



Integrating Advanced Geospatial Technologies in Cadastral Surveying and Land Administration for Sustainable Development: A Comprehensive Review

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Abstract:

Background: Worldwide, modern land administration systems (LAS) are under unprecedented pressure due to rapid urbanization, the expansion of informal settlements, insecurity of tenures, environmental degradation, and inefficient maintenance of cadastral records. Although traditional ground-based methods of cadastral surveying provide legal precision at the millimeter level, they are too costly, require a great deal of labor, and are slow to carry out on a national scale.

Objective: This article gives a thorough and systematic summary of the newly developing geospatial technologies—these include photogrammetry using Unmanned Aerial Systems (UAS), Terrestrial and Mobile Light Detection and Ranging (LiDAR), Very High Resolution (VHR) Satellite Remote Sensing (SRS), the integration of 3D/4D Building Information Modeling with Geographic Information Systems (BIM-GIS), and Distributed Ledger Technology (Blockchain)—with regard to the modernisation of cadastral surveying and land governance.

Literature search and review method: A systematic literature search was carried out in Scopus, Web of Science, IEEE Xplore, and Google Scholar for peer-reviewed studies that were published between 2015 and 2026. The explicit inclusion criteria were used to select empirical investigations, technical frameworks, and policy evaluations relating to 2D/3D/4D cadastral modelling, fit-for-purpose land administration (FFPLA), and automated spatial data extraction.

Key findings: Compared with terrestrial techniques, integrated geospatial pipelines cut the time required for carrying out cadastral surveying in the field by 60 to 75 per cent and achieve horizontal and vertical positional accuracies at the centimetre level, meeting the statutory requirements for cadastral surveys. The use of active 3D sensor fusion (LiDAR-photogrammetry) together with BIM-GIS data integration overcomes the structural drawbacks of traditional 2D planar cadastres by allowing volumetric stratification of legal rights, restrictions, and responsibilities (RRRs). Moreover, decentralized ledgers incorporated with Spatial Data Infrastructures (SDI) greatly reduce instances of title corruption, boundary manipulation, and administrative friction.

Conclusion: Geospatial technologies form a fundamental basis for attaining the United Nations Sustainable Development Goals (SDGs 1, 11, and 15); in order to realise their full potential it is necessary to address the standardisation gaps in 3D data models (for example those in the Land Administration Domain Model ISO 19152), the high computational overheads, and the regulatory obstacles that exist in developing areas.

Keywords: Cadastral Surveying, Geoinformatics, Remote Sensing, 3D Cadastre, Fit-For-Purpose Land Administration, Land Governance, the Sustainable Development Goals (SDGs).

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1. Introduction

Background of the Topic

Land administration provides the operational, institutional, and technical infrastructure by means of which the rules relating to the tenure, value, use, and spatial extent of real property are put into effect and made functional. Worldwide, secure land rights constitute the fundamental foundation of economic stability, agricultural productivity, infrastructural development, and social cohesion. At the present time, the fields of surveying and geoinformatics are going through a deep paradigm shift. The traditional dependence on labor-intensive, single-point terrestrial measurements carried out with optical theodolites, total stations, and static GNSS baselines is quickly being combined with multi-sensor remote sensing, cloud geoprocessing, automated computer vision algorithms, and decentralised data registries (Ekebuike, 2025).

Scientific Importance

The precise definition of boundaries is essential for ensuring security of legal tenure, for efficient urban planning, for accurate taxation, and for the proper management of natural resources. Since people are now living in vertical urban centres and in complicated informal outer areas, the conventional two-dimensional (2D) boundary systems are unable to take into account the complex set of rights, restrictions, and responsibilities (RRRs) connected with modern real estate, subterranean infrastructure, and aerial easements.

1.1 The Scientific and Practical Significance of the Topic

The accuracy of cadastral surveying in terms of space and its legal validity has a direct bearing on security of tenancy, the effectiveness of municipal taxation, spatial planning, and the conservation of natural resources. Since over 55% of the world's population is currently living in urban areas—a figure expected to rise to 68% by 2050—urban areas are expanding rapidly both horizontally and vertically. The high density of metropolitan development results in a complex arrangement of overlapping property rights, for example in the case of multi-storey residential complexes, underground transport tunnels, utility networks, and rights over elevated airspace. Traditional two-dimensional (2D) cadastral systems are fundamentally unable to represent these multi-layered three-dimensional spatial units without causing considerable legal uncertainty and administrative difficulty.

