Towards a Portugal's LADM-VM country profile: Conceptual integration of 3D variables and Deep Learning for rural property valuation

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Key words: Land Administration Domain Model, LADM Valuation Information Model, rural property valuation, rural property taxation, deep learning.

SUMMARY

In the context of Land Administration Systems (LAS) and with the aim of international standardization, the Land Administration Domain Model (LADM) was introduced in 2012. LADM emphasizes the importance of registering information about both public and private properties, encompassing not only surface-level aspects but also subsurface and above-surface components (3D aspects), while linking legal dimensions of ownership. To incorporate the property valuation component, the LADM Valuation Information Model (LADM-VM) was recently published (July 2025) as Part IV of the second edition of LADM. Although Portugal has not yet implemented a comprehensive 2D cadastre covering its entire territory, it has made continuous efforts to register rural properties. A significant milestone was reached in 2017 with the establishment of the *Balcão Único do Prédio* (BUPi), a simplified 2D cadastral system for rural land. However, this system was not designed to support real estate valuation, even for fiscal purposes, which in Portugal still relies on the tax asset value (Valor Patrimonial Tributário – VPT). The VPT faces notable limitations, particularly due to the consistently low taxation of rural land. In recent years, several research groups have proposed models to revise how property tax is determined. However, these approaches have not incorporated LADM-VM, nor have they considered the integration of volumetric and 3D spatial data, elements that could substantially enhance the robustness and accuracy of property valuations. This study proposes the initial development of a Portugal's country profile based on LADM-VM, aiming to modernize cadastral systems and rural property valuation practices for fiscal purposes. The proposed valuation approach relies on the productive potential of the land as the basis for determining a revised VPT, ultimately contributing to more equitable and efficient land administration policies. The strategy seeks to integrate cadastral information, 3D spatial variables, and key property attributes. This approach is grounded in LADM-VM and leverages Deep Learning architectures, such as Convolutional Neural Networks for processing image data, alongside Multilayer Perceptrons for handling alphanumeric data. The methodology adopted in this study follows the three-phase framework proposed by Kalogianni et al. (2021), consisting of scope definition, profile creation, and testing. In addition, a review of relevant literature was conducted to support the methodological approach. Building on the results of this initial investigation, the first phase has established the foundation for developing the Portuguese Country Profile. The next steps include designing the UML diagram by combining standard LADM classes with newly proposed extensions.

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1. INTRODUCTION

Over the past two decades, Land Administration Systems (LAS) have evolved significantly, expanding from two-dimensional (2D) representations to include three-dimensional (3D) perspectives. To support international standardization, the Land Administration Domain Model (LADM) was published in 2012 as ISO 19152:2012 (ISO 19152:2012, 2012). Its second edition, released in July 2025, introduced Part IV – the Valuation Information Model (LADM-VM), which offers a flexible framework for integrating valuation approaches. Although not a computational implementation, LADM-VM, through classes such as VM_MassAppraisal, provides support for integrating mathematical models, including Artificial Neural Networks (ANN) and other mass appraisal methods (Buuveibaatar et al., 2023).
While international advances in land administration and valuation models are significant, the Portuguese cadastral development still faces challenges. A complete 2D cadastre has not been achieved, despite continuous efforts to register rural properties. The creation of the *Balcão Único do Prédio* (BUPi) in 2017 marked important progress, but as a simplified 2D system, it does not support property valuation. Fiscal assessments continue to rely on the *Valor Patrimonial Tributário* (VPT), a metric that remains limited and often results in the consistent under-taxation of rural land.
At the same time, international experience demonstrates promising directions. Several countries have already developed LADM-based country profiles (Kalogianni et al., 2021), and a growing body of research has applied Machine Learning (ML) and Deep Learning (DL) techniques to property valuation (Gao et al., 2022; Lin et al., 2021; Mimis et al., 2013; Soltani et al., 2022). Nonetheless, there is still a noticeable gap in literature: very few studies address the integration of the LADM-VM framework with DL approaches to create models that simultaneously serve cadastral management and property valuation. In Portugal, this gap is particularly relevant, as the country faces two unresolved challenges: the absence of full 2D cadastral coverage for rural properties and the continued reliance on an outdated VPT calculation method (Beires et al., 2013; DG-Reform, 2024; GTPR, 2022).
To address this gap, we propose an approach that applies DL techniques within the structure of LADM-VM. The goal is to modernize VPT calculation for rural properties while contributing to the development of a Portuguese LADM-VM country profile aligned with international standards. In addition to the conceptual contribution presented here, future work will focus on the implementation of the proposal through the development of the database structure and the creation of a Web3DGIS-based visualisation prototype.
This paper is structured as follows: Section 2 reviews related studies; Section 3 describes the adopted methodology; Section 4 outlines the current VPT calculation and alternative proposals; Section 5 discusses the application of DL techniques and defines model variables; Section 6 presents our initial contribution to Portugal's LADM-VM country profile, including the

analysis of the LAS, its mapping classes and, the potential link with DL; finally, Section 7 concludes with main findings and future work.

2. LITERATURE REVIEW

In this literature review, we highlight the fundamental concepts and relevant studies that support the two central pillars of our research: the LADM-VM (Section 2.1) and the application of DL techniques in real estate valuation (Section 2.2).

