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Developing GeoAI Integrated Mass Valuation Model Based on LADM Valuation Information Great Britain Country Profile

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ABSTRACT

Access to information pertaining to land facilitates strategic planning for individuals, businesses, and governmental entities and allows them to anticipate and address contemporary challenges such as climate change, housing requirements, and economic prosperity. Improvements in information technologies contribute to data creation, analysis, and dissemination processes that enable gaining knowledge about land-related events. Greater use of location data within property technologies gives rise to an efficient and sustainable land administration system. GeoAI can contribute greatly to the solution of spatial problems by extracting information from complex data through geospatial intelligence. Property valuation requires a spatially explicit model to evaluate locational factors with spatial analyses. In this study, a Land Administration Domain Model (LADM)-based mass valuation model is developed for Great Britain by integrating GeoAI techniques. First, the LADM Valuation Information package is matched with the country's current organizational structure and it is extended according to the needs to create a country profile. After developing the conceptual model, a database schema is created and automatic conversion to the physical model is conducted. Loading different data sources into the database, a mass valuation application is carried out through spatial analysis and Random Forest regression analysis. As a result, a highly accurate and holistic valuation model is implemented based on the international land administration standards.

1 | Introduction

Geospatial data have diverse usage areas including land use, planning, and housing. Lack of standardization is one of the most challenging aspects of efficient data management (van Oosterom and Lemmen 2015; Lemmen et al. 2018; Adad et al. 2020). Accessing location data in a standardized and machine-readable format can help unlock economic, environmental, and social value in sustainable land administration. To improve the accessibility of spatial data and increase interoperability between organizations, there is a need for a holistic framework that models each stage in a standard way.

The Land Administration Domain Model (LADM) is a standard used for conceptually modeling land-related processes together with underground and above-ground assets. It enables defining relations between parties, administrative units, and their rights, restrictions, and responsibilities (3R). LADM provides integration of different public registries and increases interoperability between organizations. It is vital to create a digital, secure, and resilient Land Administration System (LAS) to solve land-related challenges and to create value through better use of geospatial data. Domain-specific applications such as valuation and taxation can be carried out efficiently based on the LADM since it can be extended according to the needs of countries.

Adoption of the LADM can make a significant contribution to the development of effective land administration. The LADM Valuation Information Model (LADM_VM), which is planned as one of the packages of the LADM version two, provides an extensive property valuation model. With the implementation of the LADM core module and LADM_VM, it will be possible to associate the valuation registries in the basic land administration database with other public institutions' databases such as land registry and cadastre, population, and address.

The first version of the LADM was inadequate for completely modeling property valuation processes since it only covers a few attributes, such as value, type, and date of valuation (Kara et al. 2024). There was a need to include exterior and interior criteria that may affect the property value, valuation information, and sale statistics. Lemmen, van Oosterom, Kalantari, et al. (2019) declared the improvements and additions planned to be made on the first version of LADM and stated that with the second version, the model will include more semantics. In this context, New Working Item Proposal was presented to ISO TC 211 by FIG (Kara et al. 2017; Lemmen, van Oosterom, Kara, et al. 2019; van Oosterom et al. 2019). Several countries have already developed LADM_VM country profiles for their current status and needs to improve property valuation processes based on the LADM. These countries are the Netherlands (Kara, Kathmann, and van Oosterom 2019), China (Xu et al. 2019), Türkiye (Kara et al. 2018, 2021), Crotia (Tomić et al. 2021), Montenegro (Radulović et al. 2023), Serbia (Radulović, Sladić, and Govedarica 2022), and Mongolia (Buuveibaatar, Lee, and Lee 2023). The UK countries do not have a LADM country profile, but they followed the INSPIRE directives for a long period.

The UK has been developing critical land administration and geospatial data policies. Location data can contribute greatly to the sustainable development of cities. For instance, housing and local planning is identified as one of the priority areas in the UK's Geospatial Strategy (GOV.UK 2023b). A successful land registration system leads to better conveyancing and an efficient property market. Making property information more accessible gives rise to better strategy and policy development. HM Land Registry has set goals such as providing secure and efficient land registration, facilitating digital transactions for property buying and selling, providing near real-time property information, and ensuring accessibility to digital register data to achieve an efficient and sustainable land administration system (HM Land Registry 2022). Geospatial Commission has also published policy papers to underpin the importance of location data in the property sector (GOV.UK 2023a). It is highlighted that improved use of location data enables innovation in the property sector, boost productivity, improve residential areas, and achieve net zero targets. From city planning to land and property management, location data, services, and applications are essential for a well-functioning property sector.

Processing geospatial big data by using the traditional GIS analysis approach causes some technical difficulties. GeoAI can contribute greatly to the solution of spatial problems by extracting information from complex data through geospatial intelligence (Yan et al. 2019; Chu et al. 2019; Janowicz et al. 2020; Liu and Biljecki 2022). It gives much better results when applied to spatially explicit models instead of general models in object detection (Pi, Nath, and Behzadan 2020; Li et al. 2023), image classification (Demertzis and Iliadis 2020; Hussain et al. 2020), semantic segmentation (Neupane, Horanont, and Aryal 2021; Chaurasia et al. 2021), prediction (Hosseini et al. 2023; Ali et al. 2022), interpolation (Lin et al. 2017; Zhu and Cao 2023), and simulation (Gonzales-Inca et al. 2022; Kimura et al. 2020; Schoppa, Disse, and Bachmair 2020) applications. The property valuation procedure also requires a spatially explicit model to evaluate locational factors with spatial analyses. Recently, there has been an increase in the utilization of artificial intelligence techniques like machine learning regression and clustering analysis in mass valuation studies (Gao et al. 2022; Mete and Yomralioglu 2023; Sisman and Aydinoglu 2022). More accurate valuation models can be created with the GeoAI approaches.

An effective and holistic property valuation system that can work together in accordance with national and international standards is an important need for all countries. It is seen that many international organizations are working in cooperation for efficient land administration systems within the scope of sustainable development goals. Although the UK has a strong database about land registries and sold property prices, it lacks a comprehensive property valuation model. In this study, it is aimed to design and develop a holistic property valuation system for Great Britain based on LADM_VM. In this sense, the study covers matching LADM Valuation Information package with the UK's current organizational structure and extension of the fundamental model according to the needs to create a country profile. This is the first study to develop the LADM_VM Great Britain country profile and integrate GeoAI techniques into LADM-based mass valuation applications. Section 2 explains the LADM standard and land management legislative framework in the UK. Section 3 covers development of LADM-based mass valuation of residential properties in England and Wales. It also includes creation of physical model with a database implementation and developing a mass valuation application through spatial analysis and regression analysis. The last section discusses the results of the work, evaluates conceptual modeling and regression analysis, and concludes the research.

2 | Background

There are many international organizations working on the land administration domain to support sustainable development goals such as the establishment of an effective land management system and the protection of property rights throughout the world. Framework for Effective Land Administration (FELA), developed by the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) for policy guidance to member countries in land management and administration processes in line with the Sustainable Development Goals (UN-GGIM 2019). For the purpose of effective land management, the concepts of suitable, adequate, interoperable, sustainable, flexible, comprehensive, and fit-for-purpose land management were emphasized. It is also stated that the several objectives such as developing a broad vision to understand, support, and promote effective land management; providing strategic guidance for countries' action plans; supporting the continuous improvement of land administration and management procedures, techniques, and tools are targeted for implementation of the Integrated Spatial Information Infrastructure and achievement of the Sustainable Development Goals.

