Locational Variables in Mass Appraisal: Conceptual Classification Grounded in Systematic Review and Integrated into the LADM Valuation Model

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Key words: Mass Appraisal, Locational Variables, Property Valuation, LADM ISO 19152-4.

SUMMARY

Property valuation requires the consideration of multiple factors, with locational attributes playing a decisive role in explaining market heterogeneity. Despite their relevance, the use of locational variables in mass appraisal models still lacks conceptual standardization, limiting their integration into international land administration frameworks.

This study aims to propose a conceptual classification of locational variables based on a systematic review of international literature. A total of 55 articles published between 2015 and 2025 were analyzed, applying Natural Language Processing (NLP) techniques and semantic clustering to identify, normalize, and categorize variables. The analysis resulted in seven main categories: geographic coordinates, spatial units, central accessibility, public transportation, urban services and amenities, environmental features, and neighborhood socioeconomic context. Among these categories, the most frequent variables were associated with urban services (54.5% of the studies), public transportation (43.6%), and central accessibility (27.3%). In total, more than 120 distinct locational variables were identified and normalized, with the most recurrent being proximity to schools (36%), hospitals (33%), commercial centers (27%), public transportation (metro/train stations in 24% and bus stops in 16%), and the city center (31%). The categories variables were then integrated into the Valuation Package of ISO 19152-4 (LADM), considering exclusively the two-dimensional (2D) context traditionally applied in urban mass appraisal. This systematization reinforces the potential for adopting a standardized and interoperable model, while opening the path for future extensions to 3D contexts. The results demonstrate that the conceptual structuring of locational variables enhances transparency, comparability, and applicability of mass appraisal models, aligning empirical practices with international land administration standards.

Palavras-chave: Avaliação em Massa, Variáveis Locacionais, Avaliação Imobiliária, LADM ISO 19152-4

RESUMO

A avaliação imobiliária exige a consideração de múltiplos fatores, sendo as variáveis locacionais fundamentais para explicar a heterogeneidade dos valores de mercado. Apesar dessa relevância, sua utilização em modelos de avaliação em massa ainda carece de

sistematização conceitual, dificultando a integração a padrões internacionais de administração territorial.

Este estudo tem como objetivo propor uma classificação conceitual das variáveis locacionais com base em revisão sistemática da literatura internacional. Foram analisados 55 artigos publicados entre 2015 e 2025, utilizando técnicas de Processamento de Linguagem Natural (PLN) e agrupamento semântico para identificar, normalizar e categorizar as variáveis. A análise resultou em sete categorias principais: coordenadas geográficas, unidades espaciais, acessibilidade central, transporte público, serviços e amenidades urbanas, características ambientais e contexto socioeconômico da vizinhança.

Entre essas categorias, destacaram-se como mais recorrentes as variáveis associadas a serviços urbanos (54,5% dos estudos), transporte público (43,6%) e acessibilidade ao centro da cidade (27,3%). No total, foram identificadas e normalizadas mais de 120 variáveis distintas, das quais se sobressaem proximidade de escolas (36%), hospitais (33%), centros comerciais (27%), transporte coletivo (estações de metrô/trem em 24% e pontos de ônibus em 16%) e centro da cidade (31%).

As categorias de variáveis foram então integradas ao Valuation Package da ISO 19152-4 (LADM), considerando exclusivamente o contexto bidimensional (2D), tradicionalmente aplicado em avaliações urbanas. Essa sistematização reforça a possibilidade de adotar um modelo padronizado e interoperável, ao mesmo tempo em que abre caminho para futuras extensões em contextos 3D. Os resultados demonstram que a estruturação conceitual das variáveis locacionais amplia a transparência, a comparabilidade e a aplicabilidade dos modelos de avaliação em massa, alinhando práticas empíricas às diretrizes internacionais de administração fundiária.

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1. INTRODUCTION

Property taxation is one of the oldest forms of public revenue and, in Brazil, taxes such as IPTU and ITBI (BRASIL, 1988) are critical for municipal financial sustainability. The Valor Venal do Imóvel (assessed market value), defined by the National Tax Code (BRASIL, 1966), constitutes the basis for IPTU calculation and should reflect actual market conditions (De Oliveira; Bandeira; Noberto, 2024), promoting fiscal justice and tax equity (Carranza et al., 2019).