2.1 The LADM-Valuation Information Model

The LADM is a conceptual model that can be used to define data models related to Land Administration (LA) using a standardized global vocabulary (Tomić et al., 2021). It provides a shared ontology, defining a common terminology for LA (Lemmen, 2019). It establishes a model that encompasses key components related to LA and cadastral information regarding rights, responsibilities, and restrictions (RRR), which affect land cover, including coverage of water resources and elements located below or above the surface, as well as spatial components (Buuveibaatar et al., 2023; ISO 19152:2012, 2012; Lemmen et al., 2015).
The standard is an abstract and conceptual model with three packages related to: parties (people and organizations); basic administrative units, rights, responsibilities, and restrictions (property rights); spatial units (parcels and the legal space of buildings and utility networks) with a sub-package for surveying and spatial representation (geometry and topology) (ISO 19152:2012, 2012; Lemmen et al., 2015).
The recent update, LADM II (Parts I–V, 2024–2025), includes the Valuation Information Model (LADM-VM), designed to facilitate property valuation, transaction analysis, mass appraisal, and sales statistics (Çağdaş et al., 2016; Kara, Çağdaş, Işıkdağ, et al., 2018; Kara et al., 2019, 2021 OGC, 2019). LADM-VM enables integration of valuation databases with LAS, supporting both information systems and data exchange (OGC, 2019; Kara et al., 2021). Studies have addressed LADM-VM in contexts such as national dataset integration (Buuveibaatar et al., 2023), registration–taxation system linkage (Xu et al., 2019), conceptual extensions (Buuveibaatar et al., 2023; Kara, Çağdaş, Işıkdağ, et al., 2018; Xu et al., 2019), valuation workflows applied to tourist taxation (Radulović et al., 2023), and prototype implementations (Kara et al., 2020, 2021; Tomić et al., 2021). However, none have applied LADM-VM directly with DL techniques for rural property valuation.
Below, Figure 1, we present some of the core classes to be incorporated into our model, as discussed by Çağdaş et al. (2016) and Kara et al. (2018, 2021). VM_ValuationUnit represents the basic valuation unit, associated with LA_BAUnit, corresponding to land, buildings, or combinations (e.g., condominiums), with attributes such as identifier, type, neighborhood, and utilities. VM_ValuationUnitGroup allows grouping or zoning of units with similar characteristics or functions. VM_SpatialUnit represents land parcels as the subject of valuation, including current and planned uses, aligned with INSPIRE standards. VM_Valuation records valuation outputs, linking units and responsible parties. VM_MassAppraisal specializes VM_Valuation to incorporate mass appraisal contexts, describing models, sample sizes, and methods including regression, time series, clustering, and ANN. This last class is where our

study incorporates DL architectures to estimate VPT values, which are then extended to VM_Valuation.

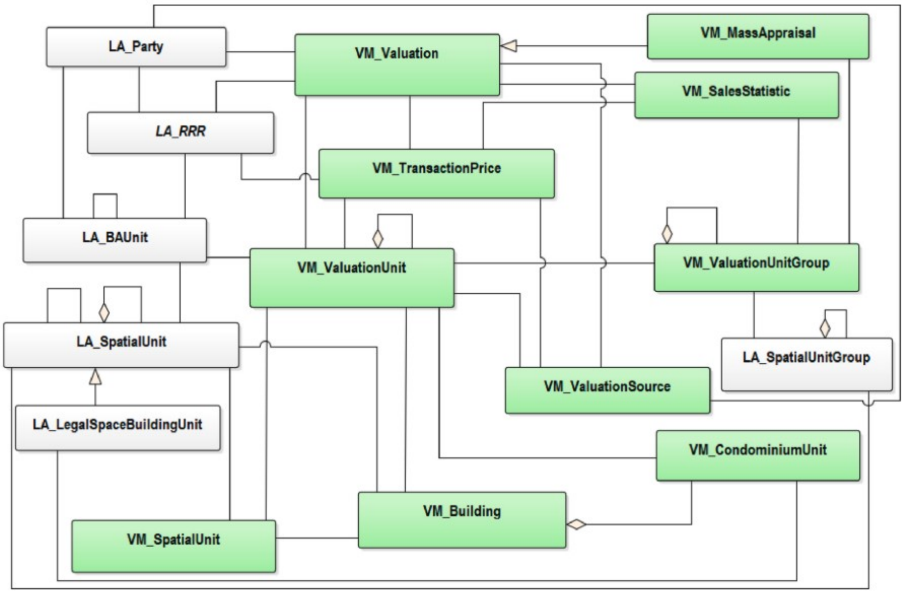

Figure 1. The main classes of the LADM Valuation Information Model (green) and LADM classes (grey). Adapted from Kara et al, 2021.

2.2 Deep Learning architectures

Considering our intention, test both Deep Learning (DL) architectures, Multilayer Perceptron (MLP) and Convolutional Neural Networks (CNN), it is important to understand what they are and how they can be applied to our case study. In this context, the MLP is a classical feedforward ANN composed of an input layer, one or more hidden layers, and an output layer. As a type of ANN, it can be classified as a DL model when structured with multiple hidden layers. Each neuron in one layer is fully connected to all neurons in the subsequent layer, and the model learns by adjusting synaptic weights through backpropagation (Goodfellow et al., 2016). MLP can represent highly non-linear functions and are effective for supervised learning tasks involving structured data (Goodfellow et al., 2016). This architecture is particularly suitable for processing structured alphanumeric data, such as statistical property attributes.

In contrast, CNN are DL models designed to process data with a grid-like topology, such as images or raster datasets. Rather than fully connected layers, CNN employ convolutional layers that apply filters across the input to automatically extract relevant spatial patterns. LeCun et al. (2015) note that "convolutional networks are designed to process data that comes in the form of multiple arrays, such as colour images composed of three 2D arrays containing pixel intensities in the three colour channels" (LeCun et al., 2015). This makes CNN particularly well-suited for analysing geospatial raster data, such as digital elevation models, land cover maps, or satellite imagery, enabling the model to capture complex spatial relationships that may influence land productivity.

Although it remains uncertain whether CNNs will significantly contribute to our approach, their inclusion is supported by recommendations found in recent studies on property valuation.

