

GREEN INFRASTRUCTURE, SMART CITIES AND COMMUNITY CENTRIC APPROACHES IN SOUTH AFRICA: A THEORETICAL REVIEW OF SUSTAINABLE URBAN DEVELOPMENT

T.L NKOSI¹ and S.H.P. CHIKAFALIMANI²

^{1,2}Construction Management & Quantity Surveying, Durban University of Technology, Durban, RSA.
Email: ¹thalenten@dut.ac.za, ²SamuelC@dut.ac.za

Abstract

This paper examines how innovative practices are conceptualized and implemented in the pursuit of sustainable infrastructure development in South Africa. It responds to the fragmentation in existing literature by integrating key domains, including green infrastructure, smart city initiatives, the Integrated Urban Development Framework, and community-centric approaches, to develop a more coherent understanding of sustainable infrastructure transitions. A narrative literature review was conducted using academic studies, policy documents, and institutional reports published between 2015 and 2025. The analysis employed thematic synthesis, guided by theoretical lenses such as sustainable development, innovation diffusion, resilience, and spatial justice. Findings indicate that innovations such as urban reforestation, nature-based flood management, digital water metering, and participatory upgrading of informal settlements can yield interconnected ecological, social, and economic benefits when supported by effective governance and policy alignment. However, challenges such as institutional fragmentation, corruption, funding limitations, technical capacity constraints, and the digital divide continue to hinder scalability and equitable implementation. The study also highlights the dominance of descriptive research and a lack of integrative theoretical frameworks in existing literature. Overall, the paper contributes an integrated conceptual perspective that links innovation, resilience, and spatial justice, offering insights for more inclusive and coordinated sustainable infrastructure development in South Africa and comparable Global South contexts.

Keywords: Green Infrastructure; Innovation Diffusion; Smart Cities; Sustainable Infrastructure; South Africa.

1. INTRODUCTION

Global concerns about climate change, biodiversity loss and widening social inequality have intensified pressure on infrastructure systems to become more sustainable, resilient and inclusive [1,2]. Internationally, sustainable infrastructure is increasingly framed as a critical lever for achieving low carbon development, climate adaptation and social justice in rapidly urbanising contexts [3,4]. South Africa faces these global sustainability imperatives under particularly complex historical and structural conditions. Decades of conventional, resource intensive infrastructure provision, combined with entrenched socio-economic inequalities, have produced systems that are environmentally damaging, economically fragile and unevenly distributed across space and social groups [5,6]. Within South Africa, infrastructure and urban development are shaped by overlapping crises in energy, water and sanitation, as well as escalating climate related risks [7]. Persistent load shedding, ageing and poorly maintained networks, and significant non-revenue water undermine economic performance and public trust in state institutions [8]. At the same time, coastal and riverine cities such as Durban increasingly confront destructive floods, storm surges and heatwaves that expose the vulnerability of existing built environments [1]. These pressures intersect with the enduring

legacy of apartheid spatial planning, in which historically marginalized communities remain concentrated in peripheral or hazard prone areas with limited access to quality infrastructure and services, and with ongoing governance challenges related to institutional fragmentation, corruption and limited technical capacity [5,9]. In response, a diverse range of innovative practices has emerged around sustainable infrastructure in South Africa. These include green infrastructure initiatives such as urban reforestation, wetland restoration and nature-based flood management; smart city and digital solutions for water, energy and transport systems; integrated planning frameworks such as the Integrated Urban Development Framework (IUDF); and community centric approaches to informal settlement upgrading and local environmental management [10].

