Multipurpose Territorial Cadastre Governance: Lessons from Cotia's Experience in Light of LADM Principles in the Brazilian Context

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Key words: Multipurpose Territorial Cadastre; Cotia; Municipal Cadastre Management; Land Governance; LADM Model.

SUMMARY

The modernization of land administration systems in developing countries, such as Brazil, faces the dual challenge of overcoming the complexity of legacy systems and resource constraints. This paper analyzes the experience of modernizing the Multipurpose Technical Cadastre (CTM) in the municipality of Cotia, São Paulo, as a case study on the pragmatic application of international principles in a context of high socio-spatial complexity. The methodology involved integrating historical data with high-resolution geospatial inputs, such as orthophotos (10 cm GSD) and mobile mapping imagery, on a web-based GIS platform. The main result was the creation of a unified database for approximately 115,000 properties, with functional interoperability with the municipal tax system. An analysis of the solution reveals a strong conceptual convergence with the Spatial, Administrative, and Source packages of the Land Administration Domain Model (LADM - ISO 19152), even without a formal adoption of the standard. It is concluded that a fit-for-purpose approach is a viable path for cadastral modernization, and that the greatest value of standards like the LADM may lie in their function as a "conceptual map" that guides incremental, problem-driven implementations. This experience offers valuable lessons for land governance and the promotion of social inclusion in Brazil.

Palavras-chave: Cadastro Territorial Multifinalitário; Cotia; Gestão Cadastral Municipal; Governança Territorial; Modelo LADM.

RESUMO

A modernização dos sistemas de administração de terras em países em desenvolvimento, como o Brasil, enfrenta o duplo desafio de superar a complexidade dos sistemas legados e a limitação de recursos. Este artigo analisa a experiência de modernização do Cadastro Técnico Multifinalitário (CTM) no município de Cotia, São Paulo, como um estudo de caso sobre a aplicação pragmática de princípios internacionais em um contexto de alta complexidade socioespacial. A metodologia envolveu a integração de dados históricos com insumos geoespaciais de alta resolução, como ortofotos (10 cm GSD) e imagens de mapeamento móvel, em uma plataforma SIG web. O principal resultado foi a criação de uma base de dados unificada para aproximadamente 115 mil imóveis, com interoperabilidade funcional com o sistema tributário municipal. A análise da solução revela uma forte convergência conceitual com os pacotes Espacial, Administrativo e de Fontes do Land Administration Domain Model (LADM

- ISO 19152), mesmo sem uma adoção formal do padrão. Conclui-se que a abordagem *fit-for-purpose* é um caminho viável para a modernização cadastral, e que o maior valor de padrões como o LADM pode residir em sua função como um "mapa conceitual" que guia implementações incrementais e focadas em resolver problemas práticos, oferecendo lições valiosas para a governança territorial e a promoção da inclusão social no Brasil.

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1. INTRODUCTION

Land administration in emerging nations stands at a critical crossroads: on one hand, the urgency to provide legal security and public services to rapidly expanding populations; on the other, the complexity and cost of traditional cadastral systems. Overcoming this dichotomy requires innovation and pragmatism. This paper explores this dynamic through the analysis of a Brazilian case study, the municipality of Cotia, investigating how a cadastral modernization approach, inspired by international principles, can offer valuable lessons for 21st-century land governance.

1.1 Context and Justification

Effective land governance is a pillar of sustainable development, yet in countries like Brazil, it faces historical challenges. Rapid and often disorderly urban expansion, coupled with complex registration systems, creates a critical gap between the reality of land occupation and its cadastral representation. This discrepancy not only compromises fiscal justice and urban planning but also perpetuates tenure insecurity, limiting the public sector's ability to implement effective, evidence-based policies. The severity of this scenario has motivated federal initiatives such as the National System for a Territorial Information Management (SINTER), which aims to unify the country's diverse cadastres.