Mohit Jain & Arjun Srihari, (2023) investigated the applicability of CNN for predicting real estate prices by integrating both visual and non-visual elements. Their proposed model incorporated architectural aspects such as design, quality, and neighbourhood aesthetics, and demonstrated greater explanatory power compared to traditional ML models (Mohit Jain & Arjun Srihari, 2023). The results showed that CNN-based models outperformed baseline approaches, such as linear regression, gradient boosting, and random forest regression, in capturing the subtle interconnections between visual attractiveness and property values (Mohit Jain & Arjun Srihari, 2023).

Furthermore, as noted in Jafary et al., (2024), recent studies recommend the use of DL techniques, particularly CNN, to extract valuable features from visual data that could improve the accuracy of land valuation models. This perspective aligns with our objective to explore how spatial patterns extracted via CNN might enhance the predictive performance of the proposed valuation framework.

Although the models proposed by Jain and Srihari (2023) and Poursaeed et al., (2018) were developed for urban real estate contexts, we regard their findings as a validation of CNN applicability to property valuation tasks. With the necessary adaptations, we aim to test the use of CNN to predict the value of rural properties for fiscal purposes. Building on these insights, our approach explores how spatial patterns derived from CNN may contribute to more accurate and robust estimations within the rural land valuation framework.

3. METHODOLOGY

The development of the Portuguese LADM-VM country profile followed the three-phase framework proposed by Kalogianni et al. (2021), which comprises definition of scope, profile creation, and testing. The first phase, definition of scope, has been completed and is discussed in this work. In the second phase, we advanced to the initial stage of profile creation, involving mapping the current LAS with the corresponding LADM classes. Additionally, a review of relevant literature on LADM-VM was conducted (Buuveibaatar et al., 2023; Kara et al., 2018, 2020, 2021; Radulović et al., 2023; Tomić et al., 2021).

Beyond the framework suggested by Kalogianni et al. (2021), our methodological approach was organized into sequential phases, distinguishing between the development of the LADM-VM country profile and the applied DL component:

LADM-VM methodology:

1. Problem Identification – The research problem, described in Section 1, is the absence of a cadastral and property valuation system for rural land based on LADM-VM. To address this, we analysed the current situation in Portugal and conducted expert interviews in the field of territorial management.
2. Literature Review – A systematic review was performed to identify scientific studies developing models based on LADM-VM and research applying DL techniques to property valuation. Keywords included "LADM", "LADM Valuation Information Model", "property taxation", "property valuation", and "deep learning". Searches were conducted in Scopus and Web of Science and restricted to English-language publications.

3. Analysis of Current Taxation Practices – This phase focused on examining how rural property tax is currently calculated in Portugal and reviewing proposals from other research groups for potential improvements or reforms.
4. Identification of Stakeholders – Key stakeholders involved in land administration and property valuation were identified to ensure that the country profile aligns with national practices and user requirements.
5. Mapping LAS Classes with LADM-VM Classes – The existing LAS classes were mapped to the corresponding LADM-VM classes, forming the foundation for the country profile.

Deep Learning methodology:

6. Identification of Variables – Based on the theoretical framework, key variables that could influence rural property values, particularly those related to agricultural and forestry productivity, were identified (Beires et al., 2013; DG-Reform, 2024; GTPR, 2023; Xu et al., 2019). At this stage, 3D spatial variables were also incorporated to potentially improve predictive accuracy.
7. Selection of DL Architectures – The most appropriate DL architectures were selected according to the dependent and independent variables. Considering the geospatial and alphanumeric nature of the data, experiments will be conducted using CNN and MLP models.

Finally, we sought to connect LADM-VM with DL. Through a flowchart (Annex A), we present the main data sources, data, and their relationships with LADM, as well as their role as inputs to the DL model.

4. OVERVIEW OF RURAL PROPERTY TAXATION IN PORTUGAL

In Portugal, rural and urban property taxation is based on the Municipal Property Tax (*Códigos do Imposto Municipal sobre Imóveis* – CIMI), using the tax asset value (VPT) defined by Decree-Law No. 287/2003 (Decreto-Lei nº 287, 2003). For rural properties, VPT is calculated from land income, determined as the balance of annual agricultural or forestry production, without considering market value, as follows:

$$\textbf{VPT} = \text{Land Income} \times 20 \text{ (rounded up to the nearest ten euros)}$$

The Municipal Property Tax (IMI) is then applied at 0.8% of VPT. This approach results in low VPT and IMI revenues, favoring absentee landowners and speculators (Beires et al., 2013; GTPR, 2022).

To address these limitations, the Working Group for Rural Property (GTPR) was established in 2021 (Order 7722/2021) to propose solutions for rural land management and consolidation (GTPR, 2022; Despacho nº 7722, 2021). Key issues identified include discrepancies between property records in the Portuguese Tax and Customs Authority (*Autoridade Tributária e Aduaneira* – AT) and the Institute of Registries and Notary (*Instituto de Registo e Notariado* – IRN), lack of cadastral registration and geometric information, and VPT values significantly below market prices (GTPR, 2022). GTPR proposed revising VPT to reflect productive potential, considering ecological value, planning instruments, easements, and land-use policies:

$$\mathbf{VPT} = \mathrm{BEV} + \mathrm{MJV} - \mathrm{MNV} + \mathrm{ACV}$$

where BEV represents ecological value based on land productivity, MJV and MNV are majorants and minorants from planning instruments, and ACV are adjustment values from national land-use policies.

In 2024, the Directorate-General for Structural Reform Support (DG Reform) of the European Commission Reform provided technical assistance to AT to develop a model aligning VPT with market values (DG-Reform, 2024). They argue that while it may be efficient for urban property taxation, it is not suitable for rural land. As noted by DG-Reform (2024), "The land tax on rural properties accounts for only 0.5% (€8 million per year) of the total land tax revenue in Portugal, a figure significantly lower than in comparable jurisdictions".