Within this context, mass appraisal is strategic by enabling standardized and comprehensive estimates of property values (SILVA, 2006; DE CESARE; SILVA; SILVA, 2023). However, this practice still faces challenges, such as outdated cadastral data and technical and institutional obstacles. (Eguino et al., 2020; Felis et al., 2025).

Several studies indicate that locational variables such as accessibility, urban infrastructure, and public services exert a strong influence on the formation of property prices (Bourassa; Hoesli; Peng, 2003; Hornburg; Hochheim, 2017; Sharma et al., 2024). The absence of these variables in valuation models compromises estimate quality and exacerbates tax distortions

The Brazilian federal government has driven the modernization of territorial management, particularly through the Multipurpose Terrestrial Cadastre (CTM) and the Real Estate Market Observatories (OMI), as provided for in Ordinance No. 3.242/2022 (BRASIL, 2022). Such initiatives aim to promote greater data integration and improve the basis for tax calculations.

Against this backdrop, there is a need to standardize locational variables within interoperable conceptual models. The Land Administration Domain Model (LADM – ISO 19152), particularly Part 4 (Valuation Package), represents one such initiative, by integrating valuation concepts into an international cadastral standard (Kara et al., 2021; Frederico; Carneiro, 2014).

Therefore, the current study aims to classify, based on a systematic review, recurring locational variables in mass appraisals and relate them to the LADM Valuation Package in an urban 2D context.

2. THEORETICAL FRAMEWORK

2.1. Mass Appraisal of Real Property

Mass appraisal estimates the value of groups of properties at a given time using standardized methodologies and statistical analyses (IAAO, 1990; Ciuna et al., 2017). Unlike single-property appraisal, which relies on direct comparison, mass appraisal relies on large databases and

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models capable of capturing market heterogeneity (Raslanas et al., 2010; De Cesare et al., 2023).

This technique is applied in both the private sector for credit and investment, and the public sector, as the basis for taxation and urban policy (Silva, 2020; Arribas et al., 2016). Its effectiveness depends on models that incorporate both structural and locational factors of the market.

2.2. Real Estate Market

The real estate market is influenced by multiple factors, such as geographic, socioeconomic, demographic, and regulatory ones, and it is characterized by heterogeneity and spatial dependence. (Silva, 2020; Carranza et al., 2019). Land, being immovable and finite, is strongly impacted by location (Raslanas et al., 2010; Usman et al., 2020).

Property valuation is associated with urban infrastructure, territorial planning and public policies (Silva, 2006, 2020). Understanding these dynamics is key to developing effective assessment models that align with local realities. (Bourassa; Hoesli; Peng, 2003; Cunha, 2023).

2.3. Locational Variables

The typical nature of real estate, defined by durability, heterogeneity and immobility, gives location a central role within the composition of property values (Kiel; Zabel, 2008; Lockwood; Rossini, 2011). These factors range from objective aspects, such as accessibility to urban centres and the availability of public transport, infrastructure and services, to subjective elements, such as the perception of safety and environmental quality (Gallimore; Fletcher; Carter, 1996; Melanda; Hunter; Barry, 2016).

The literature shows that ignoring such variables introduces significant distortions in valuation models, resulting in overvaluation or undervaluation of properties in certain areas. (Carranza et al., 2019). Pioneering studies such as Basu and Thibodeau (1998) and Pace et al. (1998) highlighted the importance of incorporating spatial components into statistical models, influencing the evolution of hedonic models and territorial segmentations (Bourassa; Cantoni; Hoesli, 2007, 2010).

More recently, advanced methods such as Geographically Weighted Regression (GWR) and Principal Component Analysis (PCA) have been employed to address spatial variability and variable redundancy, enabling more refined models integrated with Geographic Information Systems (Ünel; Yalpir, 2019).

