

Article

Applying the Land Administration Domain Model (LADM) for Integrated, Standardized, and Sustainable Development of Cadastre Country Profile for Pakistan

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Abstract: Rapid urban growth necessitates focused attention regarding its policy and governance to ensure affordable housing, transparent and efficient real-world systems, reduce social inequalities, and promote sustainable development. This study delves into the semantics and ontology for developing a Land Administration Domain Model (LADM) profile in the context of Pakistan's Land Administration Systems (LASs), which currently face issues due to manual record-keeping, lack of transparency, frauds, and disintegration. Establishing a baseline through Record of Rights (RoR) and Property Information Report (PIR), alongside surveying and mapping procedures defined by laws and rules, forms the foundation for LADM profile development. This study explores the transition from manual LAS to 2D/3D representation, using LADM as a conceptual guideline. The LADM profile's three key packages—PK_Party, PK_Administrative, and PK_SpatialUnit—a sub-package, and external classes are examined, with proposals for digitalisation and modernisation. Additionally, the study includes expert consultation, and highlights the significant support that the LADM implementation offers to achieve Sustainable Development Goals (SDGs) in Pakistan. In conclusion, the study underscores the need for a comprehensive and inclusive approach to address organisational overlaps and ambiguities within LAS, positioning PK LADM as a transformative force for sustainable urban LAS in Pakistan, aligning with broader SDGs. Recommendations include exploring realistic land valuation, integrated ownership and location verification systems, addressing historical survey data challenges, and promoting wider stakeholder adoption for sustainable 2D/3D urban LAS using LADM and its edition II as a way forward towards the creation of a smart city and digital twin.

Keywords: real estate; land administration; 3D LAS; urban planning; land tenure; SDGs; LADM



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1. Introduction

Asia and Africa are projected to experience the largest share of global urban growth in the coming decades, with an estimated 2.2 billion additional people expected to reside in cities by 2050 [1]. The significant population influx towards urban areas requires careful attention to urban policy, planning, governance, and resilience. Cities worldwide find themselves at a pivotal moment as they strive to shape a sustainable urban future. They face the formidable challenge of accomplishing multiple objectives, such as ensuring affordable housing, implementing effective urban sprawl management, reducing social

inequalities, combating traffic congestion, and addressing numerous other interconnected challenges [2–5]. Technology has revolutionised the modern world, transforming it in countless ways and emphasising enhanced efficiency, accessibility, and transparency in various real-world manual systems and operations, as is also noted in FIG Publication 80 [6–12].

The availability of a well-functioning Land Administration System (LAS) is a baseline for good governance, effective land use planning, and promoting investment by establishing reliable land records [13–16]. Establishing and recording secure property rights supported by efficient registration procedures helps to achieve social and economic development [17]. Transparent land tenure is vital for dispute resolution, hence increasing the protection of land rights [18–20]. However, most of the global population lacks (access to) secure land and property rights [21,22]. Capacity building, collaboration, and adoption of technology supported by strong legal and institutional frameworks are among the key parameters that are crucial to achieving sustainable LAS development [23–27].

The population in Pakistan has rapidly grown to 241.5 million in 2023, where the annual growth rate in urban areas is notably higher at 3.65 percent compared to rural areas, which is at a 1.9 percent growth rate [28]. Like developed countries, Pakistan also needs more (2D/3D digital) land data to manage the influx, particularly for urban LAS and its planning-related themes [29–34]. The digital data must be standardised for input in an anticipated National and Provincial Spatial Data Infrastructure (NSDI) [35] and synchronised with other national requirements like spatial planning, taxation, tenure, census, and electoral delimitations [36,37].

Like many other developing countries, Pakistan's recordation of land tenure and property rights is characterised by complexity, fragmentation, and outdated systems, necessitating essential reforms in the future [30,38–50]. The establishment of the LAS in the country is rooted in a system introduced by the British more than a hundred years ago, and is primarily driven by fiscal purposes and the objective of revenue generation. Land administration in urban areas involves various organisations with overlapping roles and responsibilities [3,51]. In response to rapid urbanisation and high population growth [1,2,52,53], Pakistan is experiencing a complex and critical situation related to the recordation of the relationship between people and land [54]. The demand for land is significantly high due to its limited availability, particularly in urban areas [55,56]. Moreover, the complexity is exacerbated when land administration and management is handled manually, laws are vague, and their implementation is poor [57–60]. For example, the Land Acquisition Act [61] does not exclusively deal with land acquisition to develop (private) housing societies [62]. The society developer acquires land based on the market value and registers the land at the value the government decides. There is a huge difference in the price where the land market value is much higher than the one decided by the government through the Deputy Commissioner (DC) rate or the Federal Board of Revenue (FBR) rate. Developing countries suffer social and economic backlash for poor-performing LAS with poor-quality LAS data [63,64]. State land encroachment is a widespread phenomenon attributed to the manipulation of manual land records and misuse of authority [65–68]. According to a recent government statement, the estimated value of state land encroachment in the country amounts to 32.7 billion USD (conversion rate 171 PKR = 1 USD) [69]. In addition, state institutions themselves are implicated in the deprivation of individuals' rightful ownership, thereby intensifying the issue [70]. Although Pakistan is trying to establish a digital cadastre and land information system [71–73], the efforts so far are not fruitful enough to transform the land market and spur socio-economic development. Survey of Pakistan [74] developed a unified domain model to modernise the British Colonial LAS, and thoughtfully incorporated the agricultural-based revenue system. In order to further enhance its efficiency, implementing and maintaining a LADM-based data model should be considered. Moreover, it is imperative to establish an integrated LAS that incorporates both the Colonial and contemporary LASs. The rigid planning and restrictive laws [75] underneath the manual urban LAS, combined with pervasive corruption within the LAS,

have led to profound confusion among citizens. The lack of clarity and transparency in the land acquisition process led to financial losses, amounting to millions of dollars for a public LAS organisation in Islamabad, the capital city of Pakistan [76,77].

The International Organization for Standardization (ISO) Technical Committee (TC211) introduced the ISO 19152:2012 Geographic Information—Land Administration Domain Model (LADM) [78] as a reference model for global standardisation in the land administration domain [79–81]. More than 40 countries across the globe have designed their LAS country profile by adopting the generic guidelines provided by the LADM [82–87]. Ten countries developed a real implementation of the standard.

The Sustainable Development Goals (SDGs) are an extensive agenda for worldwide development by 2030 [88]. The United Nations set 17 goals and 169 targets under the SDGs, representing a shared vision and a framework for collective action towards a sustainable and prosperous future for all. LADM also plays an important role in implementing the SDGs 1, 2, 5, 8, 11, 12, 16, and 17 [89,90]. Lemmen and Van Oosterom [79], Chen and Van Oosterom [91], and Rajabifard [92] stressed the need for further research on the development of LAS and the usability of the LADM to achieve the SDGs.