They proposed the Land Base Value (LBV) that estimated using: agricultural profitability, based on parish-level Standard Production Value provided by the National Institute of Statistics (*Instituto Nacional de Estatística* – INE), agricultural production data from the Agricultural Accounting Information Network (*Rede de Informação de Contabilidades Agrícolas* – RICA), and land cover maps from the National Mapping and Cadastral Agency (*Direção-Geral do Território* – DGT) and; forestry profitability, calculated using wood production potential, market quotations from the Simplified Market Quotations for Forest Products System (SIMeF), operational costs from the Directorate-General for Agriculture and Rural Development (*Direção-Geral de Agricultura e Desenvolvimento Rural* – DGADR), forest management data from the Institute for Nature Conservation and Forests (*Instituto da Conservação da Natureza e das Florestas* – ICNF), and forest fire history. Independent variables were subsequently evaluated to identify the most significant factors for predicting profitability and estimating LBV (DG-Reform, 2024).

Although these initiatives improve valuation accuracy, they do not incorporate the LADM-VM, employ DL techniques, or leverage 3D spatial data to enhance predictive precision. To fill this gap, this study proposes a DL-based approach grounded in LADM-VM, integrating spatial and alphanumeric data to provide a more precise, scalable, and policy-aligned model for rural property valuation.

5. Deep Learning-Based model for tax asset value estimation

Our proposal considers the use of DL for estimating the VPT, rather than traditional ML techniques such as linear regression or decision tree. This choice reflects our intention to explore the capabilities of DL to identify patterns and behaviours through iterative testing and validation. Specifically, we aim to assess the model's performance when incorporating various types of data, including 3D geospatial data, raster and vector geospatial information, and alphanumeric attributes.

Therefore, we will consider the framework already developed by DG Reform regarding the definition of the dependent variable (agricultural and/or forestry profitability). As for the independent variables, we will consider suggestions from previous studies, particularly those related to agricultural and/or forestry productivity (Beires et al., 2013; DG-Reform, 2024; GTPR, 2023; Xu et al., 2019), alongside our own initial considerations and proposals, such as 3D variables. These will serve as inputs to the DL model, as outlined in Table 1. However, we emphasize that this set of variables is not definitive; it remains open to the inclusion or exclusion of new variables as we progress through further testing and validation phases.

Initially, we consider that some of the required data will be more readily accessible through open databases. However, certain datasets may not be obtainable due to restricted access or limited public release. In such cases, we propose the use of data synthesis techniques to simulate realistic conditions and demonstrate the model's potential effectiveness even in the absence of real-world data.

To generate many of the variables listed in Table 1, such as the biophysical characteristics of rural properties and 3D variables, we propose ETL (Extract, Transform, and Load) processes using Geographic Information Systems (GIS) tools, automated through libraries in the Python programming language. This forms part of the model's initial geoprocessing phase, which focuses on the analysis and processing of both geospatial and alphanumeric data.

The 3D data will be ETL from the proposed 3D cadastral representation of rural property based on LADM-VM, resulting in the 3D variables to be used as input features for the DL. For this purpose, LiDAR (Light Detection and Ranging) data will be utilized, considering that the DGT is in the process of making such datasets available for the entire Portuguese territory (DGT, 2025). The altimetric information from this survey is currently available as a point cloud with an average density of 10 points/m² in LASzip (LAZ) compressed format, covering approximately 90% of the territory (DGT, 2025). Once processed, these 3D datasets may provide insights into how topographic and volumetric features influence the productive potential of rural land. Additionally, it is possible to explore complementary spatial indicators such as visibility analysis and noise propagation (Kara et al., 2020), which can be integrated into the model. Although not directly related to agricultural or forestry yield, these factors may influence land usability and perceived value, particularly in rural development scenarios involving rural tourism, ecotourism, conservation, or multifunctional land use.

To handle the heterogeneous nature of the input data, we propose hybrid DL architecture. A MLP will be employed to process structured inputs, including alphanumeric attributes and extracted geostatistical indicators. In parallel, a CNN will be applied to raster-based inputs.

Besides conventional layers such as digital elevation models, solar exposure maps, and land cover data, the 3D point clouds after transformed in 3D variables will be converted into raster representations. This conversion allows the CNN to capture spatial patterns and textures that may influence rural land productivity. To achieve this, we plan to use Python libraries such as *laspy* (for reading LAZ files), *open3D* (for point cloud manipulation and rendering), and *NumPy* (for grid-based conversion and rasterization). Finally, the outputs of both network branches will be concatenated and passed through fully connected layers to produce a continuous output: the estimated VPT.

The model will be trained as a supervised regression problem, using profitability values, derived from DG Reform's methodology, as ground truth. To ensure generalizability and prevent overfitting, the model will incorporate regularization strategies, such as dropout, batch normalization, and early stopping. Performance will be evaluated using standard regression metrics, including Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and coefficient of determination (R^2).

In summary, the proposed DL architectures a modern, flexible, and spatially sensitive approach to rural property valuation. By integrating multidimensional data and advanced computational techniques, it offers the potential to enhance both the accuracy and transparency of VPT estimation in Portugal.

Table 1. Proposed variables to use and test as input in the DL model.

Group variable	Sub-group variable	Variable
3D Variables	Volumetric	Volume Property
	Solar and energetic estimation	Solar potential estimation
		Shadow estimation
		Energy demand
	Hydrological estimation	Water volume demand
		Water potential estimation
	Spatial impact assessment	Visibility analysis
		Noise propagation
	Morphometry	Elevation
		Slope Angle, Aspect and Position
		Terrain Ruggedness Index
		Proxy of radiation exposure
Biophysical Characteristics	Pedology	Ph
		Soil: texture, fertility, salinity, erosion, thickness
	Bioclimatic indicators	Ombrothermic index
		Thermicity indexes
Restrictions and public utility easements	Natural resources	Water resources
		Geological resources
		Agricultural and forestry resources
		Ecological resources
	Built heritage	Classified buildings
	Equipment	National Defense
	Hazardous activities	Establishments/industries with explosive products
		Establishments/industries with hazardous substances
	Infrastructure	Water supply
		Wastewater drainage
		Electric grid
		Gas and oil pipelines
		National/regional road network
		Municipal roads and paths
		Railway network
		Airports and airfields
		Telecommunications
		Lighthouses and maritime signals
		Geodetic markers
Risks	Natural hazard exposure	Rural fires
		Floods
		Landslides
	Climate degradation	Droughts
		Desertification
	Environmental sensitivity	Vulnerability and susceptibility maps
	Soil degradation	Compaction risk index
Accessibility	Road network proximity	Distance to the nearest paved road
		Distance to the nearest main road or highway
	Access route conditions	Condition of access roads
		Estimated travel time to the nearest urban centre
	Urban and service proximity	Distance to the nearest town or urban area
		Access to public transportation or rural logistics services
	Agro-logistics integration	Proximity to storage centres, cooperatives
		Proximity to agro-industrial hubs or distribution centres

