Geospatial Intelligence for Equitable Property Valuation and Developmental Local Governance: A Hybrid Digital Twin Approach for Cape Town

Matthew FERGUSON and Chris TANNER, South Africa

Key words: Digital twins, LiDAR, Oblique Aerial Imagery, Remote sensing, AI-driven change detection, Property valuation, Urban governance

1. SUMMARY

Rapid urbanization, historical spatial inequality, and growing pressure on municipal finances require cities, particularly in the Global South, to modernize property valuation systems in ways that are efficient, transparent, and socially just. This paper examines how the City of Cape Town, in partnership with Woolpert, has integrated geospatial intelligence, digital twins, AI-driven change detection, and Lean methodologies to support a more complete, equitable, and responsive valuation system.

Situated within the constitutional mandate of developmental local government and the Municipal Property Rates Act (MPRA), Cape Town's transformation demonstrates how modern geospatial workflows can strengthen the rates base required to fund sub-economic services, indigent households, and vulnerable communities. Through high-resolution aerial imagery, light detection and ranging (LiDAR), and automated change detection, the City now more comprehensively and equitably identifies unregulated developments, including backyard dwellings and small-scale rental units that have historically been underrepresented in conventional valuation systems.

The result is a valuation system that moves beyond mere technical optimization, enabling a more inclusive representation of the built environment, faster turnaround times, enhanced data quality, and improved revenue fairness. This hybrid social-justice and technical approach positions Cape Town as a leading example of ethically grounded digital transformation in African urban governance.

Geospatial Intelligence for Equitable Property Valuation and Developmental Local Governance: A Hybrid Digital Twin Approach for Cape Town

Matthew FERGUSON and Chris TANNER, South Africa

2. INTRODUCTION

Cities in the Global South are experiencing rapid demographic and spatial transformation, with growing pressures from land scarcity, informal housing expansion, and increased service demand. Cape Town exemplifies these conditions. The 2022 Census records a population of 4.77 million, with 11.7 percent of households living in informal structures (Research Analytics, Policy and Strategy Department, City of Cape Town, 2023). These patterns reflect contemporary socio-economic pressures layered upon long-standing spatial inequality. While this paper does not center apartheid spatial planning, its structural legacy continues to shape present-day access to housing, property markets, and municipal resource distribution.

In this context, property valuation becomes a critical governance instrument rather than a purely technical exercise. The Municipal Property Rates Act mandates fairness, transparency, and continuous updating of valuation rolls (Local Government: Municipal Property Rates Act 6 of 2004 | South African Government, n.d.), aligning with constitutional objectives for developmental local government (Constitution of the Republic of South Africa, 1996 | South African Government, n.d.). Accurate, up-to-date valuation data is essential for ensuring cross-subsidization of indigent households and supporting sub-economic communities.

Globally, cities are deploying geospatial intelligence, remote sensing, artificial intelligence (AI), and digital-twin approaches to modernize urban governance (Goodchild, 2018; Data and the City, 2017). Cape Town's partnership with Woolpert represents one of the most advanced African applications of these technologies to property valuation. High-resolution oblique and nadir imagery, LiDAR, AI-driven change detection, and Lean workflow optimization have enabled a valuation system that simultaneously strengthens revenue fairness and enhances institutional responsiveness. The adoption of geospatial solutions, over a number of years, has transformed the City's approach to the valuations process, from one of traditional field surveys to an enabling desktop approach with multiple time and cost benefits.

This paper develops a hybrid academic narrative, balancing technical detail with social-justice framing, to illustrate how Cape Town's digital valuation model advances equitable and sustainable municipal governance.

3. CONCEPTUAL FRAMEWORK

Digital twins are increasingly recognized as sociotechnical artifacts that can dynamically synchronize with physical environments, enabling real-time monitoring, simulation, and predictive modelling for urban governance (Adade & de Vries, 2025). Their interactive and

immersive qualities, combined with user-friendly interfaces and real-time data, position them as powerful tools for participatory planning and agenda-setting (Adade & de Vries, 2025). By allowing citizens and policymakers to visualize spatial changes, test interventions, and negotiate priorities, digital twins transform planning from a static process into a collaborative, adaptive system. This aligns with Cape Town's approach, where the valuation roll is continuously updated through remote sensing and AI-driven change detection, allowing it to function as a fiscal digital twin that reflects the built environment and supports dynamic revenue modelling in near real time (Adade & de Vries, 2025).