Considering the current state of deteriorating LAS in Pakistan, particularly in urban areas, it is crucial to leverage the conceptual model presented in LADM to develop application software, facilitate data exchange, implement quality management for data, and standardise the LAS and harness the advantages of digitalisation in support to achieve economic development and good governance [50]. An effective LADM-based LAS is expected to enhance tenure security, streamline revenue collection, facilitate dispute resolution, and foster sustainable development within the LAS context.

In general, the scope of LAS is quite elaborative, including tenure security, valuation, use, and development aspects of land. The objective of this research is to develop an integrated, sustainable, and standardised LAS country profile for Pakistan using the first edition of the LADM published in 2012, with a focus on land tenure and its allied Rights, Restrictions, and Responsibilities (RRRs), as well as their precise location demarcation above and below ground [78]. The research questions posed in the study are:

- What are the semantics and ontologies of existing LASs in Pakistan and of LADM?
- What gaps exist in the existing LASs, and how can they be overcome by developing a standardised and integrated LADM for Pakistan?
- How can existing manual LASs be extended into 2D and 3D urban LAS using LADM?
- What support will the LADM country profile offer in achieving SDG targets for sustainable urban LAS in Pakistan?

The research study is organised as follows: Section 2 discusses the overall methodology of the research. Section 3 discusses semantics and ontologies, as well as gaps in the existing LASs. Section 4 provides details on the development of the LADM country profile for Pakistan, while Section 4.6 provides validation through expert consultation and conformance test. Section 5 covers the implementation, including the evaluation of SDGs for LAS and Framework for Effective Land Administration System (FELA), as well as PK_LADM into 2D/3D LAS. Sections 6 and 7 describe the Discussion and Conclusion, as well as Recommendations.

2. Methodology and Design Approach

The Design Science Research (DSR) method plays a crucial role in addressing critical human problems and enhancing existing systems. DSR allows for the creation of innovative artifacts, which can be termed as the model elements that represent physical entities in the Information System. This approach enables the creation of artifacts (design cycle) using a background knowledge base and scientific theories (rigor cycle), ultimately paving the way for their implementation to improve systems (relevance cycle) [93,94]. Alattas [95] implemented DSR and found it valid for the creation and integration of LADM and indoor modelling, whereas Hull and Whittal [96] implemented DSR to improve secure land tenure.

Based on the guidelines of Hevner and Chatterjee [93], Papalambros [97], ISO [78], and Kalogianni and Janečka [80], the study's methodology employs a design science research approach to create a standardised domain model for Pakistan's cadastre country profile. This study is structured into three phases to develop the profile, as illustrated in Figure 1, and details are listed below:

- **Phase-1: Scope Definition (Rigor Cycle).**
 - Review of existing manual LAS.
 - Semantics and Ontology.
- **Phase-2: Modelling PK_LADM Profile (Design Cycle).**
 - Design PK_LADM model using Unified Modeling Language (UML) in Enterprise Architect (16.1.1632) Software.
 - Validation using expert consultation and conformance test.
- **Phase-3: Implementation (Relevance Cycle).**
 - Impact evaluation using SDGs and FELA.
 - PK_LADM as a way forward for existing LASs into 2D and 3D.

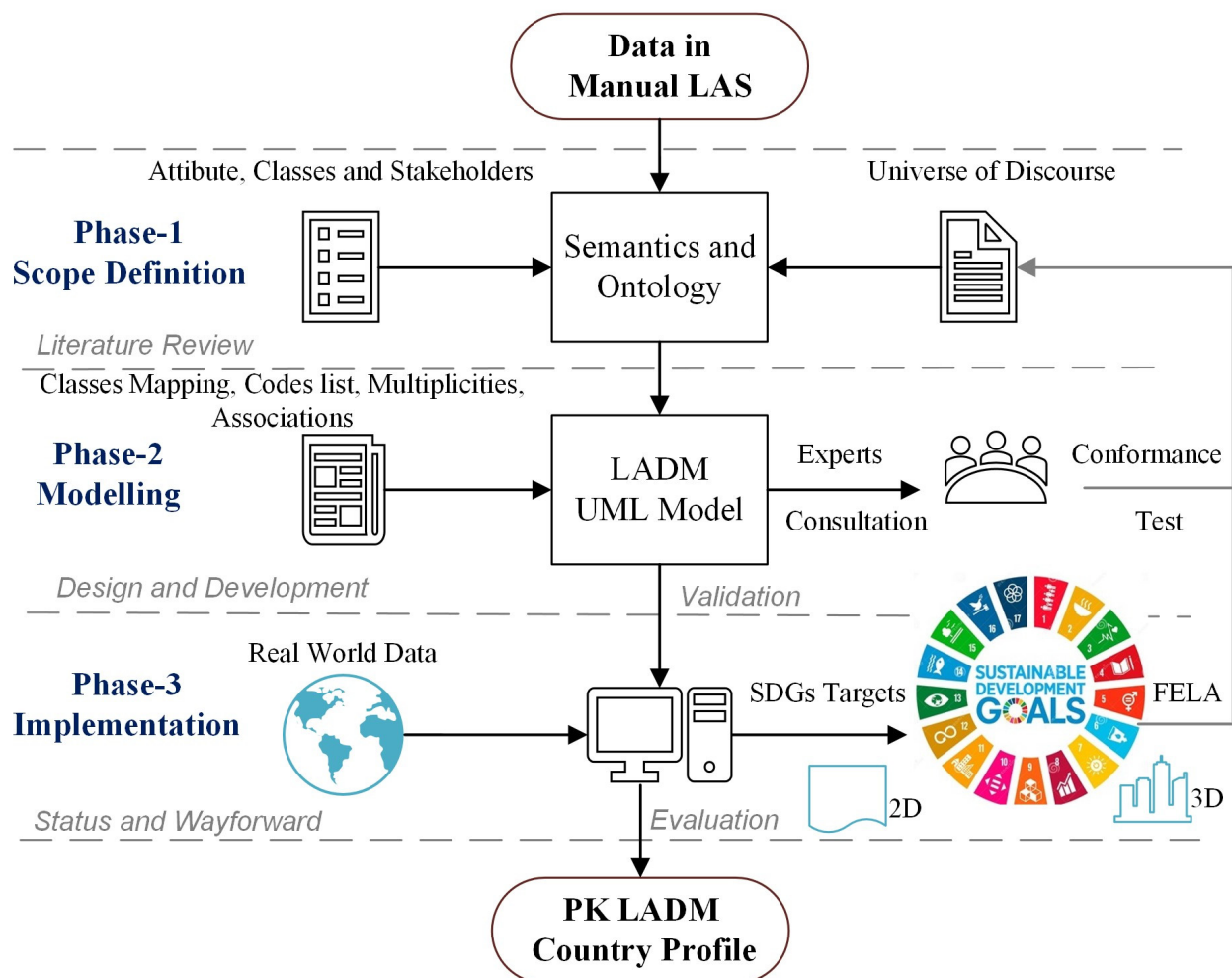


Figure 1. Methodology to develop LADM country profile for Pakistan.