In response to these challenges, the modernization of Multipurpose Technical Cadastres (MTC) has become a strategic priority. The experience of the municipality of Cotia, located in the São Paulo Metropolitan Region, offers insights into the practical application of international standards, notably the Land Administration Domain Model (LADM), standardized as ISO 19152. The project, conducted by Geopixel, enabled the integration of spatial and administrative data, interoperability between municipal systems, and the adoption of good land governance practices. This paper is justified by its analysis of this pragmatic implementation, investigating how LADM principles can be adaptively applied to overcome cadastral challenges in complex urban contexts, providing lessons and methodologies that may be useful for other Brazilian municipalities and developing countries.

1.2 Study Area: The Challenge of Cotia

The municipality of Cotia, located in the São Paulo Metropolitan Region, Brazil, constitutes an emblematic case study of land management challenges in emerging nations. With an area of 324 km² (IBGE, 2022) and a population of approximately 289,000 inhabitants (IBGE, 2025), the municipality stands out economically, exhibiting one of the country's highest Gross Domestic Products (GDP), driven by a strong service and industrial sector.

However, this prosperity coexists with deep socio-spatial disparities. Data from the Unified Registry (Cadastro Único) indicate that over 33,000 families in the municipality live in poverty or extreme poverty (MDS, 2024), and the demographic census revealed that 4.1% of the population resides in 19 subnormal agglomerates (IBGE, 2022). This duality manifests physically in the territory through a complex mosaic that combines high-standard gated communities, environmental protection areas, and consolidated informal settlements. This landscape of contrasts highlights the intense pressure on management instruments, demanding innovative cadastral solutions to promote more equitable urban planning and tenure security for all citizens.

In response to this complexity, the Municipal Government commissioned Geopixel to execute a project to update the Multipurpose Technical Cadastre (MTC). It is important to note that the project did not start with a formal adoption of the Land Administration Domain Model (LADM - ISO 19152); however, the resulting solution, focused on pragmatic needs, demonstrates a remarkable convergence with the standard's principles. The system's modular architecture, the integration of spatial and administrative data, and the very logic of its information organization make Cotia's experience a relevant source of lessons learned for cadastral modernization in other developing contexts.