This methodological evolution underscores the need to systematically map and classify locational variables so they can be integrated into cadastral bases such as the Multipurpose Terrestrial Cadastre (CTM) and the Real Estate Market Observatories (OMI). Such integration not only increases estimation accuracy and transparency in taxation processes as well as strengthens public policies for territorial planning (De Cesare; Silva; Silva, 2023; Lyashchenko; Mamedov, 2024).

In synthesis, location variables not only complement structural factors of the property, but also constitute a core element for explaining the spatial heterogeneity of the market, justifying its classification and conceptual systematization, as will be detailed in this study.

2.4. Land Administration Domain Model (LADM) and the Valuation Package (ISO 19152-4)

The Land Administration Domain Model (LADM), approved as ISO 19152 standard in 2012, represents a milestone in the international standardization of land administration. Its goal is to provide a common language for structuring information about property, restrictions, responsibilities, stakeholders, and spatial units. By proposing a unified conceptual basis, the model seeks to overcome the fragmentation of cadastral systems, promoting interoperability, transparency, and international comparability.

The initial version of LADM was structured into three packages: LA_Party, dedicated to stakeholders; LA_RRR, focused on rights, restrictions, and responsibilities; and LA_SpatialUnit, which organizes spatial units and its geometric representations.

As for Brazil, the adoption of this standard is particularly strategic given the coexistence of urban, rural, environmental, and patrimonial cadastres, which traditionally operate in isolation and with little integration. The model enables the harmonization of these bases, building national profiles which are compatible with international standards and yet adapted to local realities.

The revision conducted in Edition II expanded the scope of LADM with the creation of Part 4 (ISO 19152-4), dedicated to real estate valuation. This extension, entitled LADM Valuation Package, provides an extensible and interoperable framework for valuation processes, organized around classes prefixed by VM_.

Key classes include: VM_ValuationUnit, which defines the basic valuation units; VM_ValuationUnitGroup, which allows the clustering of properties by administrative or market zones; VM_SpatialUnit, focused on parcels and subparcels; VM_Building and VM_CondominiumUnit, which describe the physical characteristics of buildings; VM_Valuation, which systematizes valuation results; VM_MassAppraisal, intended for statistical mass valuation models; as well as VM_TransactionPrice, VM_SalesStatistic, and VM_ValuationSource, focused on transactions and data sources.

The main contribution of the Valuation Package goes beyond conceptual formalization: it enables the integration of location and environmental variables into the valuation process. By aligning these dimensions with an internationally accepted standard, comparability between countries is enhanced and the interoperability of registries, records, and tax systems is strengthened.

For Brazil, its application paves the path for greater conceptual robustness in mass appraisals, supporting more transparency and efficiency in tax processes, and ensuring compatibility with real market dynamics.

3. MATERIALS AND METHODS

3.1 Study Design and Research Question

This is a qualitative, exploratory study (Gil, 2019), conducted through a systematic review of the literature (Galvão & Ricarte, 2019). The protocol followed PRISMA 2020 (Page et al., 2021) and the recommendations of Kitchenham & Charters (2007). The research question was

structured using the PICO framework (Santos, Pimenta & Nobre, 2007): Population: real estate valuation models; Intervention: use of location variables; Comparison: methods without spatial variables; Outcome: improvement in the accuracy and reliability of the models.

3.2 Information Sources and Search Strategy

The search was conducted in SciSpace (Khamis et al., 2020), through natural language, exploring semantic resources. Combinations of terms were employed on topics such as Real Estate Appraisal, Property Appraisal, Housing Price Prediction, LocationalVariables, Spatial Analysis, Machine Learning, Spatial Econometrics, and GIS. The initial return totaled 491 entries.

3.3 Screening and Eligibility

Screening by title and abstract was performed using Rayyan (Ouzzani et al., 2016), resulting in 273 eligible studies. After organization in Mendeley (Elsevier, 2021), the following filters were applied: Period: 2015–2025 (inclusive); and in the analysis Type: peer-reviewed only; Languages: Portuguese, English, Spanish; Deduplication: by DOI and, in its absence, by normalized title; Exclusions by content: (i) purely theoretical studies without empirical application of location variables; (ii) review articles; (iii) missing/incomplete methodologies; (iv) remaining duplicates; (v) languages outside the accepted trio; (vi) exclusively rural scope. Using these criteria, 62 studies were kept for automatic analysis. To ensure full-text availability, an active search was conducted on the CAPES/CAFe Journal Portal. Seven articles could not be obtained, consolidating 55 complete publications.