1.2 The Present Problem and Shortcomings in Global Land Governance

Even after many decades of investment by institutions, it is estimated that 70% of the world's population do not have formal and legally recognized land rights, this being mainly the case in developing countries in Sub-Saharan Africa,

Latin America, and South-East Asia. In these areas, the standard methods of cadastral surveying are economically unviable, technically inflexible, and procedurally slow. Traditional land titling involves costly field operations, the manual marking of each parcel's corners, and bureaucratic registration processes for deeds which often take years to complete. As a result, customary lands that are not recorded, peri-urban informal settlements, and agricultural holdings remain very susceptible to land grabbing, boundary disputes, forced evictions, and uncoordinated urban expansion.

1.3 What is currently known and the technological developments

Flexible and scalable alternatives have recently been introduced in the field of geomatics engineering as part of the Fit-For-Purpose Land Administration (FFPLA). Data of high resolution obtained from Unmanned Aerial Systems (UAS), airborne Light Detection and Ranging (LiDAR), and Very High Resolution (VHR) satellite constellations enable quick and cost-effective data collection. At the same time, international standardization frameworks, particularly the ISO 19152 Land Administration Domain Model (LADM), offer formal semantic schemas that link the geometry of spatial boundaries with complex legal rights, restrictions, and responsibilities (RRRs).

1.4 The research gaps and the purpose of this review

Although the technological capabilities of individual geospatial sensors are well described in the technical literature, there are still considerable gaps concerning their practical integration when used together within official cadastral procedures. Important questions remain as to how legal boundary precision can be balanced with the scalability required by approaches that are suitable for a given purpose, how production-grade 3D/4D cadastral models can be implemented, and how geospatial land administration contributes to the measurable indicators set out in the United Nations Sustainable Development Goals (UN SDGs). This review offers a thorough summary of recent innovations in the field of geospatial technology as applied to cadastral surveying, critically examines their real-world performance, and proposes practical frameworks for sustainable land governance.

2. The methodology and strategy for carrying out the literature search

In order to maintain scientific rigor, ensure reproducibility, and achieve comprehensive coverage, this review adheres to a structured methodology for carrying out a literature search and synthesising the findings, one that is in accordance with the standard PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

2.1 The choice of database and the search strategy

A bibliographic search was carried out systematically in five main academic indexing databases: Scopus, Clarivate Web of Science (Core Collection), IEEE Xplore Digital Library, ScienceDirect (Elsevier), and Google Scholar. The search focused on peer-reviewed journal articles, international conference proceedings, and official technical standards that were published between January 2015 and April 2026.

2.2 Search strings and Boolean structure

Targeted keyword queries combining primary domain concepts with technical and policy terms were deployed using Boolean operators:

- Primary Domain: ("Cadastral Surveying" OR "Cadaastre" OR "Land Administration" OR "Cadastral Mapping")
- Technological Vector: AND ("UAV Photogrammetry" OR "Drone" OR "LiDAR" OR "Remote Sensing" OR "BIM-GIS" OR "Machine Learning" OR "Blockchain")
- Application & Policy: AND ("Sustainable Development" OR "SDGs" OR "Tenure Security" OR "3D Cadaastre" OR "Fit-For-Purpose")

2.3 The criteria for inclusion and exclusion

The corpus was filtered according to defined eligibility criteria:

- Criteria for inclusion: (a) empirical studies which provide quantitative data regarding positional accuracy, acquisition speed, or cost-efficiency; (b) theoretical and conceptual frameworks that conform to the ISO 19152 (LADM) or Open Geospatial Consortium (OGC) specifications; (c) case studies that examine cadastral modernization in urban, rural, or informal tenure situations; (d) peer-reviewed literature written in English and published between 2015 and 2026.
- The criteria for exclusion are: (a) unverified non-academic technical reports that lack empirical validation; (b) studies which are concerned exclusively with generic remote sensing and have no relevance to cadastral or land tenure matters; and (c) duplicate publications, short editorial letters, and non-peer-reviewed conference abstracts.

2.4 The process of screening and selecting a corpus

The first database query produced 1,420 records; after both automated and manual elimination of duplicates (amounting to 560 cases), 860 distinct records were subjected to screening of their titles and abstracts. Full-text evaluation was then carried out on 210 of the articles selected, which led to the establishment of a final synthesis corpus consisting of 88 high-impact empirical studies, basic technical standards, and institutional frameworks.

