AI Opportunities for Cadastre in Support of Integrated Land Administration

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Keywords: Multipurpose Cadastre, Artificial Intelligence, Land Administration Domain Model (LADM), Cadastre 3D, Land Administration.

SUMMARY

Artificial intelligence (AI) is creating unprecedented opportunities to modernise land cadastre systems, transforming them into dynamic, integrated tools that support sustainable development and climate resilience. While traditional cadastral data management has often relied on manual, fragmented processes, AI offers scalable and adaptable solutions that significantly enhance efficiency, automation, and interoperability. These advancements are particularly crucial amid global challenges such as rapid urbanisation, socio-environmental vulnerabilities, and the pressing need for adaptive responses to climate change. The transition to 3D cadastre further amplifies this complexity, requiring sophisticated tools to maintain updated databases and adhere to international standards, such as the Land Administration Domain Model (LADM). While these advances are necessary and welcome, they also demand new tools and approaches to overcome the limitations still present in traditional cadastral systems. In large, diverse countries such as Brazil, structural inequalities between municipalities in terms of population size, institutional capacity, human resources and technological infrastructure represent a key barrier to universalising reliable, integrated land administration. Many local governments lack the means to maintain up-to-date cadastre databases or implement digital tools to support decision-making and policy design. In this context, AI emerges not only as a technological opportunity but also as a potential enabler of inclusion. It can enable municipalities with limited resources to automate key processes, reduce operational costs and provide better public services supported by accurate land data. This paper explores how AI technologies, including Machine Learning (ML), Deep Learning (DL), Computer Vision, and Large Language Models (LLMs), can revolutionise the multipurpose cadastre. It focuses on applications aligned with LADM and cadastre developments, highlighting opportunities for automated feature extraction, semantic integration, 3D modelling, and intelligent interaction with cadastral information. Despite significant potential, challenges persist, particularly concerning data quality, standardisation, interoperability, and the ethical implications of AI deployment. Addressing these issues through transparent, inclusive, and ethical practices is vital to fully realise AI's transformative impact on land administration, fostering more equitable and climate-resilient land governance in the 21st century.

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1 INTRODUCTION

The landscape of geospatial information science is undergoing a profound transformation, driven by rapid advancements in Artificial Intelligence (AI). This evolution extends beyond mere computational enhancements, fundamentally altering how spatial data is acquired, processed, analysed, and ultimately, how it informs decision-making in critical domains such as land administration. Historically, the management of land information has been a complex endeavour, often characterised by manual processes, disparate data sources, and varying levels of institutional capacity across different jurisdictions (Ashna; Ramadevi; Bhavani, 2024). These traditional approaches, while foundational, frequently struggle to keep pace with the dynamic nature of urban development, environmental changes, and the increasing demand for integrated and accessible land information.

The emergence of Geospatial Artificial Intelligence (GeoAI), a specialised field at the intersection of AI and Geographic Information Science (GIScience), marks a pivotal shift. GeoAI leverages advanced AI techniques, including machine learning (ML), deep learning (DL), and computer vision, to extract meaningful insights from vast and complex geospatial datasets (Janowicz et al., 2020). This capability is particularly pertinent for the multipurpose cadastre and the Land Administration Domain Model (LADM), frameworks designed to provide comprehensive and standardised representations of land rights, restrictions, and responsibilities (RRRs) (ISO, 2024). The integration of AI within these frameworks promises to overcome long-standing challenges, such as the labour-intensive nature of cadastral mapping, the difficulties in integrating heterogeneous data, and the need for more dynamic and responsive land management systems.

This paper explores the transformative potential of AI within integrated land administration, with a particular focus on its applications within the multipurpose cadastre and LADM principles. We explore how AI can address key challenges in land administration, from automating data acquisition and updates to enhancing cadastral modelling and property valuation, by examining two use cases: (i) a GeoAI pipeline that applies street-level imagery to assist map building usage in urban purpose cadastral maintenance; and (ii) the development of a chatbot, powered by large language models, and the importance of a structure conceptual models such as the LADM. By synthesising recent advancements and identifying key challenges, this work aims to foster more efficient, equitable, and resilient land governance, especially in regions facing significant socio-economic and environmental pressures, such as Brazil.

2 GEOAI IN LAND ADMINISTRATION

The integration of Artificial Intelligence (AI) into land administration systems is catalysing a paradigm shift from traditional, often manual, processes to more dynamic, automated, and intelligent workflows. This evolution is critical for addressing the complexities of modern land management, including rapid urbanisation, the need for sustainable development, and the transition towards 3D and 4D cadastres (Paixão, Nichols, Carneiro, 2012). A growing body of research explores the application of AI, particularly machine learning and deep learning, to enhance the capabilities of the multipurpose cadastre and systems based on the Land Administration Domain Model (LADM) (Andritsou; Alexiou; Potsiou, 2024; Mehmood; Ujang; Azri, 2025; Mete, 2025).