Land administration should support an effective land market, including land value and land development components. With the use of LADM, land-related data will be interoperable and easily accessible. Therefore, the economic development of countries can have an equitable and fair taxation system. Open Geospatial Community (OGC) made a general assessment about land management domain and offered suggestions about the steps to be taken for the design and development of application standards in the "OGC White Paper on Land Administration" (Lemmen, van Oosterom, Kalantari, et al. 2019). It is also stated that land management should be supported with up-to-date technologies like artificial intelligence, big data analytics, blockchain, remote sensing, and the dynamic relationship between land and people should be maintained in this sense.

2.1 | Land Administration Domain Model (LADM)

Well-functioning LAS is a need for countries to effectively manage land use and land market. Land value is one of the fundamental components of the global land administration model, which supports sustainable development goals (Enemark 2004). Various international standards such as LADM, INSPIRE, LandInfra, CityGML, and IndoorGML have been developed to conceptually model the earth, underground, lands, buildings, and cities. LADM provides a fundamental, extendable model that aims to create an effective land administration system by modeling the legal, physical, geometric, and semantic features of properties in a standard form (ISO 2016; Lemmen 2012; Lemmen, van Oosterom, and Bennett 2015). It consists of four main classes: LA_Party, LA_RRR, LA_BAUnit, and LA_SpatialUnit.

Legal, physical, environmental, economic, and geometric features of the properties subject to appraisal are needed in different data sources. A land administration infrastructure is required for these data to work together by connecting them to the registries of all public institutions such as land registry, cadastre, and municipality. The first version of the ISO LADM standard includes external ExtTaxation (K4) and ExtValuation (K7) classes for taxation and property valuation. In the LADM Edition II, conceptual data models are revised to include more semantics and detailed four-dimensional profiles, and they are integrated with several data encodings such as BIM/IFC, CityGML, IndoorGML, LandInfra, LandXML, RDF/Linked Data, and GeoJSON. This extended model will also include the LADM_VM part, which is built on the LADM Fundamentals (Çağdaş et al. 2016, 2017; Kara et al. 2020, 2021).

LADM_VM is designed as one of the core packages in the second version of LADM. LADM_VM is a conceptual model that describes the semantics of valuation processes. LADM_VM can be used to create a land information system for property valuation and has a structure that can be correlated with other public institutions' registries. LADM_VM is designed to cover all stages of property valuation such as land registry and cadastre, individual or mass valuation, recording of property prices and sales statistics, taking into account the standards and directives of institutions. LADM_VM consists of ten main classes (Lemmen, van Oosterom, Kara, et al. 2019): (1) VM_ValuationUnit, (2) VM_ValuationUnitGroup, (3) VM_SpatialUnit, (4) VM_Building, (5) VM_CondominiumUnit, (6) VM_Valuation, (7) VM_MassAppraisal, (8) VM_Transaction (9) VM_SalesStatistic, and (10) VM_ValuationSource. The conceptual model design of LADM_VM is shown in Figure 1.

LADM has been adopted by many countries around the world as a conceptual model for the effective implementation of the Land Administration System (LAS). To enable the transition from the conceptual model to the physical model and to use the designed model directly and efficiently in practice, it is necessary to determine the current situation of the countries and make plans for their needs. For this purpose, LADM country profiles are created and the relations between LA_Party, LA_RRR, LA_BAUnit, and LA_SpatialUnit are defined according to the characteristics of the countries.

A country profile should fully describe the relationship between 3R and LAS (Kalogianni et al. 2021). The LADM country profile can be a model that expresses the current situation or suggests what it should be. The LADM profile may be in scope to model the entire land administration system of the country, or it may be recommended for the application of a specific area only. For example, a country profile can be designed for the purposes of creating models such as marine cadastre, spatial planning, or property valuation for tax purposes. Following basic steps should be followed to create an LADM country profile (Kalogianni et al. 2021):

1. Defining the purpose and scope of the country profile.
2. Analysis of land administration needs and current LAS for countries.
3. Creating the conceptual model.
4. Evaluation and testing of the proposed model.

Many countries prepare legal and technical infrastructure within the scope of land and building valuation and carry out valuation studies for various purposes such as planning and taxation. They create a valuation database to record the sales values of properties and carry out mass valuation studies by integrating those data into the LAS. In the survey conducted by FIG Commission 7—Cadastre and Land Management and Commission 9—Valuation and the Management of Real Estate, information was obtained about the valuation practices of countries for taxation purposes (FIG 2017; Kara 2021). According to the survey, in which 24 experts from 22 countries participated, it was concluded that the majority of countries have a mass valuation system, but there is no holistic valuation model covering all countries. It was stated that 65% of the countries that answered the questionnaire have a mass valuation system; Denmark, Spain, Slovenia, and the

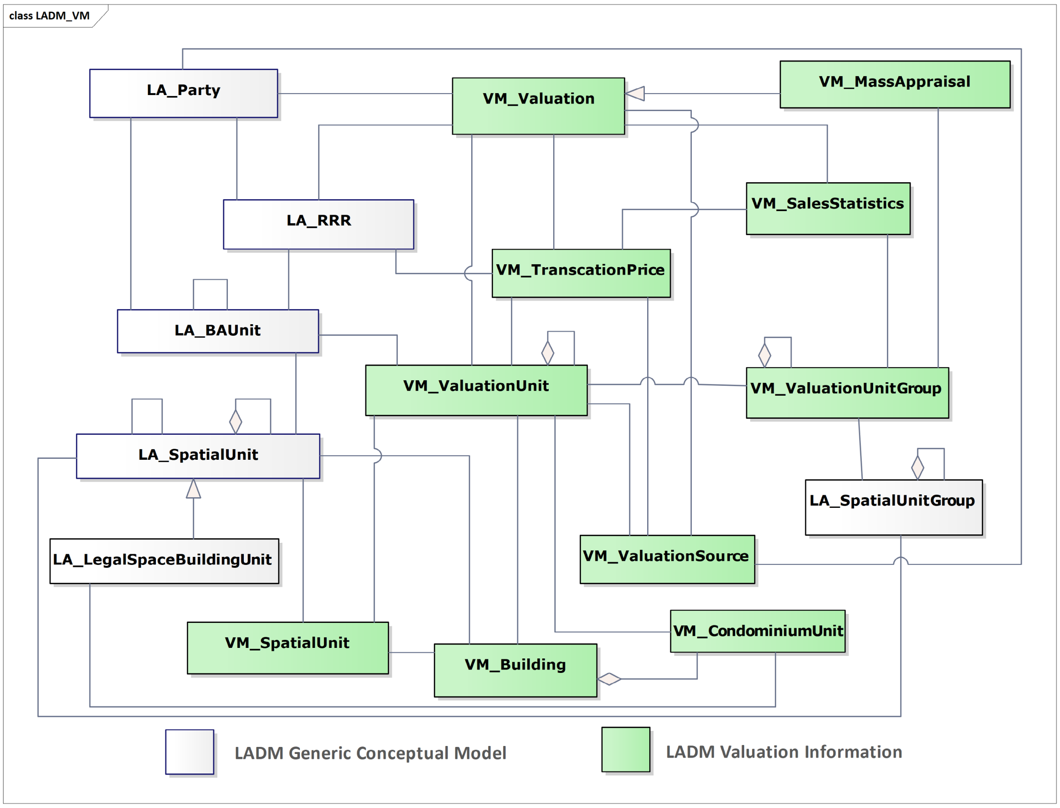


FIGURE 1 | LADM_VM classes (Çağdaş et al. 2016, 2017; Kara et al. 2020, 2021).