3.4 Data Extraction and Processing

Extraction focused on the data, methodology, results, and discussion sections, ensuring that only variables that were actually used were counted. The PLN pipeline included: (i) TF-IDF for initial term extraction; (ii) semantic normalization with multilingual Word2Vec/BERT (cosine similarity ≥ 0.7); (iii) K-means clustering (k = 7), with intracluster consistency ≥ 0.80. The classification was refined by thematic lexicon rules and scoring, aiming for a minimum accuracy of 80%, followed by manual review of ambiguous cases.

3.5 Categories of Locational Variables

Based on the pipeline and the review, the variables were organized into seven categories: Geographic Coordinates (absolute location x,y); Spatial Units (Zone/District): categorical indicators, dummies, and submarkets; Central Accessibility: distance to CBD/center; Public Transportation: accessibility to stations/stops; Urban Services and Amenities: schools, healthcare, commerce, leisure; Environmental Characteristics: views, topography, environmental quality; Socioeconomic Context of the Neighborhood: income, crime, density.

3.6 Validation and Quality Control

Following the automated classification, a manual verification was performed to check the correspondence between each extracted variable and its actual use in the original study. In cases of disagreement, human judgment prevailed, ensuring methodological rigor and semantic consistency of the groupings.

4. RESULTS AND DISCUSSION

4.1 Most Frequent Specific Variables

The systematic review used 55 studies published between 2015 and 2025 that incorporated location/locational variables into mass property valuation models. Altogether, more than 120 distinct location/locational variables were identified and standardized. Chart 1 shows the 15 location variables that appeared most frequently:
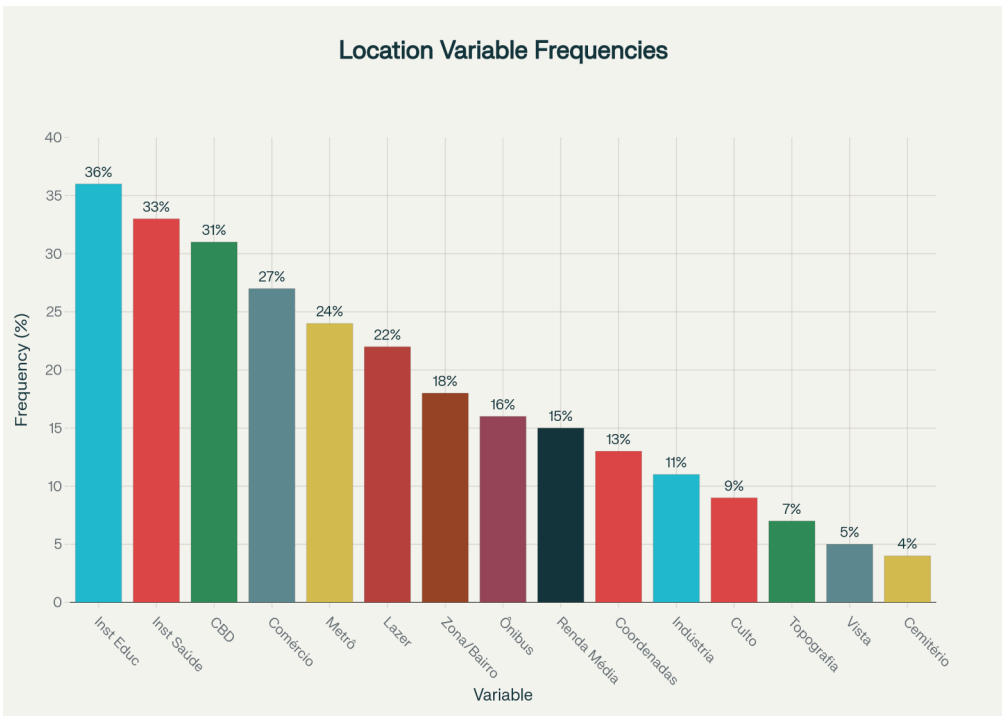