The validation of the PK_LADM includes a conformance test, as specified by ISO/TC211 in Annex A (normative) of the LADM International Standard. This conformance test comprises three levels, as outlined in Table A.1 of the standard [78]. Level 1 includes the basic LADM classes; level 2 contains common LADM classes; and level 3 has all

LADM classes. These levels are used to assess the compliance of LADM with a country profile, with the conformance levels details in sections A.2 through A.4 of the Annex. Furthermore, a country profile will not be conformant to LADM if there is no mapping of elements between the two. Additionally, for validation, a group of 20 experts from academia and industry were consulted. A draft copy of PK_LADM model and an online questionnaire (<https://forms.office.com/r/mGiBCdcySt> accessed on 15 May 2024) survey was shared with the experts via email. This is followed by an online consultation workshop conducted using Microsoft Teams (Office 365 and Build No. 1415/24050307617) with 6 available experts. The PK_LADM impact evaluation design involves considering the SDGs and the FELA. The evaluation also includes scrutiny of the SDG goals relevant to LAS, including inheritance and equal land rights for all, technology and innovation, sustainable urbanisation, transparency, tax and revenue collection, etc. FELA is also a United Nations global policy guideline for achieving sustainable development for the LAS domain [98]. The FELA outcomes already assessed by the authors of this research [30] are also included in the evaluation.

3. Phase-1: Scope of LAS in Pakistan

The country's British Colonial and contemporary urban LASs are interconnected in terms of policy, administration, and management [99]. However, it is essential to note that both operate independently within their respective domains and do not effectively share or integrate data. Property owners and buyers must comply with an exhaustive and redundant list of forms to record properties, property rights, and rights holders within and between the two systems, with the additional burden of bureaucratic and manual processes. Property transfer follows the same manual procedures in most LAS organisations, except for a few who modernised their system by digitalising their records for better service delivery. LAS functions and organisations in Islamabad and the rest of the country have diversification in terms of operations, where the Development Authority (DA) in the Federal Capital, Islamabad, and the Board of Revenue (BoR) in the provinces are two key LAS actors, along with private sector organisations. The details of functions and LAS organizations working under different ministries and authorities are given in Figure 2. The BoR is the custodian of the land and property registration and mutation in the suburbs, mainly consisting of the British Colonial LAS. In contrast, the rest of the LAS organisations in urban areas are primarily run under contemporary LAS.

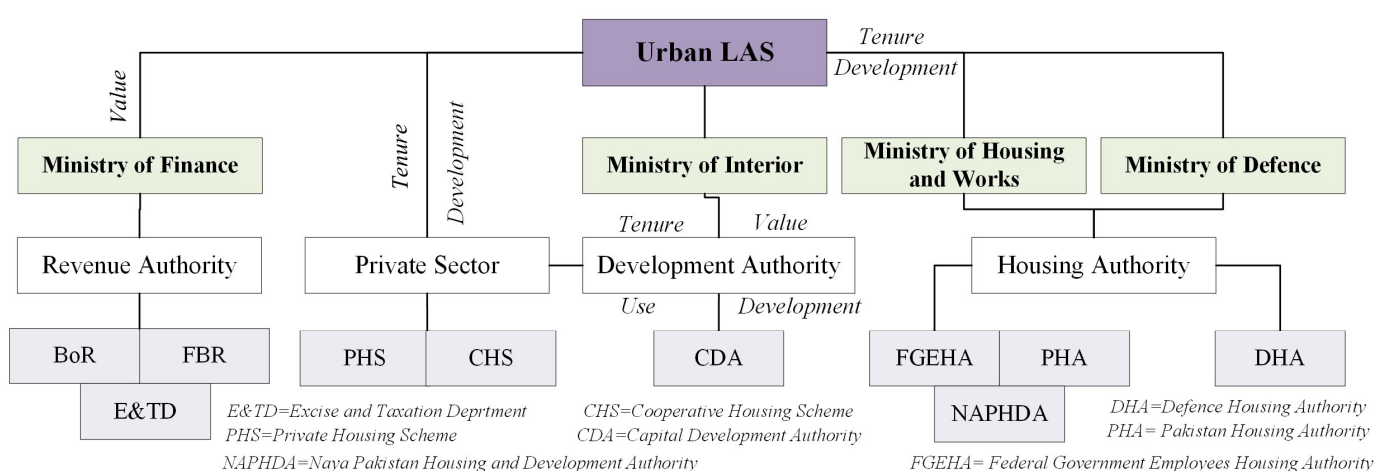


Figure 2. Mapping key LAS stakeholder organisations and their major functions in Islamabad.

The Punjab province, with the assistance of the World Bank, developed the Land Record Management Information System (LRMIS-P) between 2007 and 2017 [73]. However, the LRMIS-P can only manage the digitalisation of revenue-related attribute records in rural areas, which are mainly composed of British Colonial LAS. The LRMIS-P initiative

succeeded in recording 55 million rights holders in 23,806 revenue estates in rural areas of the province. The province saw an average of 462,020 land transactions annually over the past five years for a total of 44.3 million privately held land parcels [100]. In contrast, the property Record of Deed (RoD), also known as a registry, in urban areas and the whole cadastral mapping part (both urban and rural) in the country are still manual [101]. The LRMIS-P project's next phase is currently in progress [71], which requires careful attention and systematic development for the overlapping British Colonial and contemporary LASs in urban areas. Islamabad is still far behind in adopting digitalisation initiatives like LRMIS-P, and requires further attention to digital innovation.

In the existing manual LAS, the buyer's primary responsibility is to ensure that the property location is correct and that the seller has the original right of ownership. Land disputes in the country often arise due to joint ownership, making it crucial for a buyer to ensure a clear demarcation and partition of property in such cases [30]. The fiscal nature of LAS does not recognise separate ownership where different right holders are administered under single identification (*Khewat*) for revenue collection [102,103]. In the case of inheritance transfer, the Muslim Personal Law [104] is applicable. It also grants joint ownership rights to each family member on a single piece of land owned by their forefather. Suppose any family member intends to sell their part of joint ownership; in that case, they would need to get an official delineation of the respective piece of land and to update the official revenue records, which is rare in practice. Joint ownership often leads to disputes, as each member tries to claim the most valuable and costly part of the property.