Netherlands developed their own software for valuation. In the UK countries, although several algorithmic models are used for valuation and control of value-related procedures, there is no complete mass valuation system.

2.2 | Legislative Framework in the UK

Land registration systems in common law are classified as deed system and Torrens title system. The deed system is based on the principle of "registration of title", whereas Torrens system is based on "title by registration". England and Wales operate on the modified version of the Torrens system which is called the English system. In England and Wales, there are nearly 26 million registered titles which corresponds to 87% of land mass (HM Land Registry 2024). It is intended to improve the land registration and administration processes with HM Land Registry Digital Street Project utilizing property technologies (proptech).

The UK does not have a cadastre, yet does have a compulsory land registration system. General boundaries rule exists instead of measuring and registering precise coordinate information of parcel boundaries. However, there is no indication that the absence of a cadastre adversely affects either the economy or the functionality of the property market (Grover 2008). On the other hand, investing cadastre would ease the digital land registration process which Geospatial Commission set as a goal until 2030. Occasionally, individuals have asserted the necessity for a cadastre in Britain. However, an efficient land registration system, strongly protected property rights, well-developed valuation procedures, and high level of professional and ethical standards support the efficiency of the property market in the UK. On the other hand, a well-defined land administration system that ties relevant parties together can foster better management of rights, restrictions, and responsibilities. It can also provide a better property market, better valuation studies, better taxation policy, and more transparent transactions. Considering the current situation of the land registration processes in the UK, building an efficient land administration system is possible by creating an LADM country profile.

In England and Wales, land registration processes are conducted by the HM Land Registry which is a non-ministerial government department established in 1862. HM Land Registry registers ownership, mortgages, and interests for land and property. It is aimed to complete a significant number of registrations by 2030 (GOV.UK 2023a). In addition to providing secure, fast, and simple registration, it publishes the Price Paid Data (PPD) and beneficial statistics like House Price Index (UK HPI) with an open license.

There are two fiscal cadastre for residential and non-residential properties. They are used to generate funds through the council tax for residential properties and national non-domestic rates for non-residential properties excluding agriculture. These are maintained by the Valuation Office Agency (VOA), an agency of HM Revenue and Customs. VOA is a government agency in England and Wales that provides valuation and taxation support to government, public authorities and local authorities. VOA prepares municipal tax band lists for approximately 26 million properties and provides independent and impartial valuation and consultancy services to the sectors (VOA 2024). The

Scottish Assessors Association, the Irish Valuation Office and the Northern Ireland Land and Property Service are the other valuation institutions founded in the UK for similar purposes.

Council Tax is a local taxation system used in England, Scotland and Wales. For this taxation system implemented in 1993 with the "Local Government Finance Act 1992 (Local Government Finance Act 1992)", each property is evaluated according to criteria such as physical characteristics, area, plan status, location, and usage function assigned to tax bands. There are eight tax bands from A to H fixed for 1991 in England and Scotland, and nine tax bands from A to I fixed for 2003 in Wales. VOA assigns tax bands to the newly built properties based on the comparable sales in 1991. Council tax is applied as a combination of property tax and personal tax. Some properties are exempted from tax, and some are discounted at certain rates. In general, if two or more people reside in a house, the full tax is charged, and if one person resides, 75% of this tax is charged. In vacant houses, the tax is accrued at half the rate of the property owner. This tax is not collected from full-time students (GOV.UK 2024a).

Another type of tax levied on properties in the UK is the tax paid as a result of the purchase and sale transaction. This tax is called Land Stamp Duty (SDLT) in England and Northern Ireland, Land and Buildings Transaction Tax (LBTT) in Scotland, and Land Transaction Tax (LTT) in Wales, and it is paid for purchases above a certain price. According to the decision taken in England in 2020, there is a tax exemption for properties under £500,000 and tax is payable for purchases above this amount (GOV.UK 2024b).

The UK has made most of its public data easily accessible by publishing them under the Open Government License over the past decade. The PPD has been published monthly by the HM Land Registry since March 2012 to support open government data and data transparency (Price Paid Data 2024). The database contains all records of home purchases and sales in England and Wales from January 1995 to the present. PPD is widely used by proptech startups that develop innovative products and services for properties (Hogge 2016). PPD includes several useful attributes such as address, date of sale, price paid, and property type, which are required for price prediction in mass valuation studies.

According to UK legislation, residential and commercial properties must have an energy performance certificate (EPC) when they are built, sold, or leased (UK Legislation 2012). The EPC database was created in 2007 to reduce carbon emissions and increase energy efficiency. Department for Leveling Up, Housing & Communities (DLUHC) issues EPC for residential and commercial buildings in England and Wales for every quarter of the year since 2008. There are many attributes in the EPC database, from physical structure features to energy usage costs, for distinct building types such as apartments, detached houses, bungalows, and commercial buildings (EPC 2024).

PPD and EPC datasets contain various attributes, including full address information from OS AddressBase Premium data. There is also an integrated version of the two datasets filtered for the years between 2011 and 2019 created through address matching (Chi et al. 2021). PPD-EPC linked data contains multi-level spatial units for the UK such as Middle Layer Super Output Areas (MSOA), Lower Layer Super Output Areas (LSOA), and Local Government Areas.

3 | LADM-Based Mass Valuation of Residential Properties in England and Wales

In England and Wales, there are several open datasets that can be utilized in mass valuation processes for different purposes like taxation and planning. LADM_VM can effectively integrate different data sources to build an accurate mass valuation system for Great Britain. In this study, LADM Great Britain Country Profile is created by extending LADM_VM core model for the current status and specific needs of the countries. Then spatial criteria are evaluated with the GeoAI techniques by combining geospatial analysis and regression analysis (Figure 2).

3.1 | Development of LADM Great Britain Country Model

According to the data shared by the ISO LADM working group, country profiles of many countries are currently designed. These countries do not include England, Wales, Scotland, and Northern Ireland, which are part of the United Kingdom. Within the scope of the study, the UML class diagram of the country profile, which reveals the current situation and needs of the countries in land administration domain is modeled using Enterprise Architect software. After the creation of the main classes of the Great Britain Country Profile, their relations with the LADM Valuation Information Model are defined (Figure 3).

Within the scope of land management, various institutions such as the HM Land Registry, DLUHC, Ordnance Survey, and VOA play important roles in the UK. For example, PPD, HPI, and EPC data shared in England and Wales contain important attributes such as sales price, area, energy class, and price index of properties. Based on the duties of the relevant institutions and the data they produce, the Great Britain LADM Value Information Model (LADM_GB_VM) has been developed for mass valuation for five countries in the United Kingdom (Figure 4).

In the conceptual model created, GB_VM_Valuation class contains attributes such as valuation number, valuation method, valuation date, report number, report status, and value. The GB_VM_MassValuation class contains the analysis type, analysis date, number of criteria, number of samples, mathematical model, predicted value, and valuation performance attributes of the mass valuation study. In GB_VM_TransactionPrice class, there are sales number, date, and sales value attributes for the realized sales. GB_VM_SalesStatistics class contains important statistical information calculated by using the data of all sales realized in the past years such as sales statistics number of the price index, date, region code, region name, monthly percentage change, annual percentage change, average price, seasonally adjusted average price, index, seasonally adjusted index, and sales volume.