A growing body of academic studies, policy reports and case-based analyses investigates these developments, often highlighting both their potential benefits and their structural limitations [11, 12; 13]. However, the literature remains conceptually fragmented. Many contributions focus on specific sectors, cities or projects, and are frequently descriptive, offering limited engagement with the theoretical perspectives that could illuminate how innovation, sustainability and socio spatial transformation interact in the South African infrastructure context [14]. The absence of an integrative conceptual overview makes it difficult to understand how these different strands of work collectively advance knowledge on sustainable infrastructure transitions in South Africa, and where critical theoretical and empirical gaps persist [15]. This paper addresses that problem by providing a literature/theoretical review of innovative practices for sustainable infrastructure in South Africa, rather than a protocol driven systematic review. Its aim is to synthesise and interpret existing scholarship through key theoretical lenses such as sustainable development, innovation diffusion, resilience and spatial justice so as to clarify how innovative practices are framed, what forms they take in different urban and infrastructural domains, and how they are constrained or enabled by wider governance and socio-economic conditions [16].

The paper's contribution is twofold. First, it consolidates dispersed evidence on four major domains of innovative practice: green infrastructure, smart city initiatives, the IUDF and related policy frameworks, and community centric approaches [10]. Second, it offers a theoretical synthesis that connects these domains to broader debates on sustainability transitions and urban transformation in the global South [11,17]. By doing so, the review provides a conceptual map of current knowledge on innovative sustainable infrastructure practices in South Africa and identifies avenues for future research that can strengthen theory driven, context sensitive analyses of infrastructure change [18,7]. This study makes three key contributions. First, it consolidates fragmented literature on green infrastructure, smart city initiatives, policy frameworks, and community-centric approaches into a single integrative review. Second, it advances theoretical understanding by linking these domains through combined conceptual lenses, including innovation diffusion, socio-technical transitions, resilience, and spatial justice. Third, it proposes a context-sensitive conceptual framework that provides a foundation for future empirical and theory-driven research on sustainable infrastructure transitions in South Africa and other Global South contexts.

2. LITERATURE REVIEW

This section synthesises South African literature on innovative practices for sustainable infrastructure, organised around four major themes identified in recent work: green infrastructure, smart city and digital initiatives, policy and planning frameworks, and community centric approaches. These themes collectively illustrate how different forms of innovation respond to intertwined ecological, socio economic and governance challenges in the country's infrastructure landscape.

2.1 Green infrastructure in South Africa

Green infrastructure has emerged as a prominent strategy for embedding nature-based solutions into South African cities, particularly in response to climate risks, biodiversity loss and service backlogs. Empirical studies highlight interventions such as the Buffelsdraai Reforestation Project in eThekweni, wetland restoration under the Working for Wetlands programme, and urban greening initiatives in Johannesburg and Pretoria, including street tree planting, green roofs and vertical gardens. These projects demonstrate how restored and constructed ecosystems can provide flood mitigation, microclimate regulation, carbon sequestration and enhanced urban biodiversity, while also generating green jobs and livelihood opportunities [22,10]. Green infrastructure interventions are widely associated with multiple co benefits. Studies report ecological gains in the form of improved water purification, reduced runoff and increased habitat connectivity, social benefits through enhanced public health, recreation and community cohesion, and economic advantages linked to avoided damage costs and employment in maintenance and ecological monitoring [18]. Therefore, literature also documents persistent implementation challenges. Many municipalities lack specialised ecological and design expertise, resulting in projects that are difficult to plan, integrate and maintain over time [23]. Funding constraints and the absence of ring-fenced budget lines for green infrastructure further limit the scale and continuity of interventions, especially in fiscally stressed municipalities. Fragmented governance and land use conflicts, particularly in informal settlements and peri urban areas, complicated long-term planning and coordination, raising concerns that the most vulnerable communities may be excluded from the benefits of green infrastructure [24].

2.2 Smart city and digital initiatives

A second strand of literature examines smart city and digital innovations aimed at improving the efficiency, reliability and transparency of infrastructure services. South African examples include Cape Town's smart water management system, which uses digital meters and IoT sensors to detect leaks and monitor consumption; traffic management and smart metering initiatives in Johannesburg, Tshwane and eThekweni; and proposals such as the Lanseria Smart City, which seek to integrate digital infrastructure, renewable energy and mixed use urban form [13]. These studies typically frame smart initiatives as responses to water scarcity, energy insecurity and congestion, with the potential to enhance resource efficiency, reduce losses and support evidence based planning [9]. Evidence on the benefits of smart initiatives points to reduced non-revenue water, improved fault detection, more responsive service delivery and