The MPRA supports this technical evolution by mandating a comprehensive and frequently updated valuation roll (Local Government: Municipal Property Rates Act 6 of 2004 | South African Government, n.d.). Section 152 of the Constitution explicitly frames local government as responsible for developmental objectives, including equitable service provision (Constitution of the Republic of South Africa, 1996 | South African Government, n.d.). A complete, accurate and up to date valuation roll therefore becomes an enabler for achieving revenue fairness and equity. These provisions create a living, authoritative dataset that mirrors the physical and economic state of the built environment, meeting the essential digital twin criteria: continuous synchronization, fidelity to physical assets, and actionable insights for decision-making.

Post-apartheid transformation provides essential context. It can be argued that that meaningful governance improvement requires recognizing informal and incremental housing rather than treating it as anomalous (Roy, 2005; Ferguson, 2024). Cape Town's valuation system, by identifying and incorporating unregulated building development, reflects this understanding.

4. DATA AND METHODS

The City's modernization strategy integrates high-resolution spatial data, advanced analytics, and Lean governance methodologies. Oblique and nadir aerial imagery provide multi-directional visibility for remote assessment of structures, while LiDAR-derived surface models enable volumetric and elevation analysis. Together, these datasets contribute to the accuracy of desktop-based valuation (Ferguson, 2024).

AI-driven change detection compares multi-temporal imagery to identify unregistered structural changes. These tools are especially effective for mapping incremental backyard rentals, informal additions, and unregulated small-scale rental blocks, which can be up to three stories in height and comprise as many as 24 residential units. Unregulated developments like these are frequently underrepresented in traditional valuation datasets (Ferguson, 2024). Rather than punitive enforcement, this approach supports developmental policy by improving recognition of low-income housing markets.

Lean governance principles streamline workflows, reduce delays, and improve valuation consistency. Transitioning from a field-based model to a remote desktop model significantly increased processing capacity and reduced turnaround times. Field inspections now focus on complex properties or disputed cases.

Lean Thinking, originally developed for manufacturing, has been adapted by the City of Cape Town to transform property valuation workflows into efficient, citizen-centric processes. The city adopted Lean in 2007 to improve service delivery by focusing on what matters most to citizens. Applied to municipal valuation, Lean principles were applied sequentially to restructure valuation workflows. Value Stream Mapping was used to analyze the full valuation process across nine municipal departments, identifying bottlenecks and non-value-adding steps. Continuous flow replaced batch processing, enabling near real-time updates and significantly improving throughput. Heijunka (demand levelling) was applied to harmonize uneven demand (mura) and reduce overburden (muri), using flow metrics derived from Little's Law (Little, 2011). Finally, linear workflows were replaced with citizen service loops, allowing both residents and officials to initiate interactions, thereby improving transparency, responsiveness, and institutional trust (Ferguson, 2024).

To support the above methods, the city adopted South African National Standards (SANS) aligned with ISO for quality assurance and process improvement:

- SANS 2859-1: Sampling procedures for inspection by attributes.
- SANS 13053-1 & 13053-2: Quantitative methods for process improvement.

Figure 1 presents the lean measures of continuous improvement for citizen service loops, and Figure 2 illustrates how such citizen service loops can rationalize service delivery from the citizen's perspective (Ferguson, 2024).