A significant research thrust is the use of AI for automating the extraction of cadastral information from various data sources (Mango et al., 2023; Hosseini; Atazadeh; Rajabifard, 2025). The application of computer vision techniques to high-resolution satellite and aerial imagery, as well as street-level imagery, enables the automatic detection of buildings, infrastructure, and changes in land use. This automates the otherwise laborious process of cadastral mapping and updating, ensuring that land information systems reflect the on-the-ground reality more accurately and efficiently (Uşak; Çağdaş; Kara, 2024). For instance, deep learning models can be trained to identify informal settlements or unauthorised constructions, providing crucial data for urban planning and regularisation efforts (Sithole; Mhangara, 2025).

Another key area of application is in property valuation. AI-powered mass valuation models are being developed to provide more accurate and equitable property assessments for taxation purposes. These models can analyse a wide range of variables, including location, property characteristics, and market trends, to generate valuations that are more consistent and transparent than traditional methods (Gao et al., 2022; Mete, 2025). This not only supports fiscal management but also contributes to a fairer distribution of the tax burden.

The transition to 3D cadastres, which is essential for managing complex urban environments with multi-level ownership and rights, presents both challenges and opportunities for AI. AI can assist in the creation and maintenance of 3D cadastral models by automatically processing point cloud data from sources like LiDAR and photogrammetry. Furthermore, the integration of Building Information Models (BIM) with LADM-based systems, facilitated by AI, allows for a comprehensive representation of both the physical and legal aspects of properties (Andritsou et al., 2024; Shahidinejad , 2025; Widyastuti et al., 2025; Zamzuri et al., 2025). This integration is crucial for applications such as urban planning, infrastructure management, and disaster response.

To provide a structured overview of the recent advancements, Table 1 summarises the key research contributions, categorised by their primary application area within land administration and related initiatives in Brazil.

Table 1. A brief outline of some of significant research contributions and initiatives related to land administration in Brazil.

Application Area	Key Technologies	Main Contribution	References
Literature Review & Trend Analysis	AI, Machine Learning, Structural Topic Modelling	AI-based literature review of LADM, identifying dominant research topics and highlighting trends such as 3D cadastral modelling and country-specific LADM profiles.	(McCord, 2022; Aditya et al., 2024; Uşak et al., 2024; Hosseini et al., 2025a; Mehmood et al., 2025)
3D Cadastre & BIM Integration	BIM, 3D Cadastral Data, Sensors	Development of a low-cost methodology for creating a Digital Twin of an urban neighbourhood, enabling dynamic weather simulation and energy consumption monitoring for sustainable urban management.	(Aditya et al., 2024; Andritsou et al., 2024; Shahidinejad et al., 2025b, 2025a; Widyastuti et al., 2025)
Land Consolidation & Management	GIS, Automated Algorithms	An innovative method for evaluating the difficulty of potential land consolidation using a standardised cadastral data set, providing accurate data on work complexity at individual stages.	(Maciąg et al., 2024; Mango et al., 2023)
Mass Property Valuation	GeoAI, Machine Learning (XGBoost, LightGBM)	Development of a GeoAI-integrated mass valuation model for property tax purposes, demonstrating the potential for more accurate and fair property valuations.	(Droj et al., 2024; Gao et al., 2022; Mete, 2025)
Cadastral Data Integration with LADM (Brazil)	LADM	A proposal for modelling and implementing an integrated system for Brazilian cadastres based on LADM, confirming the viability of integrating urban, rural, and public asset cadastres.	(Santos et al., 2013; Marra et al., 2017; Purificação et al., 2019; Vasquez et al., 2019)
Multipurpose Cadastre Implementation (Brazil)	3D/4D Cadastre	A discussion on the components, benefits, and implementation challenges of the Multipurpose Cadastre in Brazil, including reflections on the transition to 3D and 4D cadastres.	(Panchiniak et al., 2009; Carneiro et al., 2012; Paixão et al., 2012; Latawiec et al., 2017; Cabral et al., 2020)