3. A review thematically concerning advanced geospatial technologies

3.1 The use of Unmanned Aerial Systems (UAS) for photogrammetry in cadastral mapping

Unmanned Aerial Systems (UAS), which are usually known as drones, have transformed large-scale cadastral mapping. By using high-resolution digital cameras, RTK/PPK (Real-Time Kinematic / Post-Processing Kinematic) GNSS modules, and automated flight management software, UAS systems fill the gap between the costly method of manned aerial surveys and the slow approach of terrestrial field work. Through Structure-from-Motion (SfM) photogrammetry, overlapping multi-view aerial images are processed to produce ultra-dense 3D point clouds, Digital Surface Models (DSMs), Digital Terrain Models (DTMs), and genuine orthomosaics, the Ground Sampling Distances (GSD) of which are often over 2 cm per pixel.

In the process of defining cadastral boundaries, surveyors and local communities are able to see visible physical boundaries—such as fences, walls, hedgerows, and drainage canals—on calibrated digital displays using orthomosaics obtained from unmanned aerial systems. This ability is essential for participatory Fit-For-Purpose Land Administration (FFPLA), since it can cut field survey operations by as much as 70% and at the same time keep the horizontal spatial accuracy within 5 cm, which is in full agreement with the statutory cadastral tolerances in both peri-urban and rural areas (Assadi & Murad, 2024).

3.2 Terrestrial and mobile as well as airborne LiDAR systems

Light Detection and Ranging (LiDAR) uses active laser pulses to record spatial coordinates (X, Y, Z) with a precision ranging from millimetres to centimetres as well as surface intensity data. Unlike optical photogrammetry, LiDAR is able to penetrate dense vegetation canopies via multiple pulse returns and thus allows for the accurate extraction of ground surfaces under dense forests and shrubbery.

- Airborne Laser Scanning (ALS): This technique is carried out using aircraft or large drones and is essential for quickly establishing a topographic baseline over a wide area, particularly for large-scale rural cadastral surveys and for defining environmental boundaries.
- Mobile Laser Scanning (MLS): When mounted on road vehicles, utility carts, or backpack systems, MLS is able to capture dense urban corridors, recording building facades at street level, the boundaries of property walls, structural overhangs, and underground asset portals with a precision of millimetres (Sindawi et al., 2025).

3.3 Satellite Remote Sensing (SRS) and the Use of Artificial Intelligence in Extracting Boundaries

Commercial satellite constellations with very high resolution (for example, WorldView-3 and Pléiades Neo) offer a spatial resolution of less than 30 cm, which allows for macroscopic cadastral monitoring and the creation of national parcel maps. Remote sensing images can support semi-automated feature extraction when used with advanced Deep Learning (DL) architectures such as Convolutional Neural Networks (CNNs), U-Net, and Mask R-CNN.

From raw satellite images, these neural networks are able to detect edge boundaries, determine road alignments, and identify building footprints, thereby turning what was previously a manual process of digitizing parcels into an automated segmentation process. It is still necessary, however, to use post-processing vector regularization algorithms in order to correct topological slivers and make sure that the extracted polygons satisfy the strict geometric and legal cadastre requirements (Asaadi et al., 2023; Formisano & Bushi, 2026).

3.4 The integration of 3D/4D cadastres, LADM (ISO 19152), and BIM-GIS

Classic 2D cadastral systems show land as flat, planar areas, a principle which does not hold true in modern cities featuring vertical high-rises, underground shopping centres, multi-level subway systems, and elevated skybridges. In order to cope with these complexities the international surveying community has developed 3D and 4D Cadastre systems.

- **3D Volumetric Cadastre:** This replaces the use of 2D polygons with 3D spatial volumes (that is, polyhedrons or Boundary Representations - B-rep) in order to explicitly record stratified property units.
- **BIM-to-GIS Interoperability:** This enables the linking of detailed architectural data (defined by Industry Foundation

Classes - IFC) with large-scale spatial registries (CityGML/CityJSON), thus allowing a smooth transition from architectural blueprints to legal land registry records.

- **4D Temporal Cadastre:** This incorporates the time dimension (t) in order to record the temporal lifecycle, the transfer history, and the transient validity intervals of rights, restrictions, and responsibilities (RRRs) (Murad & Smadi, 2009).