opportunities for greater citizen engagement through open data portals and digital platforms [13]. However, literature also underscores significant limitations and risks. Technical complexity and shortages of ICT skills at municipal level hinder implementation and long-term operation, while high upfront costs and dependence on proprietary technologies can lock cities into inflexible vendor relationships [25]. Researchers further highlight the “digital divide”, noting that unequal access to connectivity, devices and digital literacy means that smart systems may reinforce existing socio spatial inequalities if not accompanied by inclusive design and capacity building [26]. Taken together, these studies suggest that smart city innovations can contribute to sustainable infrastructure but require careful governance and attention to equity.

2.3 Policy and planning frameworks: IUDF, NDP and related instruments

A third body of work focuses on national and city level policy frameworks that seek to reorient infrastructure development towards sustainability, integration and spatial transformation. The Integrated Urban Development Framework (IUDF), adopted in 2016, is frequently cited as a cornerstone policy that promotes compact, connected and inclusive cities through mixed use development, integrated transport and coordinated investment [25]. Studies note that the IUDF, together with the National Development Plan (NDP 2030) and alignment with the Sustainable Development Goals, provides a coherent normative and strategic foundation for innovative infrastructure planning, particularly around spatial transformation, climate resilience and social inclusion [21]. Empirical analyses, however, point to an implementation gap between policy ambitions and on the ground outcomes. At municipal level, capacity constraints, fragmented mandates and unstable political environments often limit the translation of IUDF principles into concrete projects and regulations, leading to uneven progress across cities and regions [6]. Some authors argue that while the IUDF and related strategies explicitly call for integrated, sustainable infrastructure, they remain insufficiently backed by dedicated funding instruments, robust accountability mechanisms and practical tools for intergovernmental coordination [27]. As a result, conventional, siloed infrastructure practices continue to dominate in many contexts, and spatial inequalities remain deeply entrenched [20].

2.4 Community centric and participatory approaches

Finally, a growing literature examines community centric and participatory approaches to infrastructure, particularly in informal settlements and historically marginalised areas. Case studies from Khayelitsha, parts of Cape Town, eThekweni and rural municipalities describe initiatives such as community led housing upgrades, urban gardens, recycling cooperatives, participatory budgeting and decentralised water governance [28] various works. These interventions frame residents not as passive beneficiaries but as co designers and co-managers of infrastructure, drawing on local knowledge and social networks to tailor solutions to context and strengthen social cohesion [23]. The literature highlights several strengths of community centric approaches. They can enhance the relevance and legitimacy of infrastructure investments, improve maintenance through local stewardship, and contribute to livelihoods and empowerment, especially where formal state provision has been inadequate [28]. At the same time, scholars stress that such initiatives often rely on precarious funding, volunteer labour and

variable municipal support, making them vulnerable to burnout and discontinuity [18]. Limited access to technical expertise and institutional backing can constrain the scale and technical quality of community driven projects, while power imbalances and tokenistic participation processes sometimes undermine genuine co production [25] Consequently, many authors call for stronger institutional frameworks, stable financing and deliberate capacity building to realise the full potential of community centric infrastructure as a pillar of spatial justice and resilience. Across these four themes, the South African literature reveals a vibrant but uneven landscape of innovative practices that engage with sustainability, resilience and spatial justice in different ways. The next section distils cross cutting barriers and enablers identified across these domains, using the conceptual lenses outlined earlier to interpret how structural conditions shape the diffusion and impact of innovation in the country's infrastructure systems.