Figure 1. Most frequent location variables in literature

Among the most recurring variables are: proximity to schools (36% of papers), hospitals (33%), shopping centers (27%), downtown (31%), and public transportation (subway/train stations in 24% and bus stops in 16%).
Although less frequently, environmental variables (such as topography, environmental quality, and the presence of green areas) and socioeconomic variables (such as average neighborhood income and crime rates) proved to be decisive in specific contexts, reinforcing the importance of adapting assessment models to local conditions.

4.2 Categories of Variables in the Literature

The variables identified in the literature were grouped into seven main categories, according to the matrix defined in the methodological section.
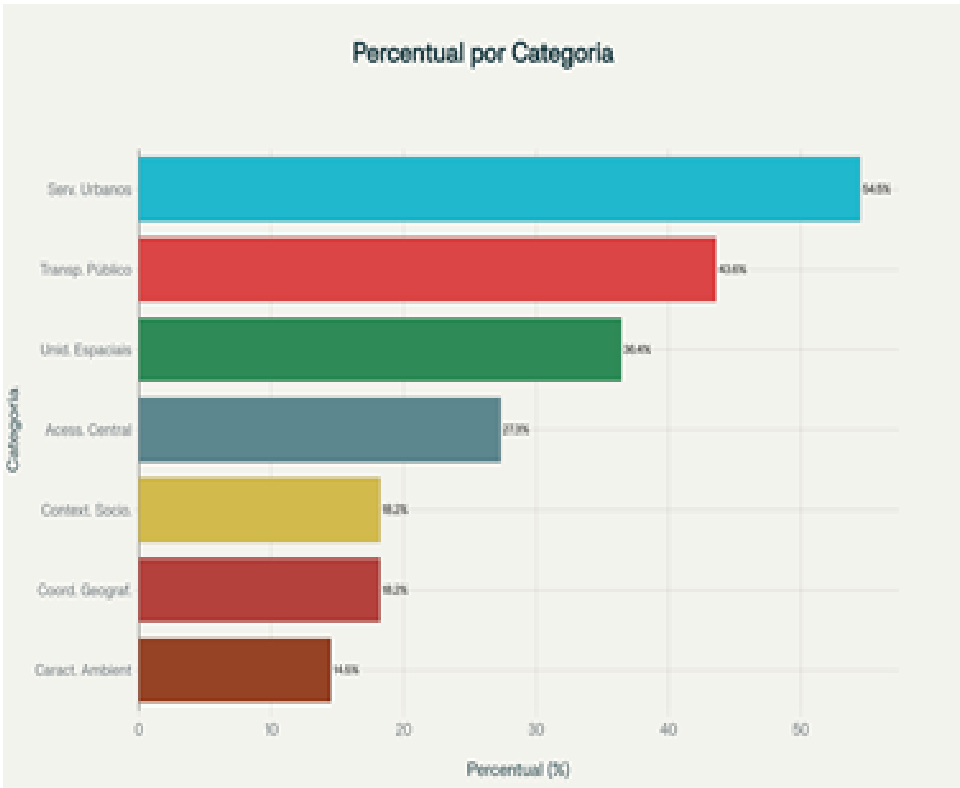

Figure 2. Frequency of location variable categories in literature

The results presented in graph 2 demonstrate that the most frequent categories of location/locational variables were Urban Services and Amenities, featured in 54.5% of papers, and Public Transport, 43.6%. Followed by Spatial Units (Zone/District), 36.4%, and Central Accessibility, 27.3%. Geographic Coordinates and Socioeconomic Context of the Neighbourhood were mentioned in 18.2% of the studies, while Environmental Characteristics had the lowest incidence, accounting for 14.5%.

These studies demonstrate that factors directly linked to the availability of urban infrastructure, access to services, and public transport modes are relevant factors when it comes to the formation of property values in urban contexts.