3.5 The modernisation of blockchain and spatial data infrastructure

The security, transparency, and immutability which characterise cadastral records are a vital component of land governance. Centralised land registry databases are still susceptible to unauthorised tampering, fraudulent duplication of titles, and administrative corruption. The combination of Distributed Ledger Technology (DLT/Blockchain) with national Spatial Data Infrastructures (SDIs) results in decentralised land record ecosystems that can be verified by means of cryptography.

Smart contracts cause title transfers, mortgage registrations, and property tax assessments to be carried out when the predetermined legal conditions have been met, ensuring that land transactions are transparent, immutable, and non-repudiable (Murad et al., 2025; Assadi et al., 2022).

4. A comparison of the different paradigms of cadastre surveying

In order to carry out a comparison of current methods for capturing geospatial data based on empirical evidence, Table 1 examines the main technological approaches with reference to spatial accuracy, acquisition efficiency, operational limitations, and the applications which are typical in the field of land administration.

Surveying Paradigm	Spatial Precision	Acquisition Speed / Coverage	Operational Strengths & Key Use	Primary Limitations
Terrestrial GNSS / Total Station	± 0.01 - 0.03 m	Low (Point-by-point manual)	Legal boundary dispute resolution, high-precision boundary monumentation	Labor intensive, slow, line-of-sight required
UAS / Drone Photogrammetry	± 0.02 - 0.05 m	High (Up to 5 km ² /day)	Fit-for-purpose rural/peri-urban parcel demarcation, orthomosaics	Weather dependent, canopy occlusion, local flight laws
Mobile / Airborne LiDAR	± 0.015 - 0.05 m	Very High (Macro corridors)	3D urban cadastre, structural property modeling, canopy penetration	High capital cost, massive data volume processing
VHR Satellite Remote Sensing	± 0.30 - 0.50 m	Regional / Continental	Macro-scale inventorying, baseline rural tenure mapping	Cloud cover vulnerability, lower horizontal precision
Deep Learning AI Extraction	IoU: 0.78 - 0.92	Real-time instantaneous	Automated parcel boundary extraction from aerial/satellite data	Requires large training datasets, topological slivers
BIM-GIS Integration (3D)	± 0.001 - 0.01 m	Site-specific scale	Stratified vertical property registration, multi-unit building titles	Complex semantic schema conversion (IFC to CityGML)

5. Critical Discussion

5.1 The compromises involved in technique and methodology

A critical examination of current geospatial literature shows there to be a basic compromise between spatial accuracy and operational scalability. Although terrestrial surveying achieves the sub-centimeter absolute accuracy which has traditionally been required by strict legal statutes, it is not economically feasible to carry out this method over large areas that have never been mapped. On the other hand, UAV photogrammetry and AI-powered satellite feature extraction offer scalable data collection, but this comes at the cost of requiring organisations to be flexible about the positional tolerances they accept.

5.2 The agreements, contradictions, and synthesis among the studies

There is a clear agreement in the literature that the use of multi-sensor data fusion (for example, combining UAS photogrammetry with LiDAR and GNSS control) should be regarded as the best approach for achieving comprehensive cadastral modernization. Nevertheless, considerable contradictions remain concerning data ownership and the legal validity of boundaries that are automatically delineated. Although technical researchers support the idea of fully automated deep learning-based extraction of boundaries, legal scholars and cadastral registrars stress that machine-drawn boundaries often misinterpret informal agreements, customary rights, and non-physical boundaries, and as a result legal disputes can arise if such boundaries are

put into effect without first having undergone participatory field verification.

5.3 Institutional, Legal, and Socio-Economic Bottlenecks

Many problems slow down progress in renewable energy. On the institutional side, rules and processes often change, which makes planning hard. Legal issues, like unclear property rights and slow courts, also block new projects. Socio-economic challenges, such as poverty and low education levels, make it difficult to get support for new energy systems. These bottlenecks stop investments and delay the spread of clean energy.

The main obstacles to modernising cadastral surveying are seldom entirely technical; rather, they are institutional and regulatory in nature. Several national survey departments still work within outdated legal statutes which come from either the colonial period or the early 20th century and which require the use of iron ground beacons and manual theodolite observations. Moreover, the existence of bureaucratic institutional silos between surveying departments, deeds registries, and municipal planning authorities stops digital spatial data from being exchanged smoothly, thus leading to data duplication and administrative inefficiency.