2.5 Cross-cutting Synthesis of Innovative Practices

Across the four thematic domains, several cross-cutting patterns emerge. Green infrastructure, smart city initiatives, policy frameworks, and community-centric approaches each contribute distinct but overlapping benefits to sustainable infrastructure development. Green infrastructure primarily delivers ecological and co-benefits, while smart initiatives emphasise efficiency and data-driven management. Policy frameworks provide strategic direction, whereas community-centric approaches enhance legitimacy and inclusivity. However, these domains also share common constraints, including institutional fragmentation, funding limitations, and capacity deficits. Importantly, the literature suggests limited integration across these domains, with most initiatives implemented in isolation rather than as part of coordinated socio-technical systems. From a theoretical perspective, this fragmentation reflects a disconnect between technological innovation, governance systems, and socio-spatial realities. Addressing this gap requires integrative frameworks that explicitly link infrastructure innovation with spatial justice, resilience, and systemic transformation.

2.6 Theoretical Reflections and Research Gaps

The reviewed literature shows that theoretical engagement in South African work on innovative sustainable infrastructure is uneven and often limited. Many studies invoke broad concepts such as sustainable development, resilience or innovation, but employ them primarily as normative labels rather than as analytical frameworks to interrogate how infrastructure systems change over time. Sustainable development and the SDGs, for instance, are frequently cited to justify interventions in green infrastructure, smart cities or community centric projects, yet they are seldom used to rigorously examine tradeoffs between environmental protection, economic growth and social equity in specific contexts [11,7] Similarly, resilience is often referenced to describe the desired qualities of urban systems exposed to climate risks, without detailed theorisation of resilience pathways, thresholds or the politics of whose resilience is prioritised [20,12].

By contrast, more formal theories such as Innovation Diffusion Theory are used in a relatively small subset of studies, mainly to explain the adoption or non-adoption of specific technologies and practices [19]. Even where Rogers' framework is referenced, the focus often remains on

identifying barriers such as cost, complexity or lack of compatibility with existing systems rather than exploring how social networks, institutional cultures and power relations shape diffusion trajectories. Concepts like circular economy, socio technical transitions and just transition, which could provide richer accounts of systemic change and the restructuring of infrastructure regimes, appear only sporadically in the South African literature [29, 18]. As a result, the dominant conceptual picture is one in which sustainable development and resilience are over used in relatively generic ways, while more critical or systemic theoretical perspectives are underdeveloped. Several conceptual gaps emerge clearly from this review. First, there is a notable lack of integrative frameworks that bring together green infrastructure, smart technologies and community centric approaches within a single analytical model. Most studies examine one domain at a time for example, green infrastructure for ecosystem services, or smart metering for water efficiency without systematically exploring how these innovations interact, complement or potentially undermine each other in specific territories ([10]. Second, although the legacy of apartheid spatial planning is widely acknowledged as a critical contextual factor, it is rarely theorised in depth within innovation focused studies. Spatial justice and spatial transformation are invoked in policy discourse, yet empirical work on smart cities or green infrastructure often treats space as a neutral backdrop rather than as a product of historical power relations that structure who benefits from innovation and who bears residual risk [5,6]. Third, relatively few studies explicitly connect infrastructure innovation to broader debates on socio technical transitions or sustainability transitions in the global South, limiting the contribution of South African scholarship to international theory building ([17].

Addressing these gaps will require more deliberate use and development of conceptual models. One promising direction is to combine Innovation Diffusion Theory with socio technical transitions thinking, such as the multi-level perspective, to analyse how niche practices in green infrastructure or community-based upgrading interact with existing infrastructure regimes and broader landscape pressures like climate change and macro-economic trends [19,29]. This combined lens would allow researchers to move beyond lists of adoption barriers and examine how power, institutions and path dependency shape the evolution of infrastructure systems. A second avenue is to integrate resilience and spatial justice into a single framework that explicitly links questions of vulnerability and adaptability with those of distribution and recognition. Such a model could help assess whether innovative practices enhance resilience for marginalised communities or primarily protect already well served areas, thereby deepening or reducing spatial inequality [12, 5].