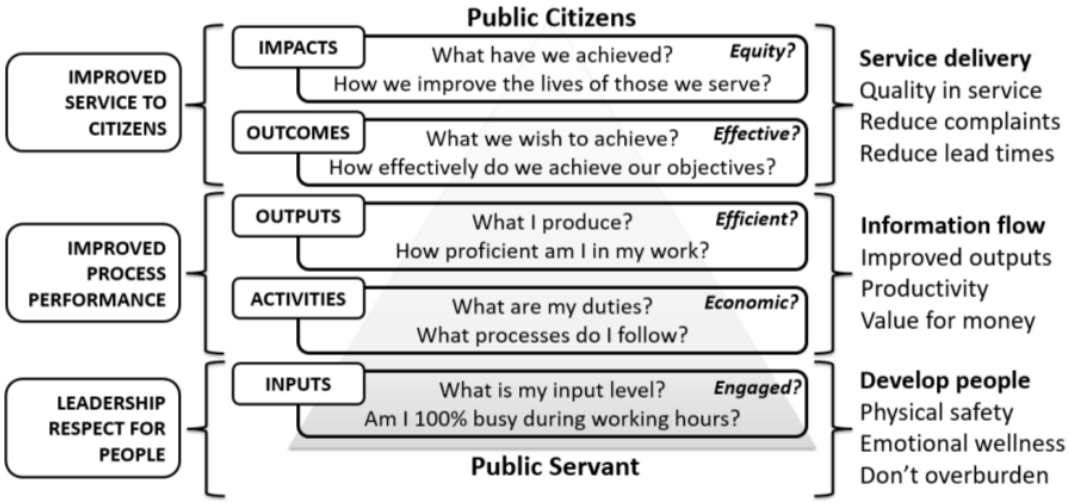

Figure 1 Measuring continuous improvement – lean principles of flow.

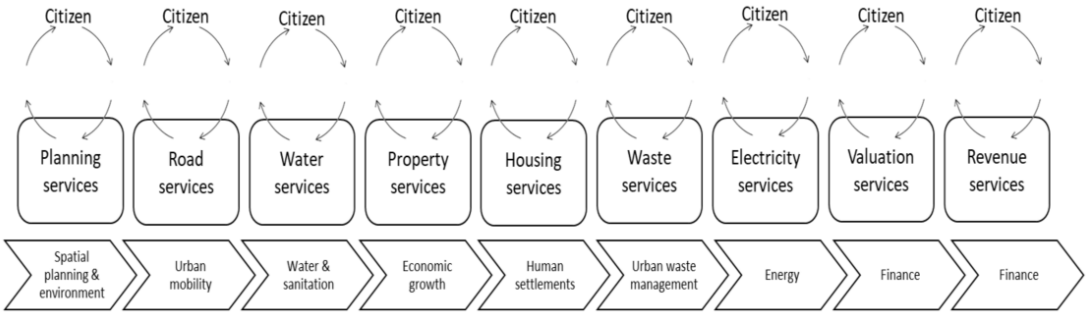

Figure 2 Property value chain rationalized as a non-linear flow.

Importantly, these methodologies are governed by constitutional principles and MPRA compliance. Ethical alignment ensures that modernization enhances, rather than undermines, transparency and fairness from a citizen perspective.

5. GOVERNANCE TRANSFORMATION

Traditionally, valuation relied on field inspections triggered by building plans or complaints. This method inherently produced uneven visibility across neighborhoods, especially where informality was prevalent. Remote sensing and AI-enabled change detection have fundamentally altered this dynamic.

The city can now detect new dwelling units, extensions, and densification patterns automatically, enabling continuous updates to the valuation roll. Remote imagery becomes the primary assessment tool, while site visits serve as exceptions. This improves efficiency and enhances spatial fairness.

Key to this shift is the move toward a digital twin environment, where the valuation dataset now links with Cape Town's broader digital ecosystem, allowing for infrastructure modelling, service-demand forecasting, and early-warning systems for unmanaged densification.

6. RESULTS

Cape Town's valuation modernization has yielded large-scale performance improvements. Over the past six years, the annual average citizen response times have improved from 122 days to 24 days in 2025. At the same time the valuation data survey throughput has increased significantly over the past six years from 30 984 workflow tasks per year to over 255 662 in 2025.

These gains translate into a more responsive valuation system and improved data quality.
A significant aspect of the change detection process is the high statistical confidence associated with properties identified as unchanged (the change detection true-negatives). This confidence

has been supported by applying the same lot-by-lot sampling plan for the quality control of machine no-change inspections and data changes processed by valuation data surveyors.

Figure 3 presents the valuation throughput trends by year, with a service time indicator of the percentage of tasks completed in 30 days.