6. LADM VALUATION INFORMATION MODEL PORTUGUESE COUNTRY PROFILE

Following the methodology proposed by Kalogianni et al. (2021) and outlined in Section 3, this section presents the results of the first phase: the identification of key stakeholders and relevant datasets (Subsection 6.1), and the analysis of the current Portuguese cadastral system with a brief historical context (Subsection 6.2). The second phase begins with the mapping of the LAS to LADM classes (Subsection 6.3) and, finally, Subsection 6.4 addresses the connection between the LADM-VM and DL.

6.1 Stakeholders

In the first phase of this research, the key stakeholders were identified, focusing on institutions that play a central role in data exchange and can provide the information required to ensure system interoperability. Among the identified stakeholders, the IRN plays a central role by ensuring the legal registration of property rights. Complementing this, the AT oversees fiscal data and manages property taxation records. DGT is the national reference for cadastral and cartographic information, providing essential geospatial datasets. At the environmental level, the ICNF contributes data on protected areas and forest resources. Finally, DGADR enriches the system with information on agricultural land use and rural development initiatives.
Table 2 summarizes the main stakeholders and the specific types of data that may be incorporated into the proposed model, supporting interoperability and ensuring the integration of legal, fiscal, cadastral, environmental, and agricultural dimensions.

Table 2. Key Portuguese National institutions.

Institutions	Role	Type of data provided
IRN	Legal registration of property rights	Ownership records, property titles, mortgages, legal transactions.
AT	Fiscal administration and taxation authority	Property taxation records, fiscal identifiers, valuation data.
DGT	National Mapping and Cadastral Agency	Cadastral maps, geospatial data, parcel boundaries, topographic information.
ICNF	Institute for Nature Conservation and Forests	Protected areas, forest inventories, biodiversity constraints.
DGADR	Agricultural and rural development agency	Land use data, agricultural productivity, rural development programs.

Finally, Figure 2 depicts a system context diagram (C4 Model, 2025), which illustrates the interaction between potential system users and the data providers that supply the services. This representation helps to contextualize the ecosystem in which the proposed model operates, highlighting both the stakeholders involved and the flow of information that supports its implementation.

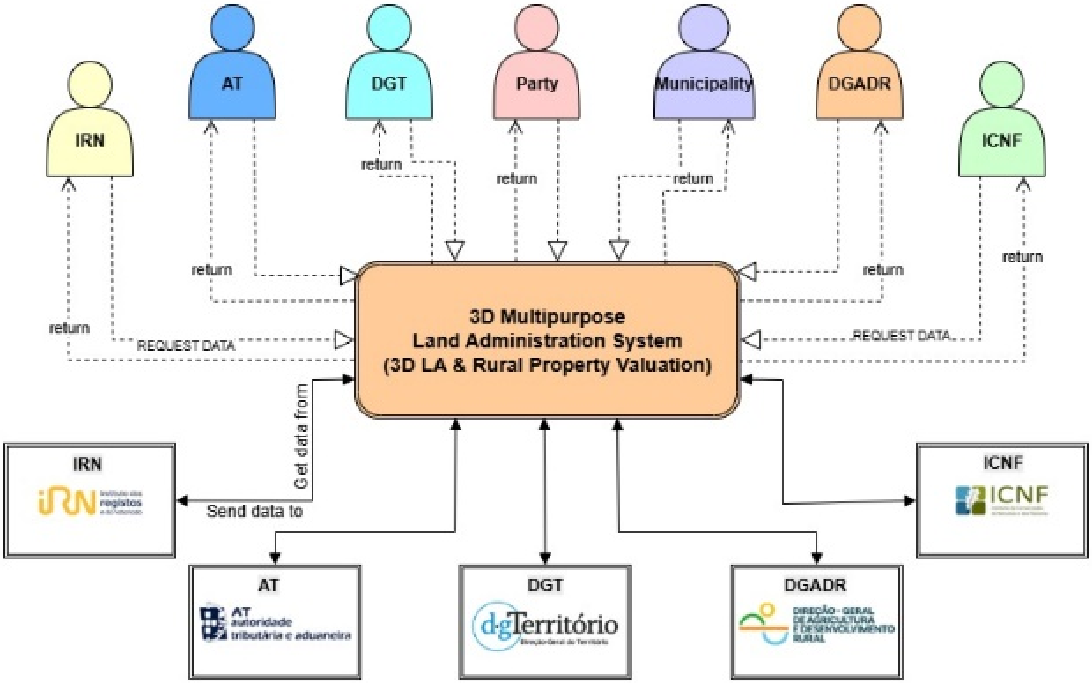

Figure 2. C4 Context diagram with potential system users.

6.2 The Land Administration System in Portugal

As part of the first phase (scope of the model), the current situation of the LAS in Portugal was analysed. Although the country has not yet implemented a comprehensive official 2D cadastre covering its entire territory, continuous efforts have been made over the years to register all rural properties. At present, the cadastral system for rural properties is regulated by the Legal Regime of the Cadastre (*Regime Jurídico do Cadastro Predial* – RJCP), established by Decree-Law No. 72/2023 of August 2023, which came into force nationwide on November 21, 2023 (DGT, 2025).