3 PROPOSALS AND DEVELOPED WORKS

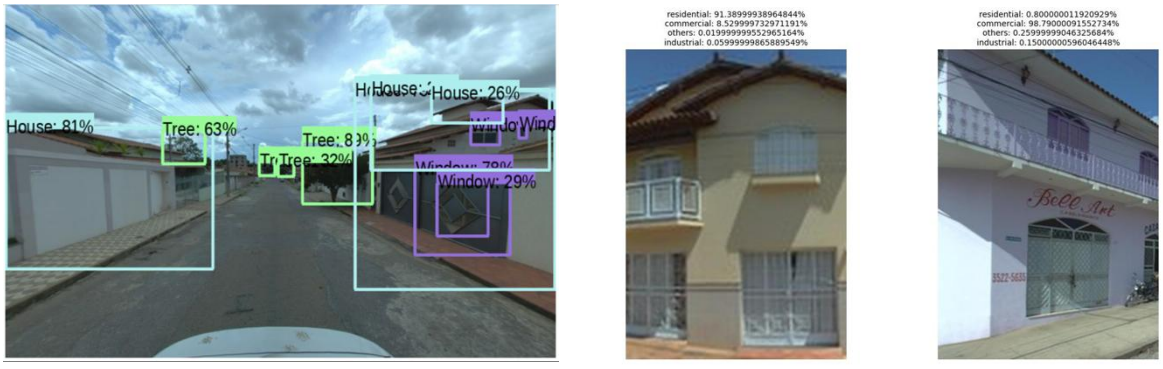
Building upon state-of-the-art technology, this section outlines specific proposals and developed works that can promote advances in the direction of the LADM by further integrating AI technologies into Brazil's multipurpose cadastre.

3.1 Enhancing cadastral data acquisition and update through automated feature extraction

Automating cadastral data acquisition and update processes offers a significant opportunity to improve the efficiency and accuracy of land administration. Traditional methods often involve labour-intensive field surveys and manual digitisation, which are time-consuming and prone to inconsistencies (Ramalingam & Kumar, 2023). Leveraging deep learning techniques, particularly Convolutional Neural Networks (CNNs), for automated feature extraction from various imagery sources provides a scalable solution. For instance, detecting irregular constructions and changes in land use can be significantly streamlined by applying CNNs to both orbital and street-level imagery (Al-Habashna, 2022). This approach, highlighted in the proposed innovations for CTM, directly optimises cadastral updates and enhances territorial fiscalisation without substantially increasing operational costs.

A concrete application of this advancement was implemented in our ongoing study conducted in a Brazilian urban environment. The research focuses on classifying urban building usage types using 360 ° terrestrial mobile mapping images. In this study, we employed advanced convolutional neural network (CNN) architectures – Inception-ResNet-v2 for building detection and EfficientNet-B7 for the subsequent classification task. While this approach is conceptually aligned with the methodology proposed by Ramalingam and Kumar (2023), our work is distinguished by using a custom-trained model specifically adapted to a dataset of 360° urban terrestrial imagery.

The methodology successfully categorised buildings into residential, commercial, industrial, and 'other' uses, achieving high accuracy in complex urban environments (Figure 1). This work not only showcases the technical feasibility of automated classification but also provides a framework for modernising the multipurpose cadastre by enabling a more dynamic understanding of urban land use patterns. The ability to automatically interpret property typologies from street-level imagery enables more efficient regularisation procedures. It provides valuable data to support decision-making, for example, in promoting equitable property taxation, addressing a critical gap faced by many municipalities.



a) Detection task

b) Examples of building usage classification (residential – right; commercial – left)

Figure 1. Example of automated building detection (a) and classification (b) using 360º terrestrial mobile mapping imagery in an urban environment.

3.2 Semantic integration and intelligent interaction with cadastral information

The semantic integration of heterogeneous cadastral data and the provision of intelligent interaction mechanisms are crucial for enhancing the interoperability and accessibility of land information (Chehrehbargh et al., 2025). The Land Administration Domain Model (LADM) provides a standardised framework for modelling land administration information (ISO, 2024), but its implementation can be challenging within contexts characterised by diverse institutional capacities and data availability, such as Brazil. AI, particularly Large Language Models (LLMs), can play a pivotal role in bridging the semantic gap between different data sources and providing more intuitive ways for users to interact with cadastral data (Okembo, 2024).

One of the current research projects being developed by the Territorial Engineering and Management Group (GENTE) at the Federal University of Viçosa, Brazil, involves creating a geospatial chatbot for citizen services. This chatbot, powered by an LLM, would be able to understand and respond to natural language queries from citizens regarding property taxes (IPTU), zoning regulations, and other geospatial information. However, effective implementation of such a system relies on the adoption of structured conceptual models, such as the LADM, which provide the necessary semantic and data interoperability. This foundational structure not only ensures consistent and context-aware responses but also facilitates the system's adaptation across different municipal contexts, thereby enhancing its scalability and broader applicability. By integrating the chatbot with an LADM-compliant database, it would be possible to provide accurate and context-aware responses, significantly reducing bureaucratic hurdles and enhancing citizen engagement.

Furthermore, the use of LLMs can be extended to support data integration and harmonisation. By training LLMs on cadastral and legal documents, it is possible to develop models that can automatically extract and classify information on rights, restrictions, and responsibilities (Widyastuti et al., 2025), and map them to the LADM structure. While this direction holds significant promise, further research is still required to fully realise these capabilities and address challenges related to accuracy, interpretability, and domain-specific adaptation. Advancements in this area would greatly facilitate the migration of legacy data to LADM-compliant systems, ensuring greater semantic consistency across heterogeneous datasets.