Future research should also expand the empirical basis for theory driven analysis. Comparative city studies across South African metros and secondary cities would illuminate how different institutional arrangements, socio spatial histories and economic structures condition the performance of similar innovations in green or smart infrastructure [6]. Longitudinal analyses of particular initiatives such as wetland restoration programmes, smart water systems or community led upgrading projects could trace how their objectives, governance arrangements and social impacts evolve over time, providing insight into learning processes and transitions dynamics [23,18]. Multi scalar studies that connect neighbourhood level interventions to municipal, provincial and national policy frameworks would further clarify how vertical and

horizontal governance relations enable or constrain innovation [25]. By pursuing these directions, South African scholarship can move beyond largely descriptive accounts of innovative practices to develop more robust, context sensitive theories of sustainable infrastructure transitions.

3. PROPOSED CONCEPTUAL FRAMEWORK

The proposed framework conceptualizes sustainable infrastructure transitions as the outcome of interactions between technological innovation, institutional dynamics, and socio-spatial conditions. Innovation diffusion and socio-technical transitions explain how new practices emerge and scale; resilience highlights system adaptability under stress; and spatial justice ensures equitable distribution of benefits. These dimensions are not independent. Rather, they interact dynamically: for example, the diffusion of smart technologies may enhance efficiency but also exacerbate inequalities if not aligned with spatial justice principles. Similarly, community-centric approaches can strengthen resilience but require institutional support to scale effectively. The framework therefore emphasizes integration across domains, positioning sustainable infrastructure as a multi-dimensional and context-dependent process.