4.3 Relevance of Location in Valuation Models

As for the analysis of linguistic patterns in the articles, regarding the relevance of location variables, it revealed that, in 64% of the studies, location was classified as a highly relevant factor in explaining property values. For 27%, it was considered to be of medium relevance, and in just 9% of cases, it was considered to be of low relevance, especially in studies with a more restricted focus on structural variables (such as built area or building type).
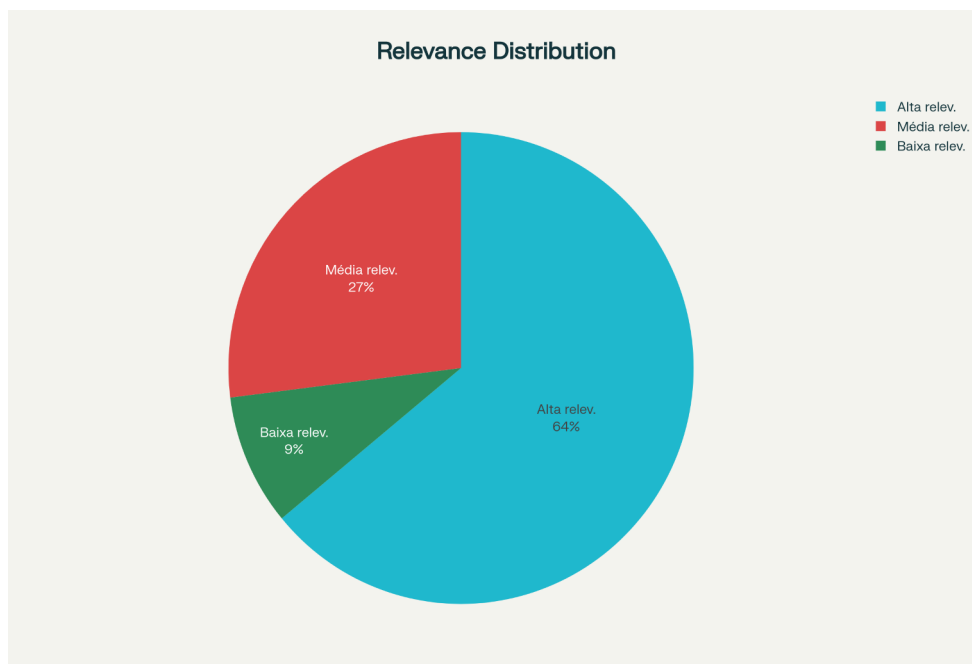
Figure 3. Relevance of the location variable in studies

Highlighting the central role of location in explaining the property market, and that the relevance of this variable can vary depending on the urban and methodological context analysed.

4.4 Integrating Variables into LADM Valuation

The empirical systematization of location/locational variables organized by classes in LADM Valuation reveals that it is possible to align semantic understandings with an internationally accepted conceptual model, expanding the possibilities for integration between public records and valuation practices.

While LADM Core predominantly represents legal and geometric aspects, the Valuation Package of ISO 19152-4 broadens the scope by formally including evaluative dimensions, such as VM_SpatialUnit, VM_ValUnitGrp, and VM_ValGrp+Sale (KARA et al., 2021; LEMMEN et al., 2019).

Based on the analysis of the seven categories of location/locational variables and the structure of ISO 19152-4 (LADM Valuation Information), with support from the studies of KARA et al. (2021) and LEMMEN et al. (2019), each category was classified into the respective categories.

It is noted that, while LADM Core majorly allocates these variables in the Spatial Unit package, LADM Valuation distributes them in different classes of the Valuation Package, such as VM_SpatialUnit, VM_ValUnitGrp, VM_Spatial+Val, VM_Spatial+Bld, and VM_ValGrp+Sale.

Such organization allows the variables used in real estate appraisal models to be structured according to formal semantics, supporting interoperability between geographic information systems, multipurpose terrestrial cadastre, and real estate taxation systems.

