. DATA AVAILABILITY

All sources analyzed in this study are publicly available documents, including government publications, academic articles, institutional reports, and news media coverage. Primary sources are cited in the bibliography and accessible through the referenced publications and organizations.

15. DISCLAIMER

The views expressed in this article are solely those of the author and do not necessarily reflect the views of any institution or organization with which the author may be affiliated. The analysis is provided for scholarly purposes and should not be construed as policy guidance or technical advice. Data systems, urban planning approaches, and governance frameworks are subject to change, and readers should consult current sources for specific information about Singapore, Rwanda, and big data for urban planning.

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