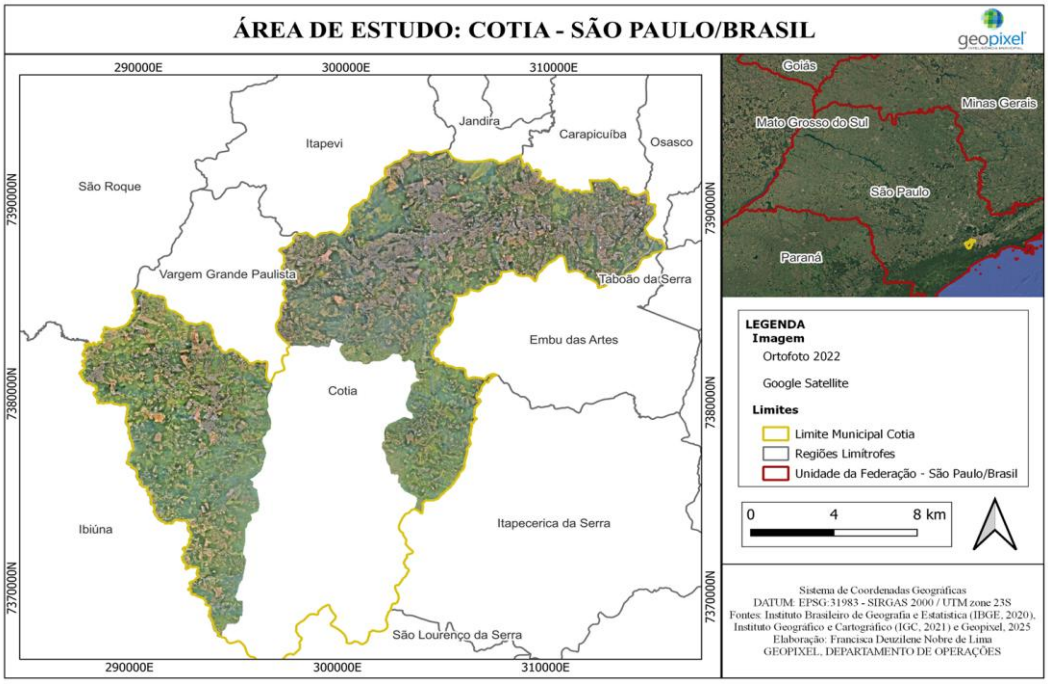

Figure 1. Map of the study area: Cotia, São Paulo/Brazil

1.3 International Context and Related Works

Global cadastral modernization has been redefined by the fit-for-purpose approach, which proposes a paradigm shift from traditional systems. Instead of focusing on geodetic accuracy and formal completeness, this approach prioritizes delivering tenure security in a fast, affordable, and incremental manner, especially in developing countries. The seminal work of Enemark (2014) argues that spatial, legal, and institutional frameworks must be flexible, using,

for example, visible boundaries from satellite imagery and recognizing a continuum of land rights.
This flexibility is crucial in the Brazilian context, where the complexity of the cadastral system is a historical challenge. A comparative study between Brazil and Portugal, for instance, highlights the disarticulation among multiple cadastres in Brazil and the need to strengthen the Multipurpose Technical Cadastre (MTC) as a central management tool (Julião; Pelegrina; Grave, 2015). The fit-for-purpose approach offers a pragmatic path to overcome this fragmentation.
It is at this nexus between the fit-for-purpose philosophy and Brazil's structural challenges that Cotia's experience gains relevance. The project's characteristics—such as the use of orthophotos for delimitation and the focus on data integration—demonstrate a notable convergence with the pragmatic principles advocated by Enemark (2014). This convergence becomes technically explicit when the project is analyzed in light of the LADM (ISO 19152), the data model that provides the standard framework for implementing the FFP approach. Thus, although the implementation in Cotia does not yet reflect the entirety of the standard, an analysis of its approach offers a practical and relevant example of how international theory can be applied to solve concrete cadastral problems in Brazil. The case of Cotia, therefore, aligns with a global trend of pragmatically using LADM principles to, step-by-step, promote interoperability and good land governance.

1.4 Structure of the Paper

The analysis of the Cotia experience seeks to highlight applied methodologies and lessons learned, discussing the prospects for interoperability and replicability of the model in other Brazilian municipalities. To this end, the paper is structured into five sections: the first contextualizes the study; the second describes the materials and methodology; the third presents the results and their alignment with the LADM; the fourth deepens the discussion on the project's challenges and potential; and, finally, the fifth section synthesizes the conclusions and recommendations, highlighting the study's contributions to cadastral modernization in developing countries.

2. MATERIALS AND METHODS

The modernization of Cotia's cadastre was based on a multiphase methodology that combined the recovery and processing of historical data with the production and analysis of new geospatial inputs. The approach aimed to ensure not only the accuracy and currency of the database but also its integration and interoperability. The adopted procedures, detailed below, were designed to build a robust and dynamic cadastral database capable of supporting the diverse demands of municipal management. The general structure of this methodology is depicted in Figure 5.