Historically, two main situations characterized property identification in Portugal. In municipalities predominantly located south of the Tagus River, cadastral operations were based on the Geometric Cadastre of Rural Property (*Cadastro Geométrico da Propriedade Rústica* – CGPR), with cadastral coverage across 118 municipalities in mainland Portugal and 10 municipalities in the Autonomous Regions of the Azores and Madeira (DGT, 2025). Additionally, in some pilot areas, the National System for the Management and Use of Cadastral Information (*Sistema Nacional de Exploração e Gestão de Informação Cadastral* – SiNErGIC) was implemented between 2006 and 2020, covering 7 municipalities in mainland Portugal (DGT, 2025).

Subsequently, other municipalities have adopted the simplified 2D cadastral system for rural properties (*Balcão Único do Prédio* – BUPi), established in 2017. This system allows property owners to declare property rights and provide parcel representations, with the possibility of conversion into full cadastral records if legal requirements are met. Of the 153 municipalities in continental Portugal not covered by CGPR or SiNErGIC, 144 have already adopted the simplified cadastre (BUPi, 2025). With the entry into force of the RJCP, areas previously under the CGPR and SiNErGIC were integrated into the new cadastral regime, while remaining part of the national cadastral map, as illustrated in Figure 3.

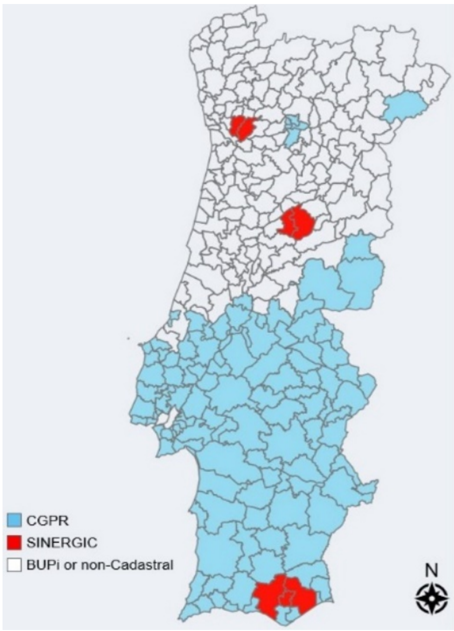

Figure 3: Cadastral operations in Mainland Portugal.

Finally, rural property valuation systems in Portugal were also analysed and discussed in Section 4, providing a clearer understanding of the existing gaps that the proposed model seeks to address.

6.3 Mapping classes

Following the analysis of the current situation in Portugal, the second phase of the proposed methodology initiates the modelling process by mapping key concepts of the LAS to the corresponding classes of the LADM. Since there is no access to the data model of the new cadastral system, and only to that of the last version implemented by SiNErGIC on an experimental basis and considering that Hespanha (2012) has already carried out this mapping, particularly for the administrative package, it is not necessary to repeat the process here. The data model of the simplified system (BUPi) is likewise not considered for mapping classes in this work, as it is a simplified system with limited geometric accuracy.

With respect to property valuation, we rely on some of the core classes of the LADM-VM, while leaving open the possibility of creating extensions to further adapt and refine the Portuguese country profile. In this proposed model, the prefix 'PT' is used to denote classes belonging to the Portuguese country profile, this prefix is in accordance with ISO 3166 (2015).

Table 3 presents a selection of LADM classes, some are already represented in the SiNErGIC (IGP, 2009), while others are not explicitly present but are nevertheless considered relevant to our proposal. While both the official cadastral model and Hespanha's (2012) proposal (has used LA_BoundaryFaceString LADM class) are grounded in a 2D representation, our approach seeks to extend this profile into a 3D Cadastre. In this context, we introduce the LA_BoundaryFace class, thereby extending the profile toward 3D Land Administration. This transition is supported by point cloud data provided by the DGT, which enables a more detailed and accurate representation of cadastral objects. This data source will be identified by the LA_SpatialSource class.

From LADM-VM, we will adopt relevant classes to support property valuation that are not present in national cadastral model, such as VM_Valuation, VM_TransactionPrice, VM_ValuationUnit, VM_ValuationUnitGroup, VM_MassAppraisal, VM_SpatialUnit, and VM_ValuationSource. Some classes, such as VM_Valuation, are implemented by AT using VPT, as explained in Section 4. However, our approach ensures consistency by integrating the core LADM-VM classes.

It should be emphasized that the goal is to incorporate as many classes as possible from both LADM and LADM-VM, whether already included in the national model or added to complement it, while ensuring that the Portuguese profile remains less complex, as suggested by (Kalogianni et al., 2021).

Table 3: LADM and LADM-VM classes adopted or extended for the Portuguese cadastral profile.

LADM | LADM-VM	National Cadastral Model	PT_VM	Inherited from
LA_Party	Party (*TipoPessoa)*	PT_LA_Party	LADM
LA_RRR	RRR (*Direitos, Deveres e Responsabilidades*)	PT_LA_RRR	Cadastral National Model
LA_BAUnit	CadastralObject and association to LandRegistryDescription	PT_LA_BAUnit	Hespanha (2012) (proposed)
LA_SpatialUnit	RealProperty (*Prédio*)	PT_LA_SpatialUnit	Hespanha (2012) (we propose to extend to 3D)
LA_Boundary-FaceString (2D)	Boundary (*Estrema*), associated with SurveyedPoint class	Not used in PT_VM	Hespanha (2012) (we propose to extend to 3D)
LA_BoundaryFace (3D)	Not present	PT_LA_BoundaryFace	LADM (new addition)
LA_Point	SurveyedPoint (*Ponto Coordenado*)	PT_LA_Point	Hespanha (2012) (we propose to extend to 3D)
LA_SpatialSource	Not present	PT_LA_SpatialSource	LADM
VM_Valuation	Not present	PT_VM_Valuation	LADM-VM
VM_TransactionPrice	Not present	PT_VM_TransactionPric e	LADM-VM
VM_ValuationUnit	Not present	PT_VM_ValuationUnit	LADM-VM
VM_ValuationUnit-Group	Not present	PT_VM_ValuationUnit-Group	LADM-VM
VM_MassAppraisal	Not present	PT_VM_MassAppraisal	LADM-VM
VM_SpatialUnit	Not present	PT_VM_SpatialUnit	LADM-VM
VM_ValuationSource	Not present	PT_VM_ValuationSource	LADM-VM