Administratively, the property-related personal record is manually maintained in the BoR's Record of Rights (RoR) register and in a Property Information Report (PIR), which is based on Allotment Files by DA and other LAS organisations in urban areas. The RoR (see Figure 3) contains attribute information related to owners, cultivator, location and identity of the land, its source of irrigation, as well as rent and revenue collection details. The PIR (see Figure 4) describes details of the owner, property type and its location, litigations, restrictions and outstanding dues status, etc. The information provided in RoR and PIR serve as key source to model the LADM country profile. The revenue estate sketch maps (see [43,44]), housing scheme layout plan, and individual house layout plan/drawing refer to the spatial component of the LAS. The scheme layout plan (see Figure 5) contains the location and measurements of properties, subdivision, overall land use allocation information, etc. The individual house drawing (see Figure 6) contains the length, width, and height of each wall/room/storey of the house. The survey benchmarks are established to carry out local measurement during the planning of housing schemes, whereas conventionally, under the colonial system, tri-junction pillars (also stone and *burji* pillars) are manually erected on the ground during the land settlement of the revenue estate, with no record of coordinate system and angular information (only having field measurement). Many of the survey marks, which are over a hundred years old, are no longer available physically.

Register **Haqdarar Zamin Estate** (if any)..... Tehsil.....
 District **1** Year **2** Book No. **3** Part **1**

[PARTICULARS OF OWNER]													
4	5	6	6	6	6	6	7	8	9	10	11	11	
No. Khewat Malik	No. Khatauni cultivator	Name of owner with Father's name, caste and residence.	National Identity Card No.	Ownership status (owner mortgagee etc)	Specific share in the joint Khewat	Precise area according to the share	Agricultural Pass Book No.	Name of cultivator with description	Survey/Khasra No. and name (if any)	Area and soil classification of each number and total Khatauni cultivator and Khewat Malik	Source of irrigation including name of well, Rajah etc.	Rent paid by cultivator, rate and demand	Demand with details of revenue and cesses
1	2	3(a)	3(b)	3(c)	3(d)	3(e)	3(f)	4	5	6	7	8	9

Serial No.

1 Location Description
 2 Year
 3 Register No.
 4 Owner ID
 5 Cultivator ID
 6 Owner Details
 7 Cultivator Details
 8 Parcel ID
 9 Land and Soil Classification
 10 Irrigation Source Information
 11 Tax Details

Figure 3. Details and description of attributes maintained in the Record of Rights by the BoR (Source: Board of Revenue Land Revenue Rules 1968, FORM XXXIV).

Subject- **APPLICATION FOR PROPERTY INFORMATION REPORT (PIR)**

I am Allottee/ Attorney of Plot/House No. **3**, Street No. **3**, Sector **3**, Measuring **3**, Islamabad. It is requested that Property Information Report may kindly be issued to me.

The status of this plot is as Under:-

a. Vacant Plot **3**

b. Constructed House **3**

No. CDA/EM/ **1** Islamabad, 20 **2**

Subject- **PROPERTY INFORMATION REPORT (PIR)**

Plot No. **3** Sector **3**, Islamabad.

With reference to the application by Mr./ Ms/ Mrs. **4** bearing OWO Dy: No. **1** dated **2** on the above subject, following information is given as desired:

1.	Court Case/ Valid Stay Order	5 (yes or no)	1 File No.
2.	Clearance of Premium of Plot/ Delayed Charges/ Extension Surcharge (Specify if due).	6	2 Date
3.	Any other charges required to be remitted before transfer of allotment.	7	3 Location & Area
4.	The position of Power of Attorney	8	4 Owner Details
5.	The position of completion certificate issued or not issued.	9	5 Litigation
6.	Conveyance Deed Executed/ not Executed	10	6 Outstanding Dues
7.	Any restriction on transfer of allotment (Specify if any)	11	7 Pending Payment
8.	Any mortgage, loan, guarantee or Court Surety.	12	8 Power of Attorney
			9 Built Status
			10 Registered Deed
			11 Restriction
			12 Mortgage
			13 Official

This certificate is only provisional and actual determination of fitness of property is done at time of issuance of NDC. CDA stands indemnified against any losses or damages to any party in any transaction.

Signature: **13**

Stamp (By Name).

Figure 4. Details and description of attributes maintained in the Property Information Report by the DA and other LAS organisations (source: Capital Development Authority Property Information Report, FORM EF-3 and EF-4).