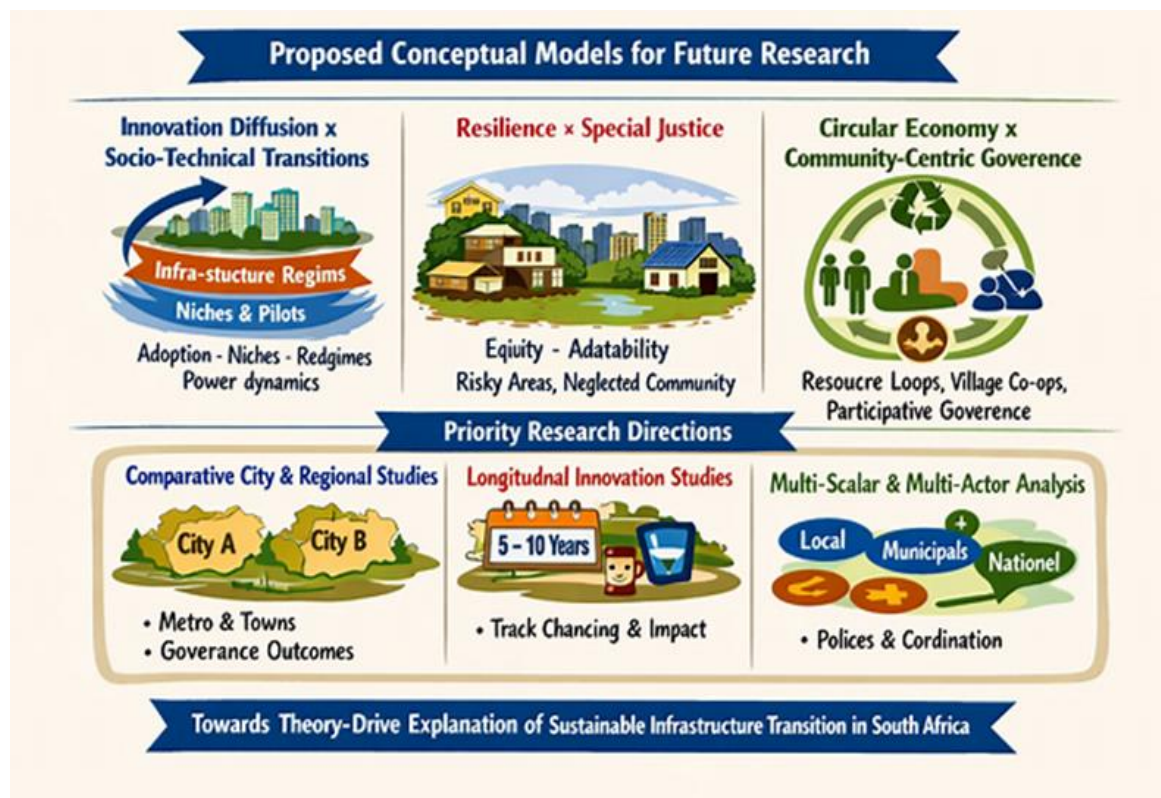


Figure 1: Conceptual models for future work

Source: Researchers own

4. LIMITATIONS OF THE STUDY

This study is subject to several limitations. First, as a narrative review rather than a fully systematic review, the selection of literature may be influenced by the authors' interpretation, despite efforts to ensure transparency and rigor. Second, the focus on South Africa, while providing important contextual depth, may limit the generalizability of findings to other regions. Third, the study relies primarily on secondary data, with limited direct engagement with empirical case studies or primary data collection. Future research could address these limitations by adopting systematic review methods, incorporating primary empirical data, and conducting comparative analyses across multiple Global South contexts.

5. RESEARCH METHODOLOGY

This study adopts a narrative literature review approach to synthesise existing knowledge on innovative sustainable infrastructure practices in South Africa. While not a fully systematic review, the study follows a structured and transparent process to ensure rigour and minimise selection bias.

Literature was sourced from major academic databases, including Scopus, Web of Science, ScienceDirect, and Google Scholar, complemented by relevant policy documents and institutional reports. The search focused on publications between 2015 and 2025, reflecting contemporary developments in sustainable infrastructure.

Keywords used in the search included combinations of: “green infrastructure”, “smart cities”, “sustainable infrastructure”, “innovation”, “community-based approaches”, “South Africa”, “urban development”, and “resilience”.

Inclusion criteria comprised peer-reviewed journal articles, conference papers, and authoritative policy reports that explicitly addressed infrastructure innovation, sustainability, or urban development within the South African context. Studies with limited relevance, lacking empirical or conceptual depth, or focusing on unrelated geographic contexts were excluded unless they contributed to theoretical framing.

The selected literature was analysed using a thematic synthesis approach, whereby studies were grouped into four dominant themes: (1) green infrastructure, (2) smart city and digital initiatives, (3) policy and planning frameworks, and (4) community-centric approaches. These themes were then interpreted through key theoretical lenses, including sustainable development, innovation diffusion, resilience, and spatial justice. This approach allows for an integrative and conceptually grounded understanding of the field while maintaining flexibility to capture diverse forms of evidence.

6. CONCLUSION AND FURTHER RESEARCH

This article set out to provide a literature/theoretical review of innovative practices for sustainable infrastructure in South Africa, with specific attention to green infrastructure, smart city and digital initiatives, integrated policy frameworks and community-centric approaches.

By synthesising a wide range of empirical and policy-oriented studies through the lenses of sustainable development, innovation diffusion, resilience and spatial justice, the review aimed to move beyond descriptive case accounts towards a more conceptually grounded understanding of infrastructure change. Three key insights emerge.

First, South Africa has generated a rich variety of innovative practices from wetland restoration and urban greening to smart metering, integrated urban development frameworks and community-driven upgrading that collectively demonstrate significant potential to enhance ecological performance, social inclusion and economic resilience. Second, despite this experimentation, implementation remains uneven and constrained by structural barriers, including fragmented governance, corruption and funding gaps, limited technical and digital capacity, and the enduring spatial imprint of apartheid.

Third, while concepts such as sustainable development and resilience are widely invoked, theoretical engagement is often shallow; more critical and systemic perspectives, such as socio-technical transitions, circular economy and spatial justice, are under-utilised, leaving important dynamics of power, inequality and regime stability insufficiently theorised. These findings carry important implications for theory and practice. Conceptually, the review underscores the need for integrated models that connect green infrastructure, smart technologies and community-centric governance within a single framework, and that explicitly link questions of innovation and resilience to those of spatial justice. Practically, it suggests that realising the transformative potential of innovative infrastructure will require not only new technologies and projects, but also reforms in governance, financing and capacity-building that intentionally target marginalised spaces and communities. By outlining combined conceptual models and priority research directions comparative city studies, longitudinal analyses and multi-scalar, multi-actor investigations the review provides a roadmap for future work that can generate more robust, context-sensitive theories of sustainable infrastructure transitions in South Africa and inform policy choices aimed at building just, resilient and low-carbon infrastructure systems.