6. Compliance with the United Nations Sustainable Development Goals (SDGs)

Geospatial technologies in cadastral surveying provide the baseline spatial infrastructure required to monitor and achieve multiple targets within the UN 2030 Agenda for Sustainable Development (Ekebuike, 2025):

Sustainable Development Goal	Specific Target	Geospatial Cadastral Contribution
SDG 1: No Poverty	Target 1.4: Equal rights to economic resources and ownership over land	Accelerated fit-for-purpose cadastral mapping formalizes land tenure for vulnerable rural and peri-urban populations, unlocking capital equity.
SDG 11: Sustainable Cities & Communities	Target 11.3 & 11.7: Inclusive, sustainable urbanization and urban planning	3D volumetric cadastres and BIM-GIS integration provide detailed spatial fabrics for resilient urban infrastructure, disaster risk zoning, and property taxation.
SDG 15: Life on Land	Target 15.1 & 15.2: Conservation of terrestrial ecosystems and sustainable forest management	High-resolution satellite and LiDAR boundary monitoring delineates protected conservation areas, preventing illegal agricultural encroachment and deforestation.

7. Future Perspectives and Research Directions

To maximize the impact of geospatial technologies in land governance, future academic research and engineering development must address key operational priorities:

1. In deep learning, hybrid neural networks are being developed that integrate image semantic segmentation with geometric graph solvers in order to ensure that the

boundary polygons obtained are topologically valid, do not overlap, and can be used legally without requiring a lot of manual editing.

2. Carrying out feature extraction, photogrammetric reconstruction, and boundary delineation in real time during a flight by integrating edge AI hardware directly onto the survey drones' payloads.

3. Dynamic 4D Legal Digital Twins: Setting up continuous pipelines for spatial updates that incorporate real-world environmental and legal changes—such as coastal erosion, modifications to infrastructure, and evolving zoning regulations—into real-time cadastral digital twins.
4. Creating modular, open-source land administration software that conforms to ISO 19152 standards in order to reduce the total cost of ownership for municipal governments in developing economies.

8. Conclusion

The incorporation of advanced geospatial technologies—such as UAS photogrammetry and LiDAR, as well as AI-driven remote sensing and blockchain-enabled spatial databases—represents a major change in the field of cadastral surveying and land governance. Such technologies eliminate the severe limitations concerning cost, time, and space that are associated with conventional terrestrial surveying methods, providing practical means of addressing the global gap in tenure security. In order to turn these technical advances into sustainable operational systems, progressive regulatory reform, the development of institutional capacity, and international compliance with interoperable data standards are required. Modern geoinformatics continues to form the essential technological base for transparent, efficient, and fair land administration around the world.

References

1. Asaadi, J., Tariq, M., & Shams, S. (2023). The Implications of Blog Writing on Writing Enhancement in English as a Foreign Language (EFL) among Students in Buqata Junior High School, Golan Heights. *International Journal of Law, Religion and Humanities Studies*, 6(7), 179–190.
2. Assadi, J., & Murad, T. (2024). Melodic mastery: Enhancing vocabulary acquisition through musical repetition. *Educational Administration: Theory and Practice*, 30(5), 1547–1557.
3. Assadi, J., Murad, T., & Wazwaz, R. (2022). The effect of using digital stories on vocabulary acquisition among Arab ESL students who live in Israel. *International Journal of Advanced Education and Research*, 7(4), 17–24.
4. Ekebuike, A. N. (2025). Integrating geospatial technologies in land surveying can support sustainable development. *World Journal of Multidisciplinary Studies*, 2(6), 30–33.
5. Formisano, M. A., & Bushi, J. (2026). Language and Organizational Communication as Drivers of Well-Being in School Organizations. *World Journal of Arts, Education and Literature*, 3(3), 1–4.
6. Murad, T. M., & Smadi, O. (2009). The effect of task-based language teaching on developing speaking skills among the Palestinian secondary EFL students in Israel and their attitudes towards English. *The Asian EFL Journal*, 11(4), 45–62.
7. Murad, T., Assadi, J., & Al-Rassim, M. (2025). Challenges in English speaking: Palestinian Arab students at Israeli colleges. *The Educational Review, USA*, 9(1), 12–21.
8. Sindawi, K., Assadi, J., & Na'Amneh, M. (2025). Epistemological Aims and the Determination of Useful Sciences: A Comparative Study of al-Fārābī and al-Ghazālī in the Classification of Practical and Theoretical Knowledge. *Review of Contemporary Philosophy*, 24(1), 379–391.