6.4 Linking LADM-VM and Deep Learning

The integration of the LADM-VM framework with Deep Learning techniques is primarily facilitated through the VM_MassAppraisal class, which provides the structure for representing mass appraisal-related information. This approach allows the combination of cadastral information, valuation units, and spatial indicators to enhance predictive performance and support decision-making in rural property assessment.

In Annex A, we present the macro-level flowchart that illustrates the overall process and identifies the data sources, the main extracted datasets, and the relationship between LADM and LADM-VM. Point cloud data extracted from the DGT serve as the basis for deriving 3D variables using specialized tools and technologies, such as *laspy* for reading LAZ files and *Open3D* for point cloud processing and visualisation. These variables are subsequently transformed into 2D raster representations, enabling their integration into the CNN for the extraction of spatial patterns and textures relevant to rural property valuation. The workflow also includes preprocessing steps to identify potential 3D variables and highlights the parallel processing of tabular datasets, which are fed into the MLP. Once processed, both data streams are concatenated, resulting in the predictive estimation of the VPT of rural properties. This process is thus linked to the PT_VM_MassAppraisal class and the resulting values are recorded in PT_VM_Valuation.

Figure 4 provides a detailed view of the procedures within the PT_VM_MassAppraisal class and its connections with other LADM-VM (in green) and LADM (in gray) classes. It highlights the type of analysis, represented here by DL techniques, applied for predicting the assessed value of rural properties, which is recorded in PT_VM_MassAppraisalAnalyseType. The PT_LA_Party class identifies the property owner(s) responsible for paying the tax calculated based on the assessed value (predicted VPT), recorded in PT_VM_Valuation. PT_VM_MassAppraisal specifies the number of properties evaluated in the process, initially limited to the parish level, represented in PT_VM_ValuationUnitGroup. PT_VM_ValuationUnit consolidates information on the common characteristics of the valuation objects (Buuveibaatar et al., 2023; Kara, Çağdaş, Van Oosterom, et al., 2018; Kara et al., 2021), while PT_VM_SpatialUnit indicates both the current and future land use and cover.

This integration demonstrates how the LADM-VM conceptual framework can be effectively linked with DL techniques to support rural property valuation. By embedding cadastral, valuation, and spatial data into the workflow, the model establishes a scalable and adaptable foundation for predictive analysis. This connection not only strengthens the theoretical basis of the Portuguese Country Profile but also paves the way for the development of a prototype that combines international standards with advanced artificial intelligence methods.

Building on this approach and following the recommendations of Kalogianni et al. (2021), the second phase of the investigation will continue with the development of UML (Unified Modeling Language) diagrams, beginning with the LA_SpatialUnit LADM class and following the workflow: LA_PointCloudObservation → LA_SurveySource → LA_SpatialSource → LA_Point & LA_BoundaryFace → LA_SpatialUnit → VM_SpatialUnit (Kara et al., 2024). Furthermore, a comprehensive model diagram based on LADM-VM will be produced. Efforts will also focus on refining the mapping LAS with the LADM classes, populating the associated code lists, and conducting the necessary tests in accordance with Annex A of ISO 19152:2012. Additional future work is outlined in the following section.

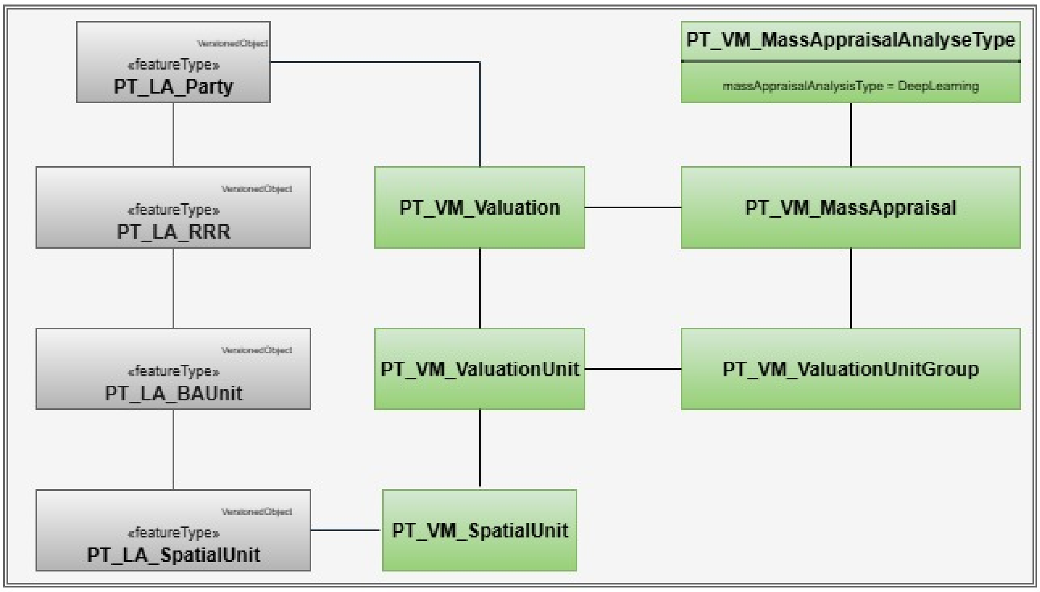

Figure 4: Mass appraisal procedure.