The spatial geometry of the properties is defined both at the land level and at the building/condominium level for valuation

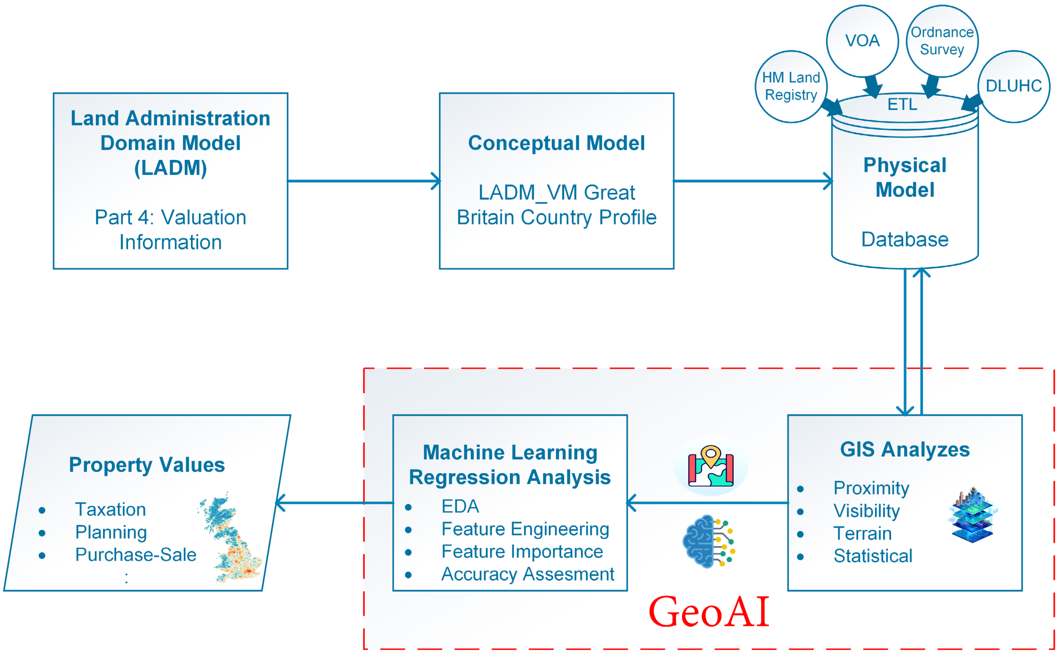


FIGURE 2 | Developing GeoAI Integrated Mass Valuation Model based on LADM Valuation Information Great Britain Country Profile.

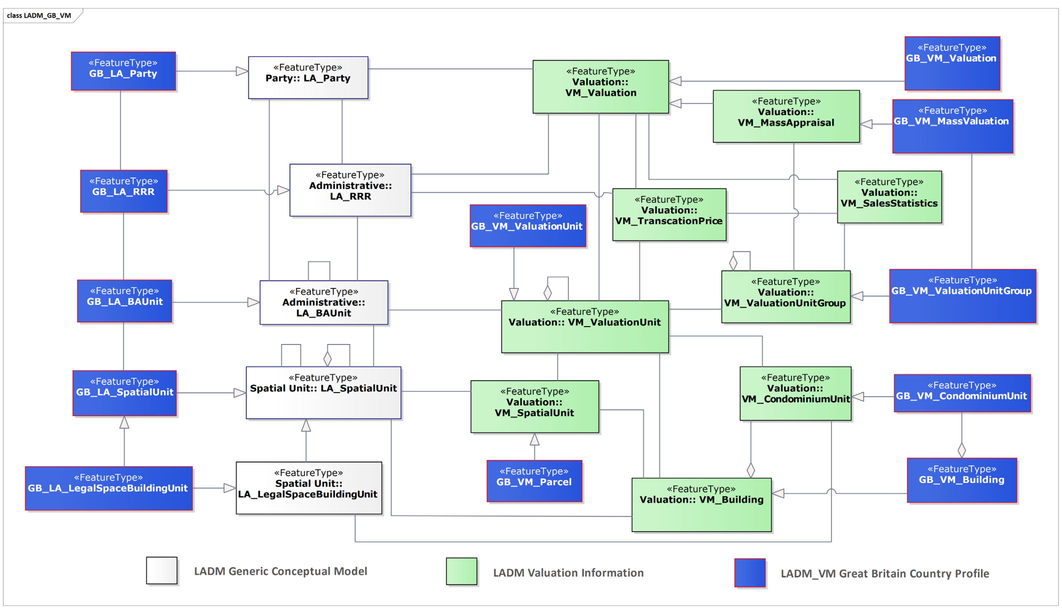


FIGURE 3 | LADM Valuation Information model relations with the country profile.

unit, parcel, building, and condominium classes. These classes contain descriptive attributes specific to parcels and buildings. In GB_VM_ValuationUnit class, there are valuation unit number, Unique Property Reference Number (UPRN), valuation unit type, characteristics of the environment, ownership type, and title deed number. The GB_VM_Parcel class has the spatial unit number and national polygon number attributes. The GB_VM_Building class contains useful attributes such as building number, building reference number, building area, property type, construction type, building properties, and construction year. The GB_VM_CondominiumUnit class, which is related to the building class, includes classes such as the condominium number, building properties, floor level, and condominium area. All code lists in the model are shown in Figure 5.

The transition from the conceptual model to the physical model is carried out with the database creation phase. In this context, a PostgreSQL database is created on a local Linux server machine to store the data of the UK LADM_VM classes. After the database setup, a connection is created using Enterprise Architect software to transfer the classes in the conceptual model to the database tables. To effectively store and manage geographic data as well as tabular valuation data, the PostGIS extension is installed, and spatial data tables are created. Finally, using ETL