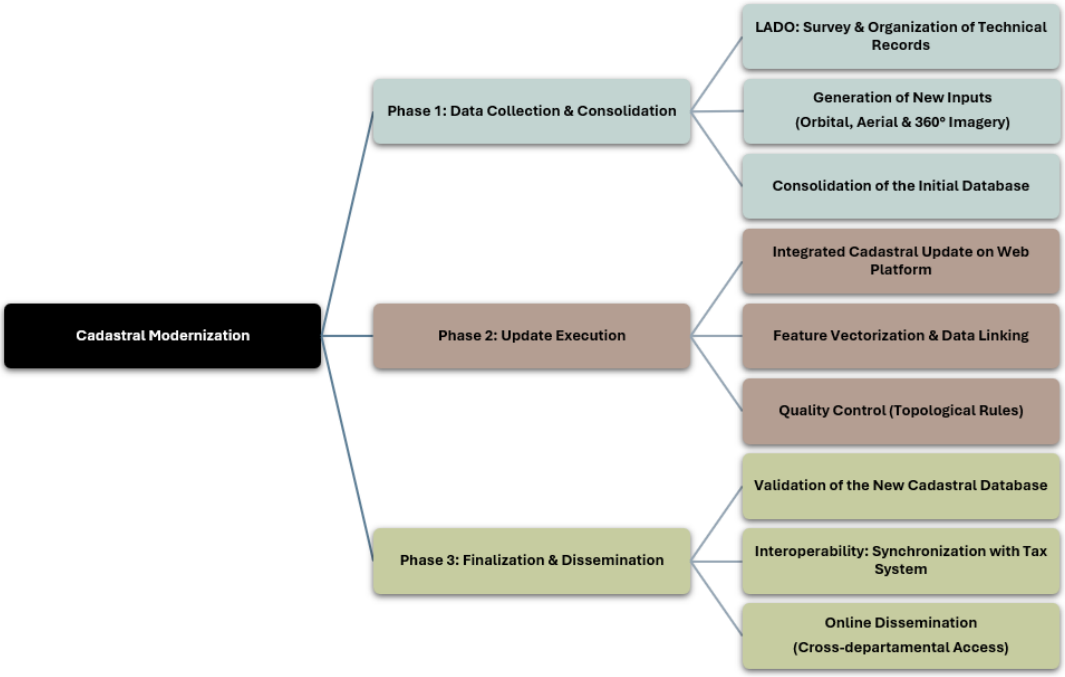

Figure 2. Structure of the cadastral update methodology

2.1 Data Collection and Consolidation

The initial stage of the project consisted of recovering and organizing the municipality's technical records, a process named LADO (Levantamento, Análise, Diagnóstico e Organização - Survey, Analysis, Diagnosis, and Organization) (Geopixel, 2025). This phase involved the analysis of approximately 779 digital files (6.5 GB), which included subdivision plans, vector layers, legal descriptions, the municipal property cadastre, and old orthophotos. All relevant material was then digitized and georeferenced to form the initial database, as illustrated in the example in Figure 2.

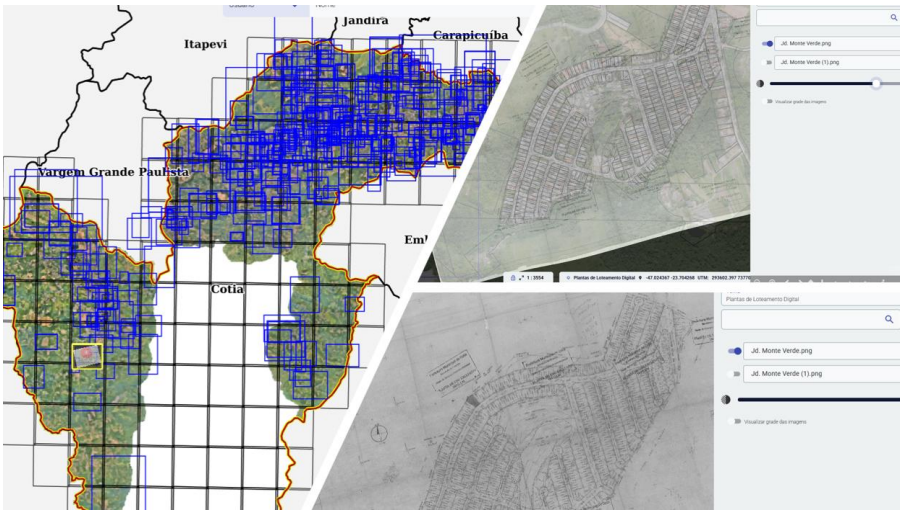

Figure 3. Example of inputs collected during the LADO stage

In parallel, new geospatial inputs were generated. The project included medium-resolution orbital imagery (50 cm GSD) in RGB, PAN, and NIR, covering the entire municipal territory, as well as the extraction of Digital Surface Models (DSM) and Digital Terrain Models (DTM) through dense matching techniques. The final orthophotos were mosaicked with radiometric corrections, optimized seamlines, and tonal post-processing, following best practices in Digital Image Processing (DIP) using Pix4D software (Geopixel, 2022).