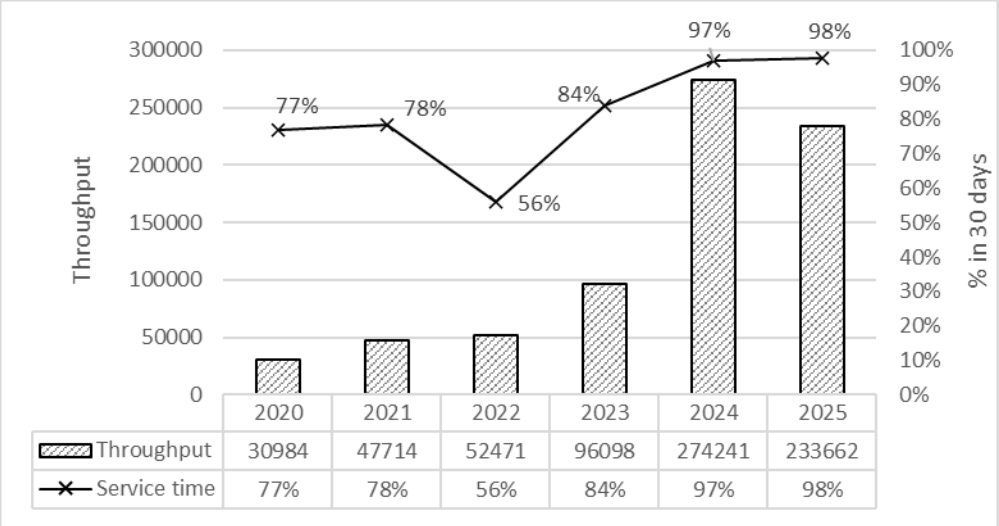

Figure 3 Valuation data survey trends by year

7. DISCUSSION

Cape Town's experience demonstrates that geospatial intelligence and digital-twin principles can support equitable governance. Global debates often criticize smart city technologies for their potential to reinforce surveillance (Sadowski, 2020), but Cape Town shows that ethical, legally grounded implementations can enhance recognition, transparency, and justice. Successful digital transformation requires institutional change alongside technological capability. The Lean-enabled redesign of valuation workflows exemplifies how public-sector processes must evolve to take full advantage of spatial technologies.

Furthermore, because most properties remain physically unchanged within any given period, urban valuation datasets naturally generate a high proportion of true-negatives, those properties in which remote-sensing analysis confirms the absence of structural alteration. This stability is analytically valuable. As Rosen's (1974) seminal hedonic price theory emphasizes, accurate modelling depends on correctly specifying structural characteristics at the time of sale. True-negatives therefore provide a reliable basis for constructing clean hedonic and repeat-sales samples free from omitted-variable bias arising from unobserved improvements (Housing Economics and Public Policy, 2002, Chapter 5). This demonstrates that repeat-sales indices are highly sensitive to misclassification of physical changes, implying that the digital twin's systematic confirmation of "no change" materially improves the precision of market indices.

Conversely, for true-positives, those properties where the digital twin detects additions, extensions, or conversions, the ability to timestamp these changes allows the City to distinguish between improvements made before a sale (to enhance marketability) and those made after acquisition (as part of investment behavior), a distinction well documented in empirical housing literature (Glaeser et al., 2008; Goodman & Thibodeau, 2003). Because building works are frequently completed shortly before listing or initiated shortly after transfer, failing to capture their timing introduces structural misclassification errors that can distort price modelling.

The digital twin's temporal precision therefore has the potential to support econometric specification by anchoring each detected change to the correct sale period. This substantially enhances the validity of hedonic regressions, repeat-sales indices, and hybrid specification models, improving both the explanatory power and equity implications of the City's valuation system. In this way, the digital twin does not merely support administrative completeness; it enhances the econometric integrity and fairness of property valuation by enabling market analyses that truly reflect the built environment as it existed at the moment transactions occurred (Palmquist, 2005).

Cape Town's experience provides important lessons for other cities facing urban densification and informality. By adopting integrated geospatial systems aligned with developmental governance principles, cities can enhance fiscal resilience while simultaneously promoting social equity.

8. CONCLUSION

Cape Town's integration of geospatial intelligence, AI-based change detection, digital twins, and Lean governance demonstrates a path toward ethical, socially grounded digital transformation. By aligning technology with constitutional commitments to fairness and developmental local government, the city has created a valuation system that is more efficient, more complete, and more equitable.

Goodchild's (2018) insights on multiscale geographic representation, data integration challenges, and the transition from digital maps to digital globe models provide strong scholarly support for interpreting the valuation roll as a digital twin backbone.