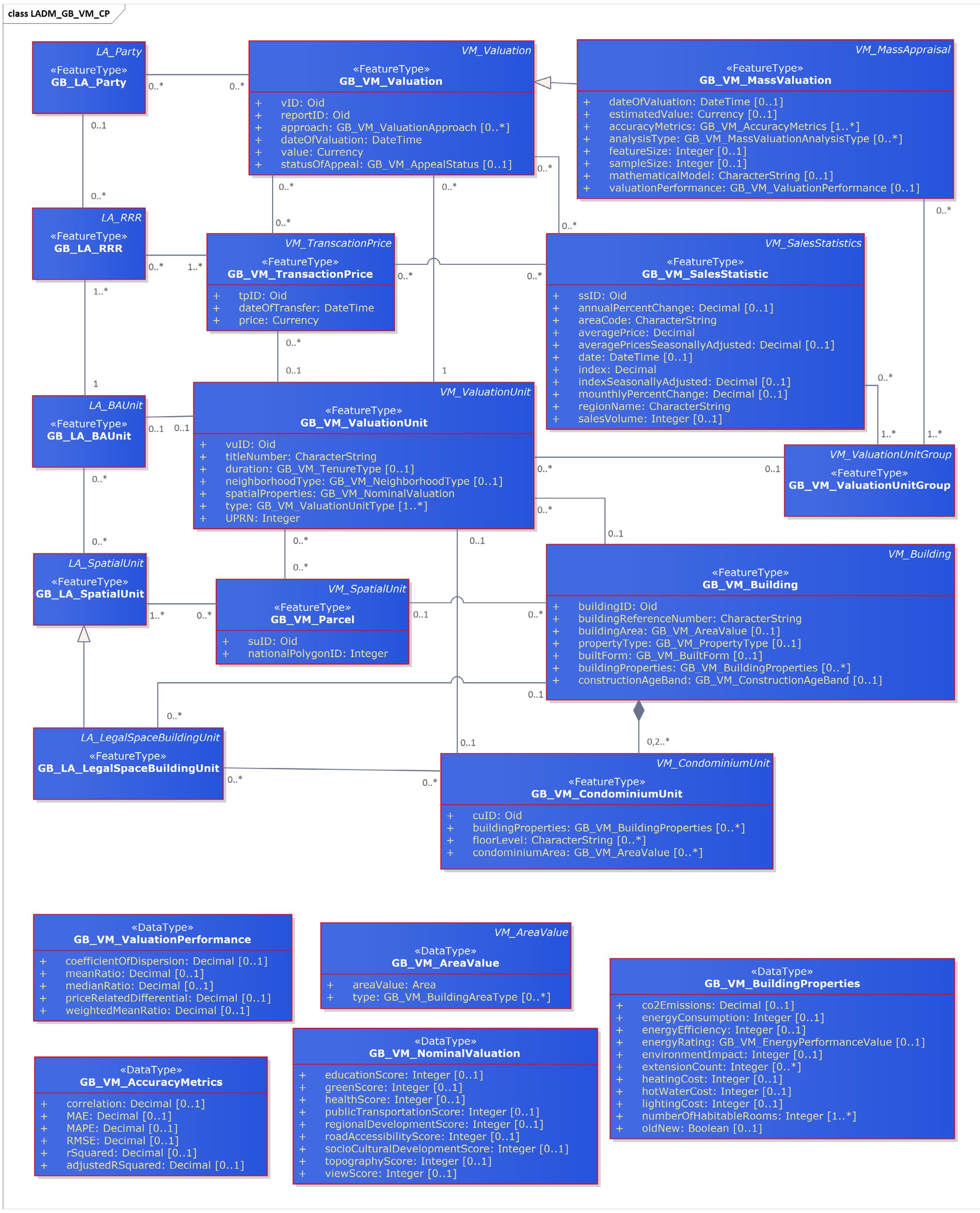


FIGURE 4 | LADM_GB_VM Great Britain country profile.

tools in FME software, different structured data from various sources are matched with the standard format suitable for the model and loaded into the database.

3.2 | Mass Valuation of Residential Properties With GeoAI Approach

3.2.1 | Spatial Analysis of Valuation Criteria

Property value maps enable revealing the price changes in a region and facilitate activities such as taxation, management, and planning. Using various open data sources, proximity, surface, and visibility analyses are carried out to create a property value database of England, Wales, and Scotland countries (Figure 6). In this context, open-source QGIS desktop GIS software is used to perform spatial analysis.

Proximity to important places such as public buildings, public transport stations, and shopping centers is one of the most effective factors in property valuation (Mete and Yomralioglu 2023; Tajani, Morano, and Ntalianis 2018; Wyatt 1997). Within the scope of proximity analysis, Euclidean Distance, which represents the distance as the crow flies between two locations with a line segment, is used. Reclassification intervals of distances are also arranged according to both walking and vehicle accessibility alternatives. For example, if the distance to the destination, such as the bus stop or metro station, is between 0 and 400 m, the proximity score of the relevant property becomes 100 (maximum score). This distance interval, known as the most

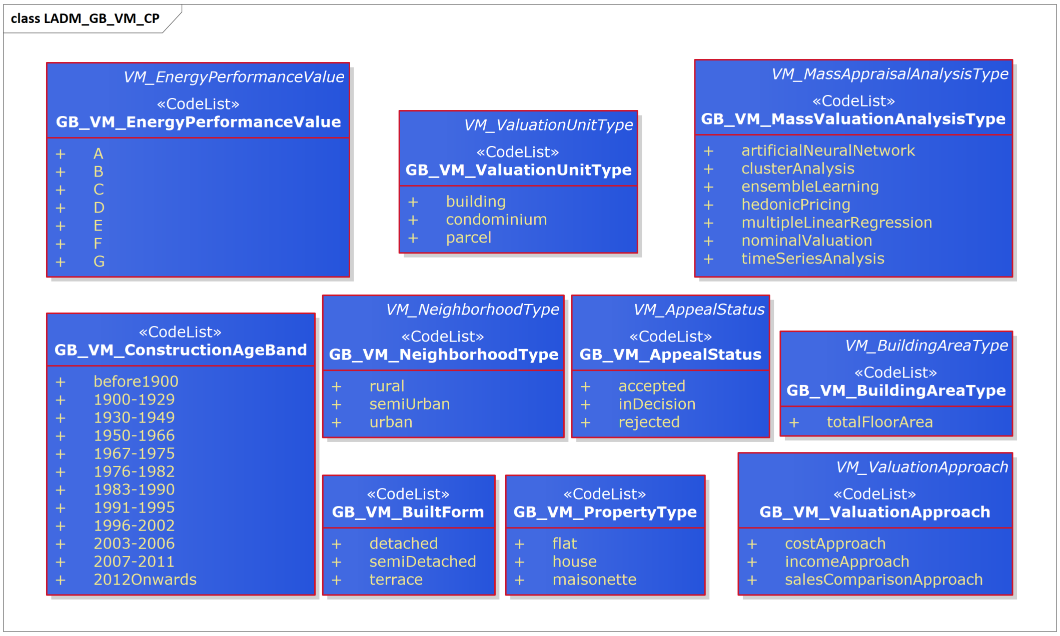


FIGURE 5 | LADM_GB_VM code lists.

comfortable distance that pedestrians prefer to walk, represents a walking distance of ~5 min, equivalent to 0.25 miles (Manaugh and El-Geneidy 2011; Yang and Diez-Roux 2012). On the other hand, a property whose destination is at a maximum distance of 1 km to places such as bus stations and airports where transportation by vehicle gets a 100 proximity score from the relevant criteria. Proximity scores are systematically reduced according to the distance, and a score of 0 is obtained after a certain distance. The classification ranges of proximity values are divided into two groups: vehicle access and pedestrian access, according to proximity studies in the literature.

Euclidean Distance proximity analysis is performed with the Geospatial Data Abstraction Library (GDAL) Proximity (raster distance) tool in the QGIS. To run the analysis, input data must be submitted in raster format. Since most of the spatial data used in the study is in vector format, the GDAL Rasterize tool is used for conversion from vector to raster format before proximity analysis. The raster data obtained after the proximity analysis are reclassified, and pixel values are normalized in the range of 0–100. In the last step, the proximity analysis is completed by cropping the raster data according to the study area.

Topography features such as slope and aspect also have a crucial effect on the property value. It is more preferred that the property is located on a flat terrain and benefits from sunlight for longer (south-facing aspect) (Huang and Hewings 2021). In this context, slope and aspect analyses are performed using EU-DEM open data, and terrain analysis scores are reclassified between 0 and 100.

GDAL Slope tool is used to perform slope analysis in QGIS software, and percent slope is calculated using EU-DEM data. To reveal the effect of the slope on the property value, the slope values are reclassified, and the analysis score of the flat lands is ensured to be higher than the sloping lands. The slope classification values of international accessibility standards are referenced while determining the reclassification intervals of slope values (ISO 2001). Finally, the raster data obtained as a result of the slope analysis is clipped according to the boundaries of the study area and the slope analysis map is created.

Aspect basically refers to the direction the slope faces on the land surface. Aspect analysis is carried out in QGIS with the GDAL Aspect tool. Aspect value measured in 360° units clockwise from the north takes the value of −1 where the slope is flat. The values from South East to South West, that is, the regions with an aspect value between 135° and 225°, are reclassified to receive a score of 100 since South facade is preferred due to the sunshine duration. The raster data is cropped according to the study area, and the aspect analysis map is created.