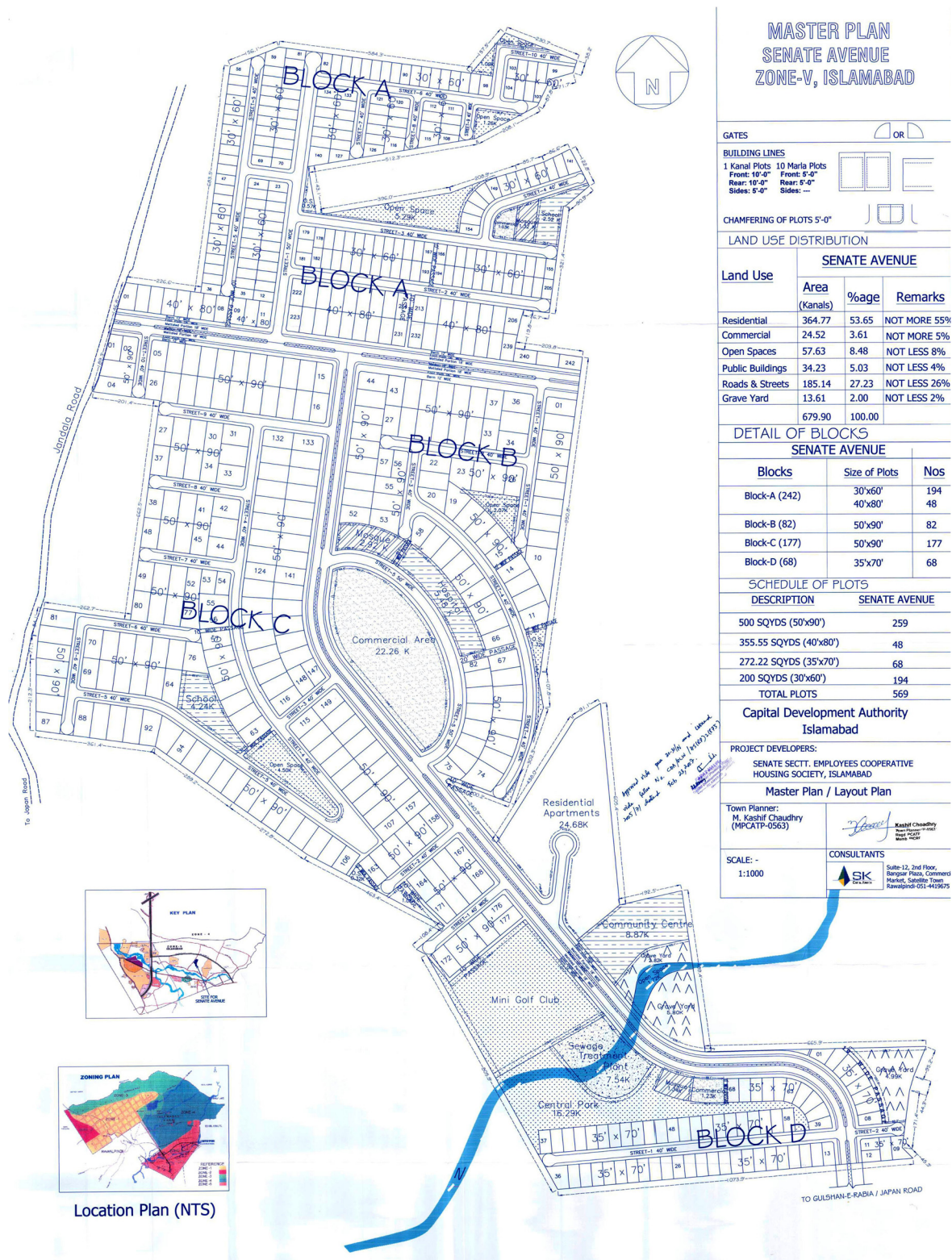


Figure 5. Housing scheme layout plan submitted at DA for approval. The layout plan contains size information of each property, the overall scheme land use, the north arrow, and the scale. The inset maps show the overall zones of Islamabad and the scheme location in Zone 5 (source: Capital Development Authority (online high quality map version can be searched through the link <https://www.cda.gov.pk/housing-societies>, accessed on 6 June 2024)).

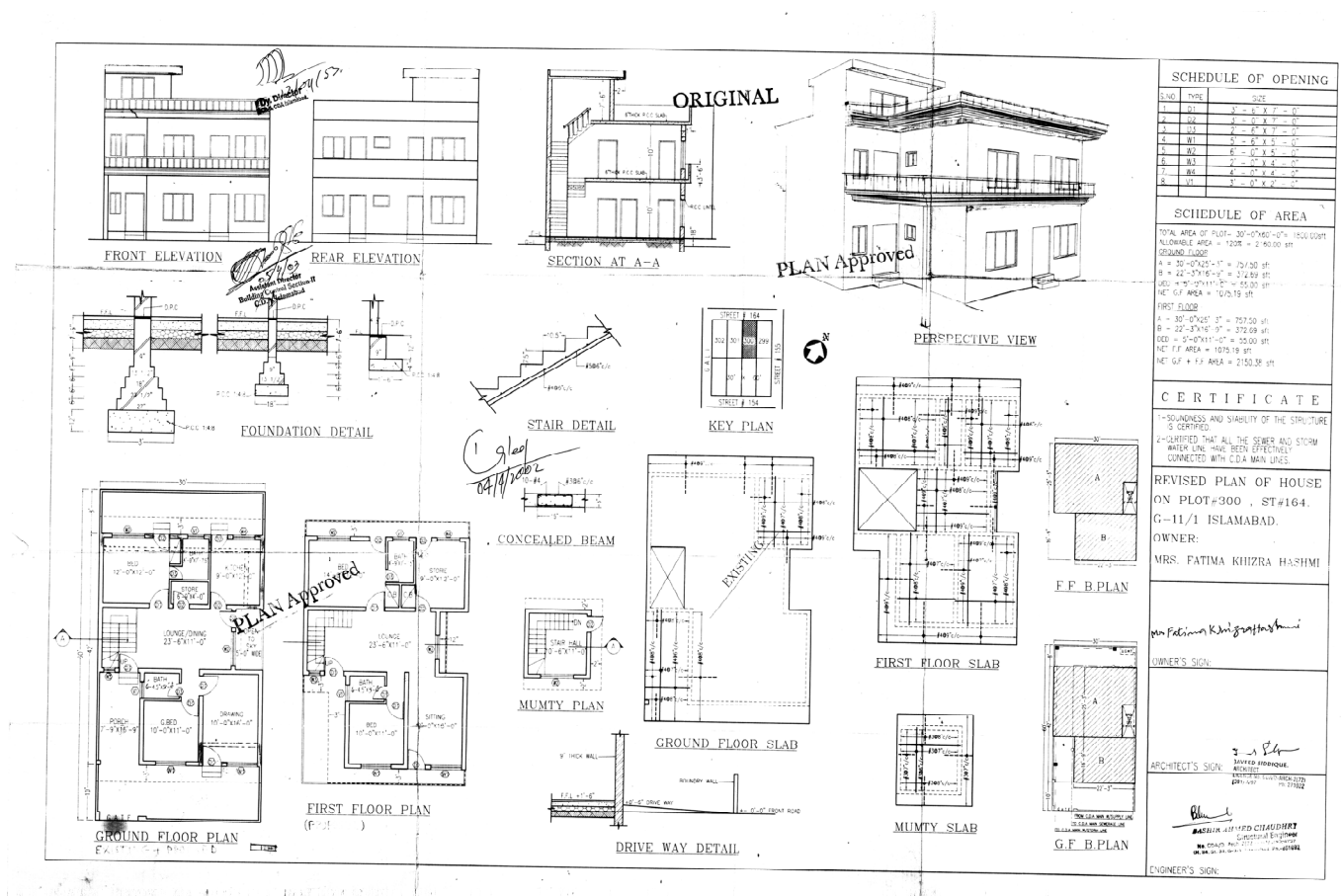


Figure 6. House layout plan submitted at DA for approval (source: Capital Development Authority).

4. Phase-2: Pakistan LADM Country Profile

The LADM country profile proposed for Pakistan is based on the primary structure of the LADM proposed by ISO [78]. The profile consists of three major classes that represent information on land or property ownership, its administration, and location, as shown in Figure 7. The Spatial Unit package has an additional Surveying and Representation sub-package. A further detailed overview of each package, along with their classes, is given in Figure 8.

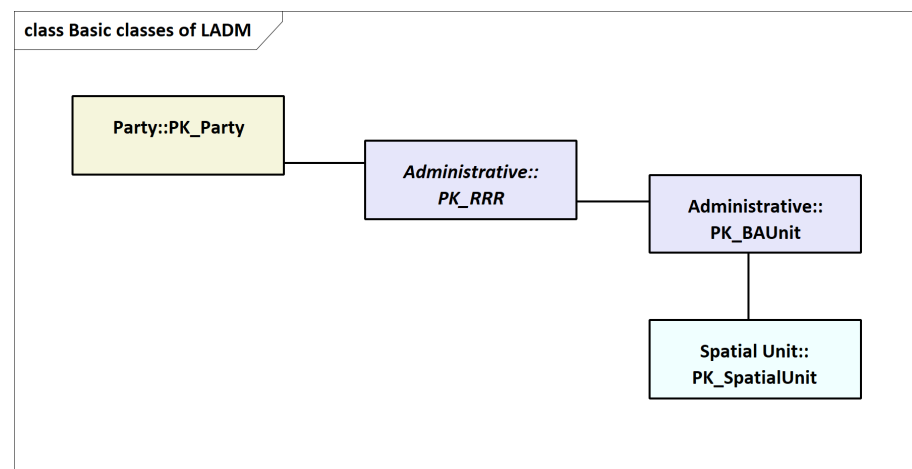


Figure 7. Basic classes of LADM country profile for Pakistan.