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Table 1. Relacionamento categoria das variáveis com classes LADM_Valuation

Category	Review examples	LADM_VM Correspondent Class	Validation
Urban Services and Amenities	Venerandi 2019; Jafary 2024;	VM_SpatialUnit and VM_ValuationUnitGroup	Distances to points of interest (schools, healthcare, commerce) modelled in VM_SpatialUnit as spatial relationship attributes; grouping in VM_ValuationUnitGroup by service provision zones.
Public Transportation	Awonaike 2022; Chanasit 2021;	VM_SpatialUnit and VM_ValuationUnitGroup	Proximity/access to stations/lines are stored in VM_SpatialUnit; accessibility zones are configured in VM_ValuationUnitGroup.
Special Units (Zone/District)	Schmitz 2024; Ali 2020;	VM_ValuationUnitGroup	The definition of administrative or market zones directly uses instances of VM_ValuationUnitGroup.
Central Business District (CBD)	Usman 2021; Chanasit 2021;	VM_SpatialUnit	Distance to the Central Business District (CBD) stored as an attribute of VM_SpatialUnit.
Socioeconomic Context Neighbourhood	Yasnitsky 2021; Osland 2016;	VM_ValuationUnitGroup	Grouping by socioeconomic characteristics is supported through instances of VM_ValuationUnitGroup, linked to external data.
Geographical coordinates (lat/long)	Melanda 2016; Ozhegov 2022;	VM_SpatialUnit	Geometry (point) of each unit registered in VM_SpatialUnit.
Environmental Characteristics	Mete 2023; Del Giudice 2017	VM_SpatialUnit and VM_ValuationUnitGroup	Basic environmental attributes (topography, land use) in VM_SpatialUnit; grouping by environmental zones in VM_ValuationUnitGroup.

5. CONCLUSION

The results of this research show that, in the analyzed literature, location variables occupy a central position in real estate valuation models, being often associated with urban infrastructure, access to services, and modes of transportation. This predominance confirms that location is a structuring element in property price formation, reinforcing the need for its conceptual systematization within international standards such as LADM. The analysis allowed these variables to be combined into seven main categories: geographic coordinates, spatial units (zone/district), central accessibility, public transportation, urban services and amenities, environmental characteristics, and socioeconomic context of the vicinity.

The proposed classification not only organizes the most recurrent categories identified in the systematic review, but also provides relevant input for public managers on the importance of these factors in explaining the spatial heterogeneity of the real estate market. Furthermore, by integrating these variables into the LADM Valuation Package (ISO 19152-4), the study contributes to strengthening cadastral and valuation interoperability, thereby increasing international comparability. The conceptual mapping highlighted that, while the LADM Valuation Package expands its representation in specific classes relevant to mass real estate valuation processes, such as those classified for the variable categories VM_SpatialUnit and VM_ValuationUnitGroup, it demonstrates the model's potential to provide semantic robustness and practical applicability.

From a practical perspective, the evidence supports the idea that adopting a standardized conceptual framework favours the integration of terrestrial cadastres, property records, and tax systems, contributing to greater transparency, comparability, and effectiveness in valuation processes. Such alignment strengthens public policies on taxation, urban planning, and sustainable land management.

Despite these contributions, some limitations must be acknowledged. The corpus selection process involved manual and automatized steps, which, although ensuring methodological rigor, may result in different outcomes when faced with new databases and constantly changing urban dynamics.

In synthesis, this study offers an initial step toward standardizing location variables and their integration into LADM Valuation through a structured and innovative classification. Future work should expand the analysis to 3D and 4D contexts, as well as to test its practical application in Brazil, in order to validate the effectiveness of the classification in mass appraisals, tax systems, and urban planning strategies.

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Camila da Silva has a degree in History from the University Centre of Brusque – UNIFEBE, a postgraduate degree in Tax Management and Legislation from UNINTER and is currently studying for a master's degree in Transport Engineering and Territorial Management at the Federal University of Santa Catarina. A municipal public employee in Brusque for 15 years, she currently acts as Head of the Geoprocessing Sector – GeoBrusque, responsible for the implementation and management of the Multipurpose Territorial Cadastre and the Real Estate Market Observatory of the municipality. Her research focuses on mass property valuation, location variables, and conceptual modelling of territorial data.

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3-5 November 2025, Florianópolis, Santa Catarina, Brazil

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