Beautiful landscapes such as forests, seas, and rivers add significant value and attractiveness to properties (Wallner 2012; Yu, Han, and Chai 2007). GIS-based visibility analysis can be performed in two and three dimensions. Since the digital elevation model is used in the two-dimensional visibility analysis, the visibility of the properties can be determined depending on the heights then, a visibility map can be produced. For this reason, two-dimensional visibility analysis is sufficient to evaluate the landscape criteria in mass valuation studies.

In the visibility analysis, the visibility of each cell center is determined by comparing the elevation angle from the observation point to the cell center against the elevation angle to the local horizon. The calculation of the local horizon considers the topographical features between the observation point and the given cell center. If the point resides above the local horizon, it is considered visible. Visibility analysis is performed using the QGIS Visibility Analysis plugin to determine the areas where the landscapes appear in the study area. Since the viewshed tool accepts only point vector data inputs for views, random points are created on sea and river lines. After the observed areas for each view are created in point data type with the "Create

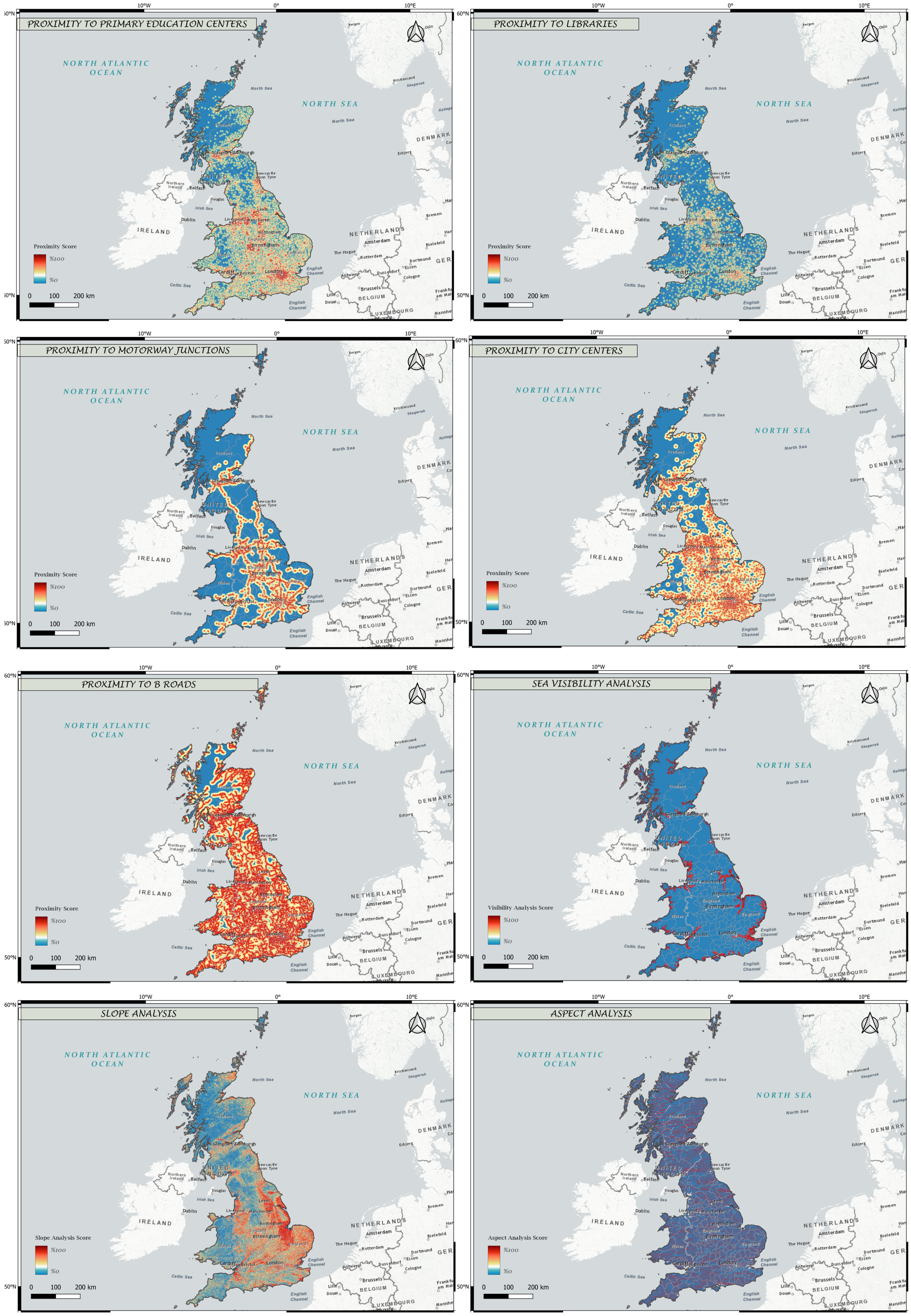


FIGURE 6 | Spatial analysis carried out for the study area.

viewpoints" tool, visibility analysis is performed, and the visibility scores are reclassified between 0 and 100. The obtained raster images are cropped according to the boundaries of the study area and visibility maps are produced for each analysis. After performing proximity, surface, and visibility spatial analyses, scores of the spatial variables are included in the non-spatial valuation determinants for creating a machine learning-based regression model.

3.2.2 | Machine Learning-Based Regression Analysis

Regression analysis is one of the fundamental types of Machine Learning methods, and it is widely used for property price prediction. There are several machine learning-based regression analysis methods such as Multiple Regression Analysis (MRA), XGBoost, CatBoost, LightGBM, and Random Forest. In this study, Random Forest regression model is used to create a valuation model since it is one of the most accurate ensemble machine learning methods (Dimopoulos et al. 2018; Ho, Tang, and Wong 2021; Mete and Yomralioglu 2023; Yilmazer and Kocaman 2020). PPD-EPC open data are used for mass valuation of residential properties in England and Wales. Input data contain physical, locational, and environmental factors such as building area, property type, built form, construction year, energy efficiency, number of rooms, green score, road accessibility, and subway station proximity.

Within the scope of regression analysis, first, PPD-EPC data is loaded into Jupyter Notebook Python environment as Pandas DataFrame, and exploratory data analysis (EDA) is performed to obtain detailed information about the data. EDA is a must-have for data science projects that provides a better understanding of data using statistics and various visualization techniques. At this stage, descriptive statistics such as minimum, maximum, mean, and standard deviation are calculated, null values in the data are checked, correlation matrix, histogram, box plot, scatter plot, and pairwise comparison charts are created. With the graph chart, it is possible to get information about the change in average housing prices over the years. In the matrix created according to the Pearson correlation analysis, the positive and negative relationships of the variables can be seen. Correlation matrix revealed a high positive correlation between price variable, building area, and the number of rooms. On the other hand, outliers detected in the price variable it is seen from the box chart that there are outlier data in the price variable, and these values should be taken into account upon detailed examination.

At the feature engineering stage, operations such as outlier detection, null data imputation, categorical data encoding, and feature selection are performed. Outliers cause deviations in the data, resulting in poor fit in the regression analysis. Outliers can be detected by evaluating descriptive graphics, calculating standard deviation, or conducting automatic detection approaches such as One-Class SVM, Minimum Covariance Determinant, Local Outlier Factor, and Isolation Forest. In this study, outliers are detected by applying 3-sigma standard deviation approach, and these values are removed from the data set. In addition, null values are filled with a reasonable method by using the mean and median value statistics. For example, the null values in the floor level attribute have been replaced with the zero value, which is the most repeated in the data and represents the floor level of the detached houses.