For urban areas, a high-precision cartographic base was generated through an aerial photogrammetric survey with a 10 cm GSD, obtained by a Remotely Piloted Aircraft System (RPAS) and adhering to the parameters of Class A of the Cartographic Accuracy Standard (Brasil, 1984).

Finally, a survey using Terrestrial Mobile Mapping was conducted to capture 360° panoramic images of urban streets, obtaining detailed information on property facades. In total, 402,286 images were collected along 1,201.1 km of roads. The capture system was equipped with six 5-megapixel cameras, configured for an image dimension of 8,000 x 4,000 pixels, a 3-meter distance between photos, and a maximum distance of 12 meters from the property frontage. The survey's quality was ensured by the use of GNSS and an inertial reference system, guaranteeing the geocoding of each image in the SIRGAS 2000 standard, with a positional accuracy of better than 1 meter and an azimuth precision of less than 5 degrees. Figure 4 illustrates the integration of these diverse data sources that compose the study's cadastral database.

Figure 4. Example of integration between orthophoto and 360° panoramic images

2.2 Cadastral Update Methodology

The cadastral update was executed in an integrated manner on the Geopixel Cidades web-based geographic information platform. The vectorization process of urban features occurred concurrently with the assignment of alphanumeric data, using the high-resolution orthophotos (10 cm GSD) as a base to ensure a positional accuracy compatible with a 1:1,000 scale, and supported by the 360° panoramic images for the correct identification of elements such as

physical boundaries (walls and fences) and building numbers. The geometries of blocks, parcels, buildings, street centerlines, and relevant improvements, such as swimming pools and sports courts, were vectorized.
During the geometric vectorization, administrative data was linked using inputs from the old records, such as subdivision plans, block plans, and, most importantly, the pre-existing fiscal property cadastre. The tabular structure was adapted to reflect the municipality's standard, in which the complete property registration number is composed of District, Sector, Block, Parcel, Unit, and Sub-unit. Each geospatial feature was enriched with specific attributes; for example, a parcel received information about its position on the block and the presence of pavement, while a building was detailed with its construction type, primary use, and number of floors.
To ensure the consistency and integrity of the new database, the entire process was accompanied by rigorous quality control, which included checking topological rules to prevent errors such as overlaps or gaps between polygons. After the completion and validation of the cadastral update on the Geopixel Cidades platform, interoperability with the municipality's tax system was established, allowing for the synchronization and flow of information between the geospatial and fiscal databases.

2.3 Architecture of the Technological Solution

The project's technological foundation was the Geopixel Cidades System, a Geographic Information System (GIS) platform that operates entirely in a web environment. The choice of a web-based architecture was strategic, as it eliminates the need to install specific software on users' machines and ensures that all technicians, from different departments, always access the same centralized and updated version of the data. This centralization is fundamental to avoiding data duplication and the creation of departmental data "silos."
The platform was designed to function as a geospatial information hub, promoting the cross-departmental sharing of content. By consolidating cadastral, fiscal, and urban planning data into a single geospatial database, the system strengthens interoperability among urban planning, environmental, and, crucially, tax systems. The online distribution of information allows updates made by one department to be immediately visible to others, creating a more dynamic and integrated land management ecosystem (Geopixel, 2022).

3. RESULTS

The application of the described methodology resulted in the creation of a unified geospatial cadastral database for the municipality. In addition to the practical outcomes of the new database, detailed below, the project provides an opportunity to analyze the convergence between the developed solution and the principles of the LADM standard (ISO 19152). The analysis of this conceptual adherence is therefore presented next.

3.1 Unified Cadastral Database of Cotia

The first tangible result of the project was the complete restructuring of the cadastral database, covering a universe of approximately 115,000 properties. The methodology allowed for the

correction of historical inconsistencies, such as the identification of de facto properties without a corresponding registration (omitted properties) and the handling of units that required aggregation or subdivision. The final product overcame the old data fragmentation, consolidating, for the first time on a single platform, the precise geometric representation of parcels with their respective fiscal and administrative data.