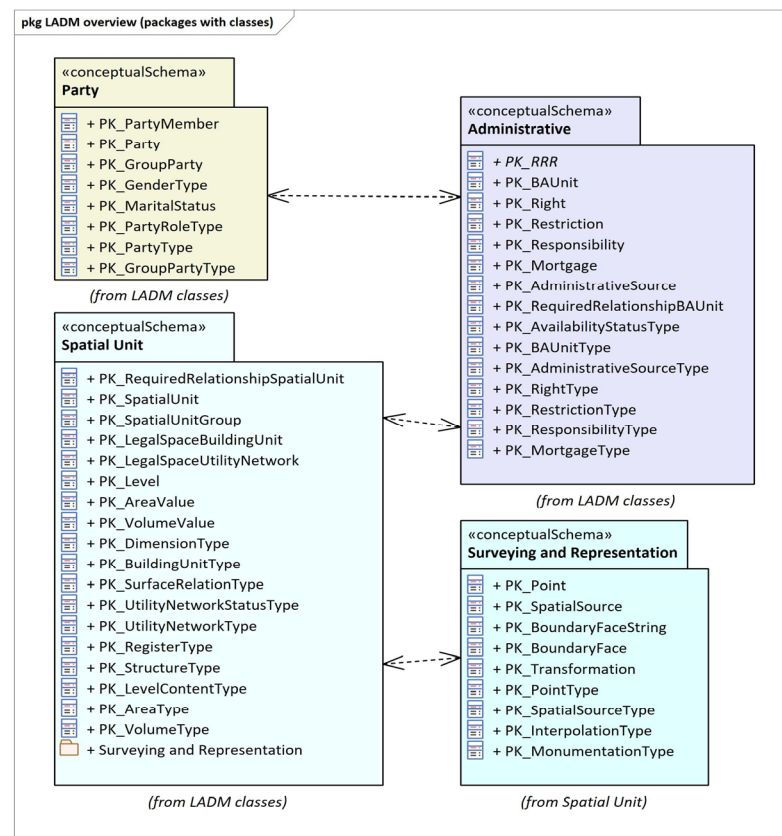


Figure 8. A detailed overview of PK_LADM packages and classes.

PK_Source is a special class and the starting point for the recordation or transfer of an interest in land or property in the form of PK_AdministrativeSource (Allotment File or Deed/Registry) and PK_SpatialSource (field measurement by surveyor); see Figures 9 and 10. “*” is used in multiplicities in UML. For example: “0..*” means zero or more instances. Multiplicities as represented in the Figures are based on [78].

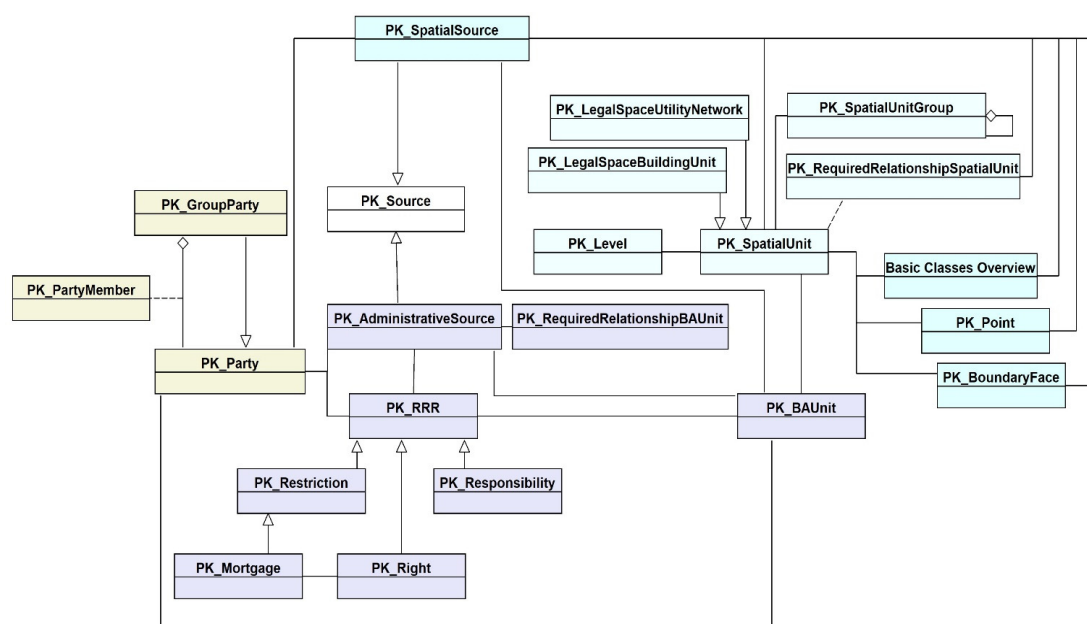


Figure 9. Overview and relationship of the LADM source class.

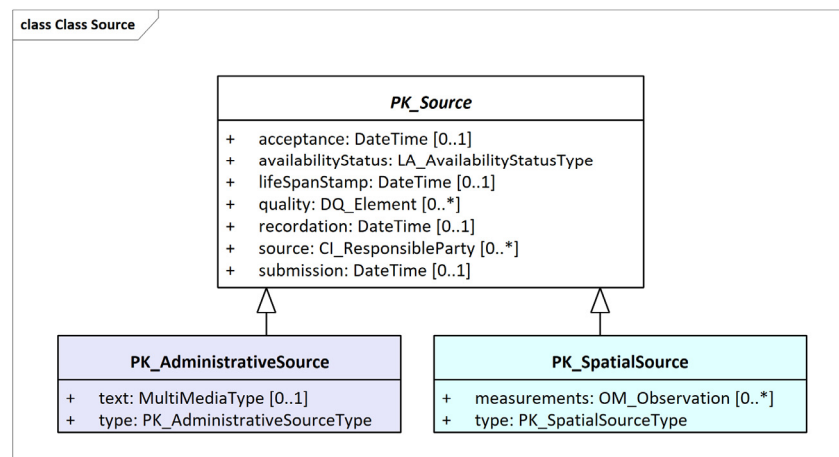


Figure 10. Classes, attributes, and specialisation of the PK_LADM source class. 0..* means zero or more instances.