3.1 Ethical and governance considerations.

Although this paper primarily explores the technical opportunities of GeoAI in land administration, it is important to emphasise that the work is exploratory and reflective regarding potential uses and points that require attention before large-scale adoption. AI applications in cadastral and land governance systems can inadvertently reinforce social inequalities or create new vulnerabilities if not critically examined. Recent debates discuss the ethical and responsible use of geospatial AI.

The ethical and responsible use of AI in cartography revolves around five critical and interconnected challenges: bias, geoprivacy, responsibility, commodification, and the combined issues of transparency, explainability, and provenance (Kang et al., 2024). GeoAI models risk amplifying existing social and spatial biases present in training data, requiring continuous effort to observe, analyse, and mitigate these effects through inclusive and equitable practices (Kang et al., 2024; Nelson et al., 2025). Major concerns are raised regarding geoprivacy, as GeoAI relies on large volumes of location data, which can lead to inadvertent

disclosure of private behaviours, surveillance risks, and the potential misuse of technologies like predictive policing (Locus Charter, 2025). Accountability is challenging because the complex "black box" nature of deep learning algorithms makes it difficult to trace decision-making processes (provenance) or assign responsibility for generating inaccurate or "unethical maps". Achieving transparency and explainability is vital to building public trust, while simultaneously, the commodification of GeoAI assets (training data, models, and cartographic output) introduces new ethical questions about intellectual property, ownership, and the potential to exacerbate the digital divide between the Global North and South (Fish et al., 2025). Ethical deployment of AI is also about social justice — avoiding solutions that inadvertently deepen the digital divide or exclude communities with weaker technical infrastructures.

Key guidelines for addressing these issues include assessing impacts and minimising harm, mitigating biases in training data, protecting the privacy of individuals and communities, and ensuring transparency and accountability in automated decision-making. By explicitly acknowledging these risks and framing our proposals as an initial step towards responsible innovation, we invite further interdisciplinary dialogue and the development of governance frameworks that can support the inclusive and equitable deployment of AI in land administration. Future studies should deepen these ethical reflections by connecting them to global initiatives (e.g., UN-GGIM's Integrated Geospatial Information Framework [UN, 2023], OGC and ISO standards) and to social inclusion concerns. Ensuring that AI-driven cadastral innovations do not exacerbate the digital divide is essential for equitable land governance. This work aims to initiate a research and policy agenda rather than provide a prescriptive framework, inviting multi-stakeholder dialogue on responsible GeoAI adoption.

4 FINAL REMARKS

The AI-driven approach to multipurpose cadastre and LADM frameworks represents a transformative shift in land administration. This paper highlights the multifaceted opportunities offered by GeoAI, presenting a use case. Additionally, it outlines the potential role of large language models (LLMs) in enabling semantic integration and intelligent interaction with cadastral information. By powering data acquisition, enhancing property valuation, and facilitating the transition to 3D cadastres, AI technologies are paving the way for more efficient, accurate, and equitable land governance systems.

Recent literature highlights a clear trend towards leveraging AI for tasks such as automated feature extraction from diverse imagery sources, which significantly streamlines cadastral mapping and updating (Uşak et al., 2024; Hosseini et al., 2025b). Furthermore, AI-powered mass valuation models are proving instrumental in achieving more accurate and fair property assessments for taxation (Mete, 2025). The critical role of AI in supporting the development and maintenance of 3D cadastral models, particularly through the integration of BIM with LADM-based systems, underscores its importance in managing complex urban environments (Andritsou et al., 2024). Specific proposals and ongoing works within the Brazilian context showed the practical applicability of some of these advancements. Initiatives focusing on automated detection of urban buildings from 360º terrestrial mobile mapping imagery in an urban classification task and the development of geospatial chatbots powered by LLMs for citizen services exemplify how AI can enhance both the efficiency of cadastral operations and

the accessibility of land information. These efforts are crucial for countries facing challenges related to data inconsistency and the need for streamlined administrative processes.
While the potential of AI in land administration is immense, challenges related to data quality, standardisation, interoperability, and ethical considerations remain (Micheli et al., 2022). These aspects underscore the importance of structured conceptual models, such as the LADM, to ensure semantic and data interoperability. Addressing these issues through methodological frameworks, interdisciplinary collaboration, and transparent governance will be essential to harnessing AI's full transformative power. Finally, the strategic integration of AI into multipurpose cadastres and LADM systems has the potential to promote more resilient, interoperable, and inclusive land administration practices globally. Still, it requires advances to be extended and reach diverse institutional capacities effectively.

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