A fundamental advancement was the establishment of a dynamic data flow between the fiscal and geospatial databases. The implemented integration allows updates made to the tabular data in the municipal tax system—such as changes in ownership or assessed value—to be reflected on the Geopixel Cidades platform. This information is automatically associated with its respective geometric representation (the parcel) through the property registration number, which functions as a linking key. This mechanism ensures that the administrative data consulted on the geospatial platform mirrors the fiscal database, strengthening governance and reducing inconsistencies between the Finance and Planning departments.

The broader result was the strengthening of the municipality's management and planning capacity. With an accurate and up-to-date cadastral database, the city government obtained a robust instrument for complex territorial analyses, such as identifying urban expansion areas, controlling land use and occupation, and simulating scenarios for public policies. The quality and structure of the generated data position the municipality for future evolutions, such as the implementation of a 3D cadastre and integration with other databases at the state and federal levels, aligning with international best practices promoted by FIG and UN-GGIM (FIG, 2020).

Figure 5. Sketch of the integration with Cotia's Geopixel system

3.2 Analysis of Alignment with the LADM

To analyze the project's conceptual adherence, it is essential first to understand the structure of the Land Administration Domain Model (LADM), standardized as ISO 19152 (ISO, 2012). The LADM is a conceptual model that organizes land administration information into main packages, including the Administrative Package (LA_Party, LA_BAUnit, and LA_RRR), the Spatial Package (LA_SpatialUnit), and the Source Package (LA_Source), among others. The

standard's objective is to provide an abstract and flexible framework for developing modern and interoperable land administration systems. The following analysis focuses on the convergence of the Cotia project with these three core packages.

Convergence with the Spatial Package (LA_SpatialUnit): The clearest convergence of the project occurs with the Spatial Package. The detailed vectorization of features such as parcels, buildings, and blocks from high-resolution orthophotos directly corresponds to the creation of Spatial Units (LA_SpatialUnit), as defined in ISO 19152. The methodology, which used 10 cm GSD imagery and followed the Cartographic Accuracy Standard, ensured the creation of a precise and reliable geometric representation of land occupation, aligning with LADM guidelines for modeling the spatial dimension of the cadastre.

Convergence with the Administrative Package (LA_Party, LA_BAUnit, and LA_RRR): The project also reflects the logic of the LADM's Administrative Package. The integration that allows for the update of data from the tax system, such as the owner's name, demonstrates a connection to the LA_Party class (the interested parties). The property registration number, in turn, functions as an analogue to the Basic Administrative Unit (LA_BAUnit), while other attributes, such as land use type and assessed value, represent the Rights, Restrictions, and Responsibilities (LA_RRR) associated with each unit. The integration that allows these attributes to be visualized on the parcel's geometry demonstrates the fundamental relationship between LA_BAUnit and LA_SpatialUnit that is at the core of the model.

Convergence with the Source Package (LA_Source): Finally, the project also addressed the concept of the Source Package. By consolidating the municipality's old records—such as subdivision plans and legal descriptions—and using them to guide the linking of registration numbers, the project implicitly treated these documents as Sources (LA_Source). These documents serve as the historical and administrative evidence that provides support and traceability to the records, a fundamental principle for the reliability of any land administration system, as advocated by international bodies like FIG and UN-GGIM (FIG, 2020).