4.1. PK_Party Package

In the LADM profile for Pakistan, the Party Package contains information regarding (group of) individuals and organisations involved in Land Administration (LA) processes, as well as detailed attributes and coded values; see Figure 11.

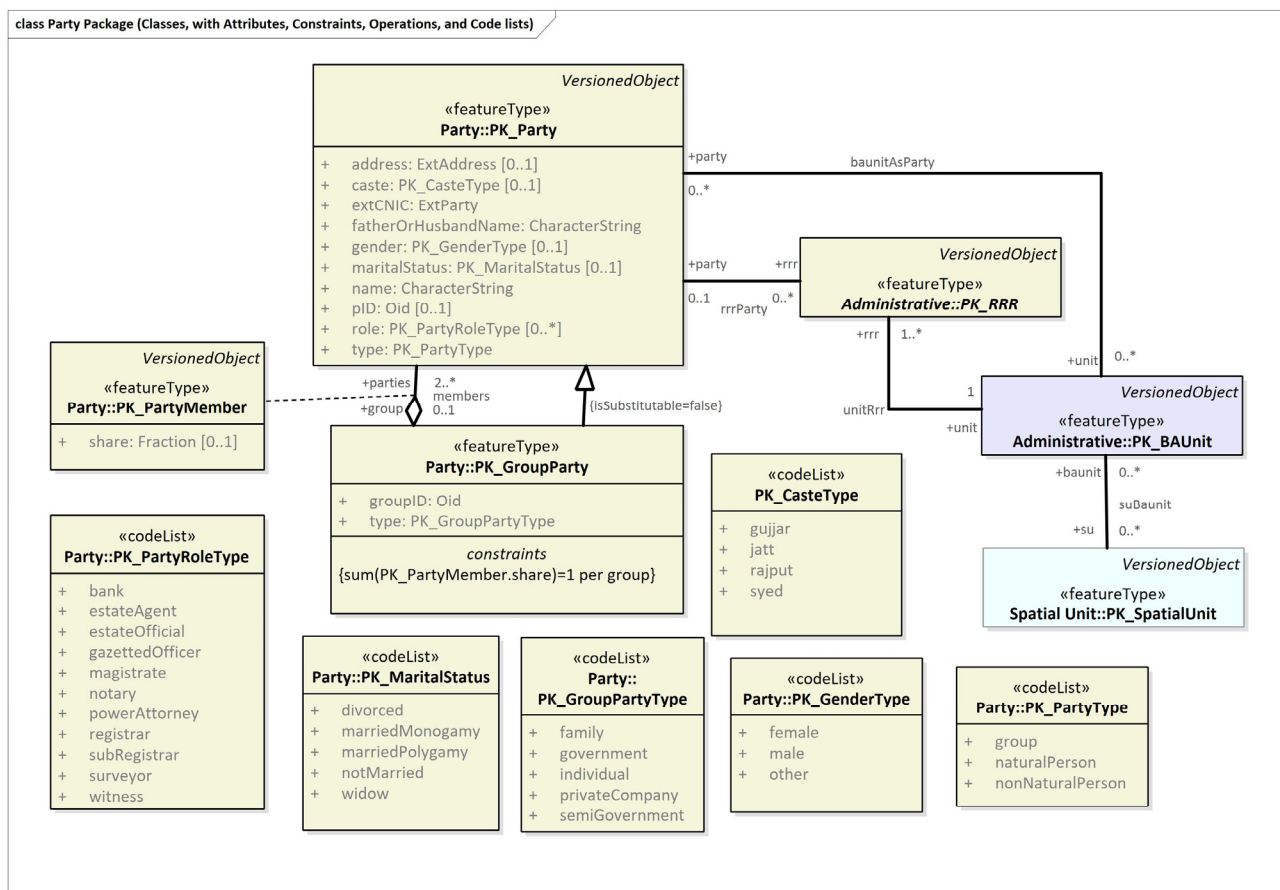


Figure 11. Classes, attributes, multiplicities, and code lists of the PK_Party package. 0..* means zero or more instances.

4.1.1. PK_Party

The PK_Party class (see Table 1) includes the information (attributes) of involved natural persons and non-natural entities. Attributes are names, address, caste, roles, father name, gender, marital status. It is required to record the father's name (to maintain the family genealogical tree to comply with Muslim Personal Law [104] for inheritance) or the husband's name, in the case of a married woman having legal interests in the property. In Pakistan, the National Database and Registration Authority (NADRA) issues a distinct Computerised National Identification Number (CNIC) to every citizen, which can serve as an external source for party identification and verification. During property registration in Islamabad, the authentication of the CNIC is not directly integrated with a NADRA central register/database, as the LAS relies predominantly on manual record-keeping. Efforts are being made to record fingerprints and photos as part of the LAS in Islamabad. However, it should be noted that this record needs to be integrated with NADRA in future for real-time verification, which is not currently a mandatory legal requirement. Due to the lack of this integration, a woman seller is required to present her blood relative as an additional witness to verify her property. Any involved party is further coded and categorised into different types, as natural person or group (company). Parties can be grouped into broad entities according to their role in the process related to LAS. The party role types are defined in accordance to the roles of professionals in the existing LAS, for example, registrar, . . . notary, surveyor, etc. The revenue record needs to include details of the owner's caste, which presents a challenge due to the vast number of existing caste classifications, numbering in the thousands. The code list PK_CasteType in Figure 11 contains values for a few major castes, but it necessitates further expansion to encompass the full spectrum. To enhance the security of women's land rights, the representation of PK_MaritalStatus should be linked to the NADRA database for real-time update.

Table 1. PK_Party class attributes overview.

Value	Overview	Type	Multiplicity
pID	The party identifier	Oid	0..1
name	Official party name	Text	1..1
fatherOrHusbandName	The party father or husband's name	Text	1..1
extCNIC	External party identifier	Oid	1..1
gender	Gender types	PK_GenderType	0..1
maritalStatus	Marital status of the party	PK_MaritalStatus	0..1
caste	The party caste or tribe name	PK_CasteType	0..1
address	The party address	ExtAddress	0..1
type	The party type	PK_PartyType	1..1
role	The party involved in the data update and maintenance process	PK_PartyRoleType	0..*

0..* means zero or more instances.

4.1.2. PK_GroupParty

The parties involved in LA processes are coded and grouped according to their role in the PK_GroupParty class. The class also has an operation to check whether the total sum of all shares of all party members in the given land or property is equal to one, see Table 2.

Table 2. PK_GroupParty class attributes overview.