Many regression algorithms require both dependent and independent variables to be in numerical form. For this reason, the categorical features in the data should be encoded. PPD-EPC data includes categorical variables such as building type (detached, apartments, semi-detached, etc.), old/new, and ownership type (property, rent). To make these features ready for use in Machine Learning regression models, the One Hot Encoding method is applied and categorical variables are encoded to form a numerical sequence. After the data preprocessing steps, Random Forest regression analysis is performed to create a prediction model with Machine Learning. The performance of regression model is evaluated with the help of various accuracy metrics.

4 | Results and Discussion

The UK has a vivid property market with around 100.000 monthly residential property transactions (HMRC 2024). Besides, UK countries have a long land registration system history that dates back to the 1800s. HM Land Registry is the responsible institution for registering ownership, providing comprehensive and up-to-date records, and assisting in the process of buying and selling property by providing accurate and reliable information about the legal status of land and property. VOA is responsible for determining the rateable value of non-domestic properties for the calculation of business rates, assessing the value of domestic properties for council tax purposes, and conducting valuations of properties to establish their market value. To connect different public registries and develop an efficient, interoperable, systematic land administration model, there is a need for LADM country profile.

Dealing with land-related problems by using traditional approaches results in mediocre performance. Using GeoAI techniques in land administration processes can increase accuracy and efficiency while decreasing processing time remarkably. The results of this article are discussed under two headings: regression analysis evaluation and conceptual modeling evaluation.

4.1 | Conceptual Modeling Evaluation

Conceptual modeling enables the representation of a system by expressing its basic principles and functions through an understandable model interpretation. LADM provides a fundamental level conceptual model of land administration system by relating land, people, and their rights, restrictions, and responsibilities. Global land administration perspective has several functions such as land tenure, land use, land development, and land value. It is vital for countries to have a well-functioning land administration system by developing a holistic country profile.

VOA values domestic properties for setting council tax bands depending on their market value as at 1 April 1991. Determination of the value of newly built properties is a struggle and may cause errors. Using the LADM-based mass valuation model, property values can be calculated with high accuracy and council tax bands can be adjusted each year accordingly. Therefore, a fairer tax collection can be ensured by all local authorities.

LADM enables connecting different public registries and integrating spatially explicit models into the land administration systems. After the LADM country profile is created, the success of the conceptual model needs to be tested and evaluated. In this context, an instance-level diagram of the model is created and represented with the PPD-EPC data according to the LADM_GB_VM country profile (Figure 7).

4.2 | Regression Results Evaluation

Various accuracy metrics such as R^2, adjusted R^2, MAE, MAPE, and RMSE are used to measure regression model performance. The coefficient of determination (R^2) shows

FIGURE 7 | Instance level diagram of the LADM_GB_VM.

how related the dependent and independent variables are in the regression analysis. The goodness of fit of the model is determined by calculating the total variance ratio with R^2. On the other hand, MAE basically refers to the difference between the true value and the predicted value. It is calculated as the sum of the absolute values of the differences, taking into account the number of observations in the error calculation. MAPE, which expresses the mean absolute deviation as a percentage, is obtained by dividing the sum of the difference between the actual value and the predicted value by the actual values. RMSE is a measure that defines the difference between the true value and the predicted value by calculating the square root of the mean of the sum of the squares of the prediction errors. A lower RMSE value indicates a better fit for estimation in regression analysis.

Using the trained regression models, estimation is performed on the validation data, and various accuracy metrics are calculated. For ensemble learning methods, Random Search is applied to hyperparameters such as the number of trees, the maximum number of levels in a tree, and the minimum number of samples required at each leaf node. Then, Cross Validated Grid Search is used to reveal the parameters of the best prediction model by focusing on Random Search results. Thus, for a highly accurate prediction, the best model parameters to be used in the training phase of the regression model are determined. As a result, the regression model has high accuracy and low error rates according to the calculated performance metrics (R^2: 0.8579, Adj. R^2: 0.8578, MAPE: 0.1941, RMSE: 101847.7448) (Figure 8).

Feature importance is a way of interpreting the model outputs for establishing the importance of each feature in the decision-making process. It allows the examination of the contribution of variables to the model in detail. On the other hand, SHAP is an explainable AI (XAI) algorithm that measures the contribution of variables to a predictive machine learning model using Shapley values (Lundberg and Lee 2017). Rooted in game theory, SHAP calculates the average contribution of all variables to the model by examining the effects of all possible alternatives. Thus, it can be determined how much a factor positively or negatively affects the prediction result. In this study, the SHAP method is used in combination with the Random Forest regression. Looking at the results, it is seen that spatial determinants greatly affect the accuracy of the valuation models and enable the creation of spatially explicit GeoAI models (Figure 9). Total floor area and proximity to the subway stations are the two significant factors that slightly affect the valuation model positively. On the other hand, the date of transfer feature affects the model on both negative

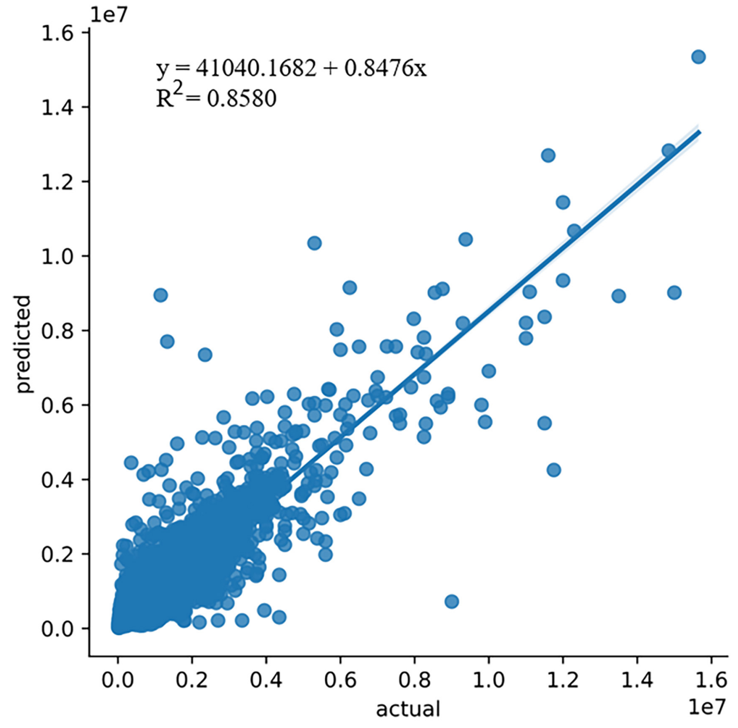


FIGURE 8 | Distribution of actual and predicted values.