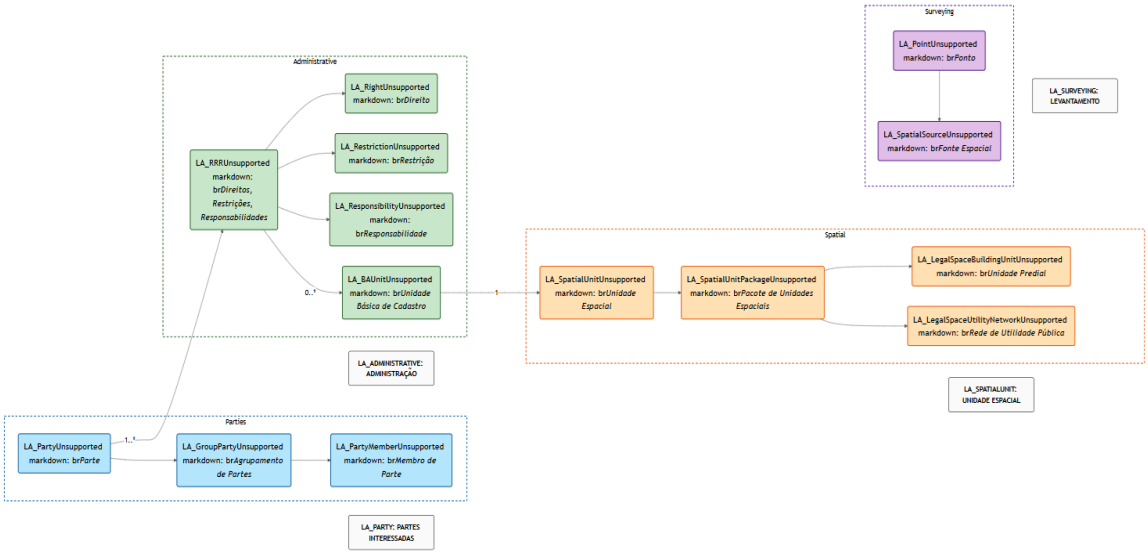

Figure 6. LADM Classes

4. DISCUSSION

The Cotia experience, although focused on solving immediate municipal challenges, raises important discussions about the model's implications for interoperability and scalability in a broader context. This section deepens the analysis of these issues, extracts the main lessons learned from the project, and explores the database's potential for future three-dimensional applications.

4.1 Interoperability and Scalability

Interoperability was one of the project's pillars, materialized through the connection between the Geopixel Cidades platform and the municipal tax system. Technically, this integration was established via an Application Programming Interface (API), which allows communication between the two systems. The data flow was designed so that updates made to the tabular data in the tax system are reflected in the geospatial database within an approximately 24-hour cycle. As detailed in Section 3.1, this mechanism ensures that the administrative data consulted on the GIS parcels mirrors the fiscal database, representing a significant step forward for information consistency in municipal management.

However, the nature of this implementation raises an important discussion about the levels of interoperability. The data flow, in its current design, is predominantly unidirectional—from the tax system to the GIS platform—and focused on synchronizing alphanumeric attributes. A change in a parcel's geometry on the GIS platform, for example, does not trigger an automatic update in the tax system. This characteristic, while functional for the primary objective of ensuring fiscal consistency, highlights the difference between technical interoperability (the API connection) and semantic and process interoperability, which would require a bidirectional transaction model and more complex business rules.

This local reality in Cotia serves as a microcosm for the challenges of scalability at the national level. The creation of a cohesive national cadastre, as proposed by the National System for Territorial Information Management (SINTER), fundamentally depends on overcoming these semantic interoperability barriers. If each municipality develops a system with its own business rules and data models, even if based on APIs, large-scale integration remains a formidable obstacle. Cotia's experience is therefore valuable for two reasons: it demonstrates the feasibility and benefits of modernization at the local level, but at the same time, it reinforces the critical need for national standardization so that these "islands of excellence" can indeed connect into a truly integrated cadastral system.

4.2 Lessons Learned from the Cotia Experience

The cadastral modernization in Cotia offers a set of practical lessons that can be valuable for other Brazilian municipalities facing similar challenges. The analysis of the experience transcends simple technical application and reveals strategic learnings about implementing multipurpose cadastres in contexts of limited resources and high complexity.