References

- 1) IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Cambridge University Press.
- 2) [OECD. (2025). *Infrastructure for sustainable development: Global outlook*. Paris: OECD Publishing.
- 3) UN. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. New York: United Nations.
- 4) World Bank. (2020). *Sustainable infrastructure for inclusive growth*. Washington, DC: World Bank.
- 5) Lee, R. (2022). *Spatial justice and infrastructure inequality in South Africa*. *Urban Studies*, 59(4), 789– 805.
- 6) Rogerson, C. (2021). *Urban infrastructure and inequality in South Africa*. *South African Geographical Journal*, 103(1), 1–15.
- 7) Skhakhane, N., et al. (2024). *Resilience and climate adaptation in South African cities*. *Climate Policy*, 24(1), 1–18.
- 8) Mirto, S. (2024). *Energy insecurity and infrastructure fragility in South Africa*. *Energy Policy Journal*.

- 9) Mashabela, M., et al. (2024). *Governance challenges in South African municipalities*. Public Administration Review.
- 10) Venter, Z., et al. (2020). *Urban greening and biodiversity in Johannesburg*. Landscape and Urban Planning, 197, 103–112.
- 11) Habiyaremye, A., et al. (2022). *Sustainability transitions in the Global South: Lessons from South Africa*. Sustainability, 14(5), 1–15.
- 12) Sutherland, C., et al. (2021). *Resilience and community capacities in South African cities*. Urban Studies, 58(9), 1–20.
- 13) Mogale, T., & Cloete, F. (2021). *Smart city initiatives in Johannesburg and Tshwane*. African Journal of Public Affairs, 13(2), 1–15.
- 14) Chan, K., et al. (2022). *Urban innovation and sustainability transitions in South Africa*. Journal of Urban Studies.
- 15) Srekumar, R. (2023). *Conceptual gaps in sustainable infrastructure research*. Journal of Sustainable Development Studies.
- 16) Rogers, E. (2023). *Diffusion of Innovations* (6th ed.). New York: Free Press.
- 17) Ojo, A., et al. (2024). *Innovation diffusion in smart city projects in Africa*. Technological Forecasting and Social Change.
- 18) Makate, M., et al. (2025). *Green infrastructure and community resilience in South Africa*. Sustainability, 17(2), 1–20.
- 19) Cilliers, J., et al. (2021). *Smart city adoption and barriers in South African municipalities*. South African Journal of Science.
- 20) Department of Environmental Affairs. (2019). *South Africa's climate change adaptation strategy*. Pretoria: Government of South Africa.
- 21) National Development Plan. (2020). *National Development Plan 2030: Our future – make it work*. Pretoria: Government of South Africa.
- 22) du Toit, M., et al. (2018). *Urban reforestation and ecosystem services in eThekweni*. Ecology and Society, 23(3), 45–58.
- 23) Pasquini, L., & Enqvist, J. (2019). *Community participation in green infrastructure planning*. Urban Forestry & Urban Greening, 38, 1–12.
- 24) Culwick, C., & Bobbins, K. (2016). *Green infrastructure planning in South African cities*. Urban Forum, 27(2), 1–20.
- 25) Department of Cooperative Governance and Traditional Affairs. (2016). *Integrated Urban Development Framework (IUDF)*. Pretoria: Government of South Africa.
- 26) Mothabi, T., & Gillwald, A. (2018). *Digital divide and ICT access in South Africa*. Research ICT Africa Report.
- 27) Schrenk, L. (2024). *Institutional fragmentation and infrastructure governance in South Africa*. Governance Journal.
- 28) Smit, D., & Parnell, S. (2019). *Participatory approaches to urban infrastructure in South Africa*. Habitat International, 85, 1–12.
- 29) Korhonen, J., et al. (2018). *Circular Economy: Conceptual foundations and applications*. Ecological Economics, 143, 37–46.