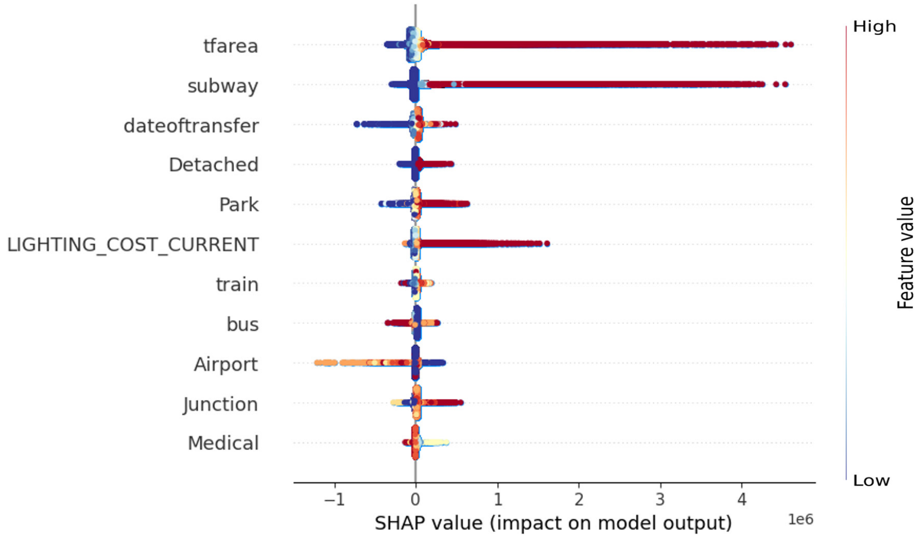
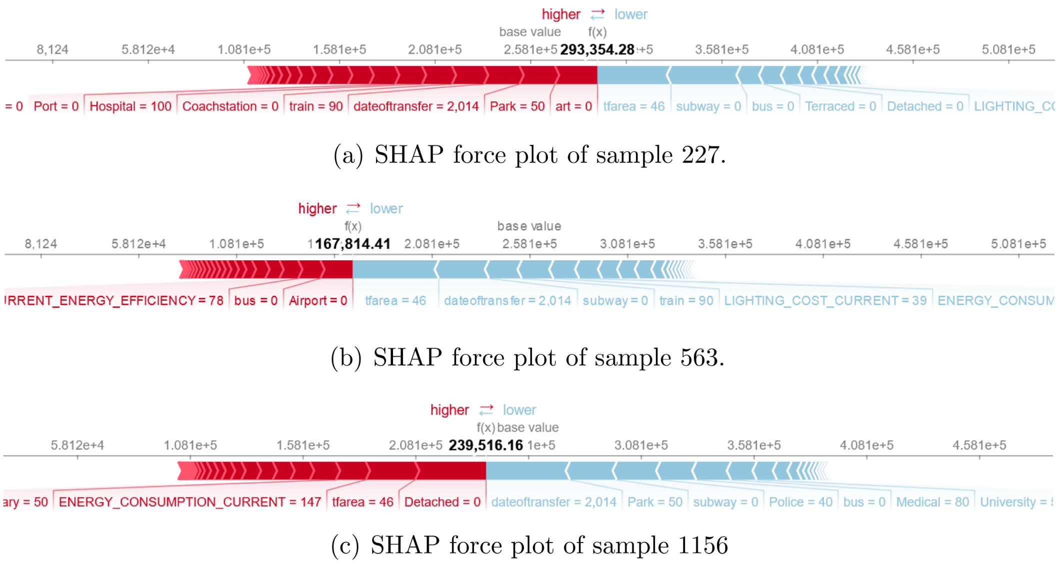


FIGURE 9 | SHAP values of the determinants.

and positive sides. Fluctuation in housing prices, especially in the last two years, resulted in varied temporal effects on the model. Proximity to the airport feature has a remarkable negative effect on the model. This indicates properties far from airports are preferred compared to nearby ones.

SHAP summary (beeswarm) plot is useful to observe the general effects of features on the model. On the other hand, SHAP force plots can be utilized for a detailed interpretation of features for each sample. Figure 10 shows the SHAP force plots of different samples that indicate contribution of each feature to the model.

Although there are several studies about the LADM country profiles, this is the first study that developed Great Britain's country profile by integrating GeoAI techniques into the LADM Edition II—Part 4 Valuation Information. It will enable the creation of an accurate valuation model compliant with international standards. In this study, all public registries and public sector data are related to each other so that a holistic approach can be adopted for the management of land and property. Physical data model contains locational, environmental, and physical attributes of residential buildings, as well as estimated value and valuation performance metrics (Figure 11).



(a) SHAP force plot of sample 227.

(b) SHAP force plot of sample 563.

(c) SHAP force plot of sample 1156

FIGURE 10 | Visualization of the SHAP values with an additive force layout.

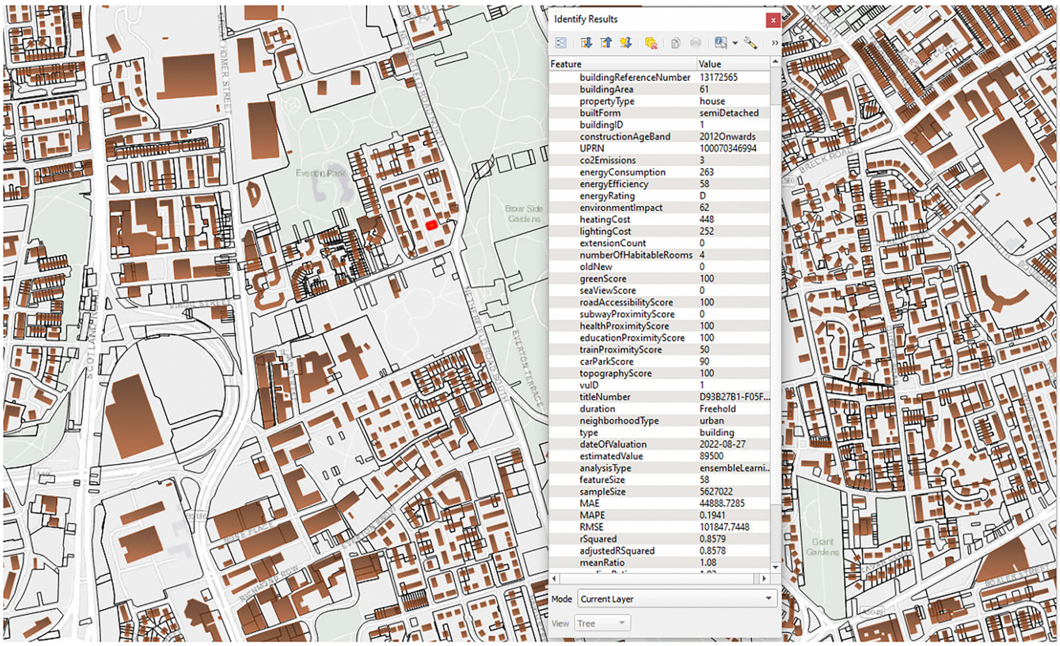


FIGURE 11 | Physical data model of the GeoAI integrated mass valuation study.

5 | Conclusion

Global land administration perspective has several functions such as land tenure, land use, land development, and land value. It is vital for countries to have a well-functioning land administration system by developing a holistic country profile. Conceptual modeling enables the representation of a system by expressing its basic principles and functions through an understandable model interpretation. LADM provides an interoperable, fundamental-level conceptual modeling of the land administration system. In this study, LADM-based mass property valuation model was developed for Great Britain. Using the Valuation Information package, which is one of the multipart coherent packages of the LADM Edition II, a conceptual model of the country profile is developed to meet the requirements and standardize valuation procedures.

HM Land Registry, VOA, and Ordnance Survey are responsible for creating different land-related data sources in the UK. There is a need for an integrated land information system to manage land and properties efficiently. Developing the GeoAI integrated mass valuation model based on the LADM Valuation Information Great Britain Country Profile provided an accurate, practical, and effective valuation system. This standard model can be used to determine the value of properties in the country for several purposes such as purchase and sale, taxation, and planning. As a future work, a 3-dimensional data model can be developed for property valuation by including visibility and lighting analyses.

For this purpose, proposed data model can be extended by using BIM-based models and digital twins of cities (Mete, Guler, and Yomralioglu 2022). This way, it will be possible to examine value changes over zoning plan implementation by generating simulations for better land use and sustainable development.

Conflicts of Interest

The author declares no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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