The main lesson is the validation of the fit-for-purpose approach as a viable path. The project focused on obtaining data that was "fit for the purpose" of effective management, using a combination of high-resolution orthophotos (10 cm GSD) and mobile mapping imagery. This

cost-effective solution allowed for the coverage of a vast area in a timely manner, reinforcing that cadastral modernization can be incremental, starting with what is most relevant to the municipality's urgent needs.
Finally, the experience teaches that the success of modernization depends on the intelligent integration of the new and the old. The connection with the tax system, even if partial, was crucial for creating immediate value and ensuring the system's sustainability. Simultaneously, the use of historical records as the source for linking administrative data not only saved resources but also ensured the legal continuity of the cadastre. The lesson is that technology should serve to solve functional problems and build upon the legacy of existing information, rather than simply replacing it.

4.3 Potential for a 3D Cadastre

Although the project's scope was the construction of a two-dimensional cadastral database, the quality and nature of the collected data have created a solid foundation for future evolutions toward a 3D cadastre. The discussion about three-dimensional potential is not merely theoretical; it responds to a growing need within the municipality, driven by verticalization and the complexity of condominium structures.
The main assets for this evolution are the Digital Surface Models (DSM) and Digital Terrain Models (DTM), which were already extracted during the image processing phase. The difference between the DSM (which includes the tops of buildings and vegetation) and the DTM (which represents the bare ground) allows for the automatic estimation of building heights throughout the urban area. This height data, when combined with the already vectorized 2D building geometries, can be used to generate Level of Detail 1 (LoD1) three-dimensional models, which are extruded blocks. This approach would already permit analyses of volumetrics, shadow impact, and a more precise calculation of total built area, especially in multi-story buildings.
Furthermore, the 360° panoramic images from the terrestrial mobile mapping constitute a rich data source for future enrichment of the 3D model, potentially to a Level of Detail 2 (LoD2), which includes the representation of roofs and facades. Although the project did not include the 3D modeling of condominiums or legally independent 3D parcels—which would require an evolution in Brazilian legislation—the existing database already provides the technical inputs to begin this transition. The path to a 3D cadastre in Cotia, therefore, can be incremental, starting with the exploration of already available data to generate value in urban planning analyses, while the debate on legal support for 3D parcels advances in parallel.

5. CONCLUSION AND FUTURE WORK

5.1 Conclusion

The cadastral modernization experience in Cotia has demonstrated that applying principles from international standards, guided by a fit-for-purpose approach, is a viable path to enhance land administration in Brazilian municipalities. The creation of a unified geospatial database

integrated with the tax system, even without a strict adoption of the ISO 19152 standard, resulted in a substantial advancement for local land governance.
The main contribution of this study is the validation of a pragmatic approach. The project shows that the greatest value of a standard like the LADM may lie in its function as a "conceptual map" that guides systems integration, rather than as a model to be implemented dogmatically. This reinforces that cadastral modernization can be incremental, focused on solving practical problems and delivering functional value to the administration.
Finally, the case of Cotia serves as a practical example of how new technologies and the legacy of cadastral information can be intelligently combined. The experience aligns with a global trend toward seeking fairer and more efficient systems, offering valuable lessons for the ongoing debate on cadastral modernization and standardization in Brazil and other developing countries.

5.2 Future Work and Benefits for Citizens

The foundations established by the project open a clear path for future technological evolutions. The most immediate is the exploration of the database's 3D potential, using the existing models to enhance urban volumetric analysis. In the long term, the vision includes the complex but necessary integration with property registries (cartórios) and the implementation of continuous database update routines, ensuring the data's longevity and relevance for municipal management.
For the population, the benefits manifest in fairer and more transparent governance. An accurate cadastre is the basis for an equitable tax system, where tax collection reflects the reality of property, and for urban planning that results in better public services and infrastructure for all. The quality of the information allows public authorities to make more assertive decisions, optimizing resources that can be reinvested in priority areas for the community.
However, the most profound and transformative impact lies in the system's potential to promote social inclusion. By providing a reliable database, the cadastre becomes the first step for future land regularization programs, offering legal tenure security to thousands of families, especially those with low income. It is the transformation of technology into dignity and opportunity that represents the true measure of success for a cadastral modernization project and its ultimate contribution to sustainable development.

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BIOGRAPHICAL NOTES

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