This hybrid approach is technically rigorous and socially grounded and shows that digital transformation can drive inclusion and resilience, contributing to a more just urban future.

REFERENCES

Adade, D., & De Vries, W. T. (2025). A systematic review of digital twins' potential for citizen participation and influence in land use agenda-setting. *Discover Sustainability*, *6*(1). https://doi.org/10.1007/s43621-025-01204-x

Ahn, C., Lotfi-Jam, F., Graham, C., Bunnell, T., & Marvin, S. (2025). Critical urban informatics for urban digital twin models. *Nature Cities*, *2*(2), 114–116. https://doi.org/10.1038/s44284-024-00171-0

Batty, M. (2024). Digital twins in city planning. *Nature Computational Science*, *4*(3), 192–199. https://doi.org/10.1038/s43588-024-00606-7

Constitution of the Republic of South Africa, 1996 | South African Government. (n.d.). Retrieved January 4, 2026, from https://www.gov.za/documents/constitution/constitution-republic-south-africa-1996-04-feb-1997

Data and the city. (2017). https://doi.org/10.4324/9781315407388

Ferguson, M. (2024). Business case for treating a city as a dissipative structure, with the flow of citizen value supported by remote sensing of the urban environment. *IOP Conference Series Earth and Environmental Science*, *1363*(1), 012086. https://doi.org/10.1088/1755-1315/1363/1/012086

Glaeser, E. L., Gyourko, J., & Saiz, A. (2008). Housing supply and housing bubbles. *Journal of Urban Economics*, *64*(2), 198–217. https://doi.org/10.1016/j.jue.2008.07.007

Goodchild, M. F. (2018). Reimagining the history of GIS. *Annals of GIS*, *24*(1), 1–8. https://doi.org/10.1080/19475683.2018.1424737

Goodman, A. C., & Thibodeau, T. G. (2003). Housing market segmentation and hedonic prediction accuracy. *Journal of Housing Economics*, *12*(3), 181–201. https://doi.org/10.1016/s1051-1377(03)00031-7

Hooli, M. (2025). Digital Twins and Urban Planning: Designing smarter, more inclusive cities. *European Journal of Computer Science and Information Technology*, *13*(44), 104–112. https://doi.org/10.37745/ejcsit.2013/vol13n44104112

Housing Economics and Public Policy. (2002). https://doi.org/10.1002/9780470690680

Little, J. D. C. (2011). OR FORUM—Little's Law as viewed on its 50th anniversary. *Operations Research*, *59*(3), 536–549. https://doi.org/10.1287/opre.1110.0940

Local Government: Municipal Property Rates Act 6 of 2004 | South African Government. (n.d.). Retrieved January 4, 2026, from https://www.gov.za/documents/local-government-municipal-property-rates-act-0

Palmquist, R. B. (2005). Chapter 16 Property value models. In *Handbook of environmental economics* (pp. 763–819). https://doi.org/10.1016/s1574-0099(05)02016-4

Research Analytics, Policy and Strategy Department, City of Cape Town. (2023). *Census 2022: Cape Town Trends and changes*. https://resource.capetown.gov.za/documentcentre/Documents/City%20research%20reports%20and%20review/Census_2022_Trends_and_Changes.pdf

Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition. *Journal of Political Economy*, *82*(1), 34–55. https://doi.org/10.1086/260169

Roy, A. (2005). Urban Informality: Toward an Epistemology of Planning. *Journal of the American Planning Association*, *71*(2), 147–158. https://doi.org/10.1080/01944360508976689

Sadowski, J. (2020). Too smart. In *The MIT Press eBooks*. https://doi.org/10.7551/mitpress/12240.001.0001

BIOGRAPHICAL NOTES

CONTACTS

Mr Matthew Ferguson
City of Cape Town
12 Hertzog Blvd
Foreshore
Cape Town
8001
Tel. +2782 373 7373
Email: matthew.ferguson@capetown.gov.za
Web site: capetown.gov.za

Mr Chris Tanner
Woolpert
Suite 1 Silvermine House
Steenberg Office Park
TOKAI
7945
Cape Town
South Africa
Tel. +2783 441 9944
Email: chris.tanner@woolpert.com
Web site: https://woolpert.com/woolpert-africa/