7. CONCLUSION AND FUTURE WORK

During this investigation, we observed that the current simplified cadastral system in Portugal, the BUPi, has made significant progress in registering rural properties by identifying their geometric location (2D) and integrating ownership data from the Portuguese Tax and Customs Authority (AT) and the Institute of Registries and Notary (IRN). While these advances are notable, we highlight the importance of adopting a cadastral system aligned with international standards, such as ISO 19152:2012.

Furthermore, we analysed the current method used to calculate the tax asset value of rural properties, which presently accounts for only 0,5% of the total property tax (rural and urban) collected by the AT (DG-Reform, 2024). We also emphasize the importance of integrating rural cadastral data with property valuation processes for public purposes into a unified model.

In response to these challenges, we proposed the development of a conceptual model that integrates cadastral and valuation data for rural properties, based on the LADM-VM and on the productive potential of the land.

Next steps will involve designing the UML diagram using standard LADM classes alongside newly recommended ones, as well as exploring the use of DL to estimate the VPT.

Future work will consist of experimental stages focused on extracting and transforming geospatial and alphanumeric data from primary sources to train and test our model. We plan to use the Python programming language along with its key libraries for geoprocessing and DL. Additional efforts will be directed toward enhancing the alignment of the LAS with the LADM classes, completing the corresponding code lists, and performing the required validations in compliance with Annex A of ISO 19152:2012. We also plan to perform tests using the DL

techniques PointNet or PointNet++ to work directly with point clouds, in order to evaluate whether processing 3D information can be optimized compared to CNN.
It is important to emphasize that the ultimate goal of our project, beyond completing the conceptual model, is to implement the entire proposal through the development of the database structure and the creation of a prototype for visualisation based on a Web3DGIS system.

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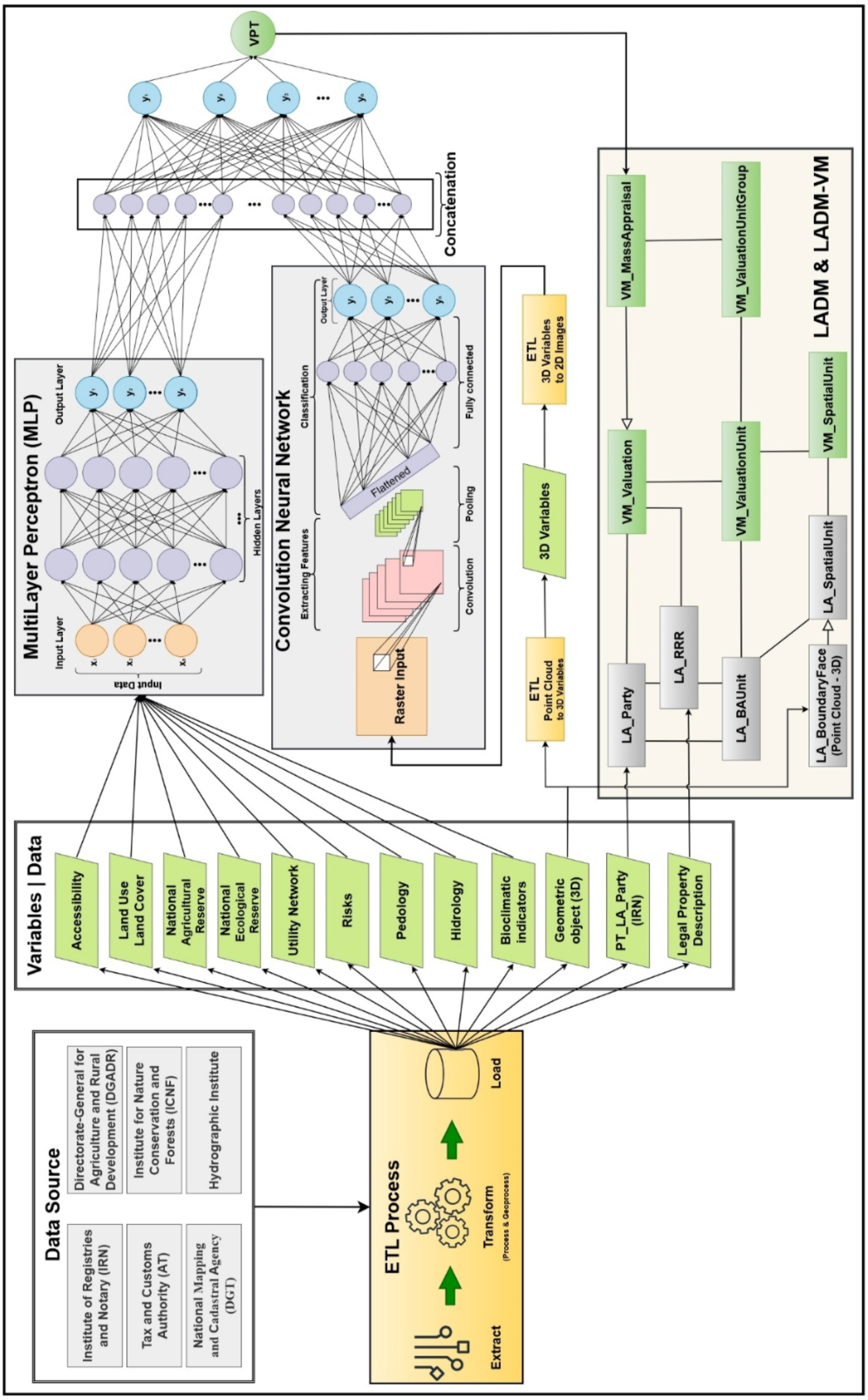
ANNEX A – PROPOSED WORKFLOW LINKING LADM-VM AND DEEP LEARNING



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