Value	Overview	Type	Multiplicity
groupID	PK Group party identification number	Oid	0..1
type	Affiliation type of the party group	PK_GroupPartyType	0..1

4.1.3. PK_PartyMember

Each party member of the PK_GroupParty can have a share in land or property and is recorded in the PK_PartyMember class, see Table 3.

Table 3. PK_PartyMember class attributes overview.

Value	Overview	Type	Multiplicity
share	The share each party member holds	Fraction	0..1

4.2. PK_Administrative Package

The Administrative Package mainly consists of information related to RRRs and the way the land is administered in any country. The details of the attributes of each class of PK_Administrative package and their coded values are given in Figure 12.

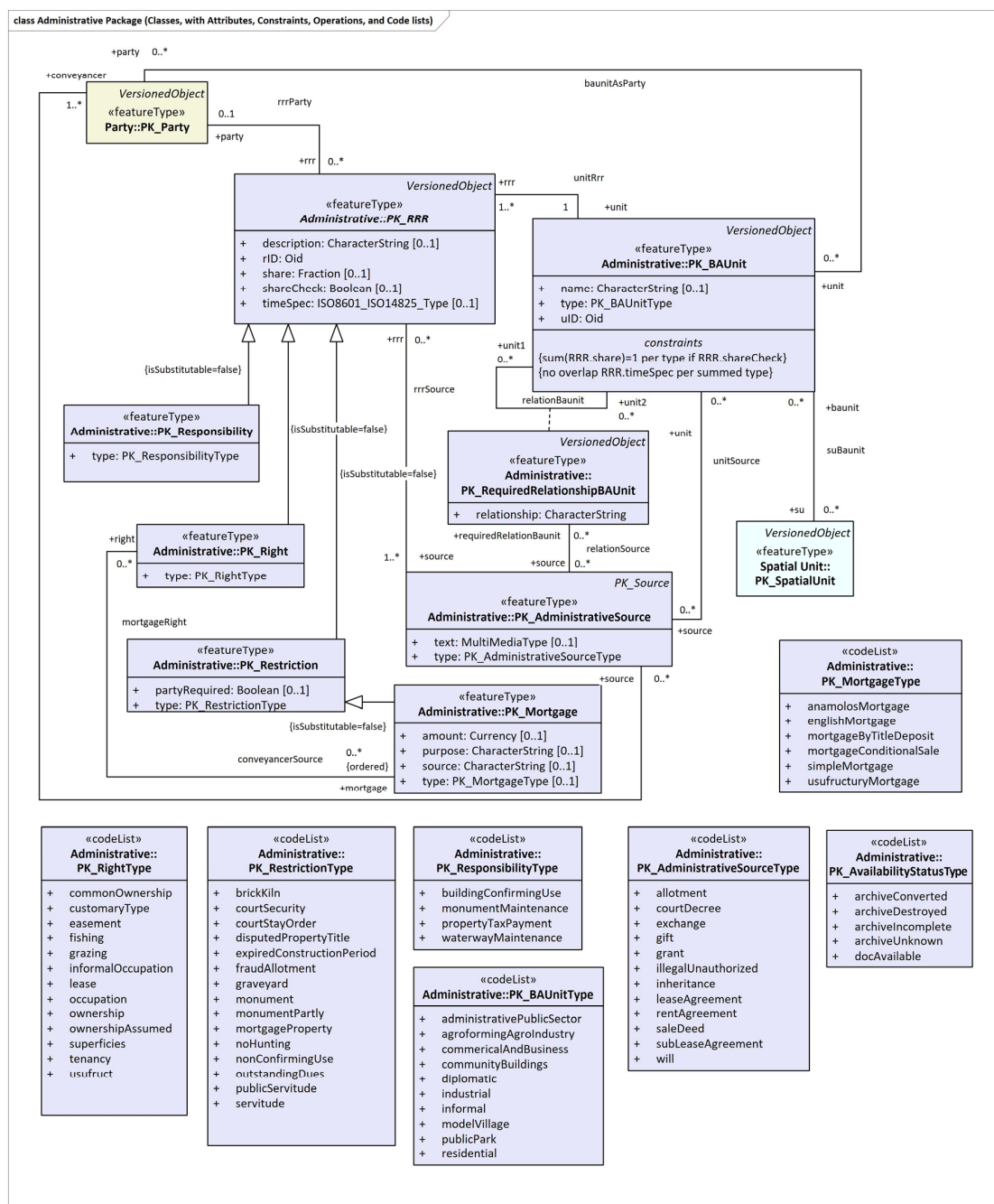


Figure 12. Classes, attributes, multiplicities, and code lists of the PK_Administrative package. 0.* means zero or more instances.

4.2.1. PK_RRR

The PK_RRR class allows for the registration and management of various rights, such as ownership, lease, tenancy, etc., that are associated with land or property. Also, it allows for the recordation of any associated restrictions, such as public servitude for building bylaws or any legal binding due to court stay order or mortgage of land or property. Two types of mortgage finances exist in the country—Islamic, and conventional—where the former is based on the principle of risk (profit-loss) sharing, and the latter depends on interest (*riba*) [105–107]. There are also certain responsibilities with each land or property, such as building conformal use, as per designated land use guidelines by development authorities or payment of dues such as annual property tax, etc. The operational use of sharing right at a certain point of time is described through the existing ISO standards including ISO 8601:2004, Data elements and interchange formats—Information interchange—Representation of dates and times and ISO 14825:2011, Intelligent transport systems—Geographic Data Files (GDF)—GDF5.0, see Table 4.

Table 4. PK_RRR class attributes overview.

Value	Overview	Type	Multiplicity
description	RRR's description	text	0..1
rID	RRR's identifier	Oid	1..1
share	Party's share in RRR	Fraction	0..1
shareCheck	If a constraint on the some of shares is applicable	Boolean	0..1
timeSpec	Operational use of a right in time sharing	ISO 8601 or 14825 type	0..1

4.2.2. PK_BAUnit

A BAUnit (different from a spatial unit) represents the smallest administrative control unit within the LAS with at least one RRR attached. A BAUnit has no temporal dependencies with RRRs. The BAUnit can consist of types (categories) based on land use, taxation, or any other administrative classification. In Pakistan, land use classification in urban areas is performed rigorously; however, the classes for taxation purposes are broad and vague. The BAUnit within Pakistan's profile is proposed according to the land use categories. A Party has no RRRs associated with it in case the party has a specific role, see Table 5.

Table 5. PK_BAUnit class attributes overview.

Value	Overview	Type	Multiplicity
name	Given name of PK BA unit	text	0..1
type	List of PK BAUnit types	PK_BAUnitType	1..1
uID	PK BA Unit identifier	Oid	1..1

4.2.3. PK_AdministrativeSource

The PK_AdministrativeSource (see Table 6) is a specialisation class of PK_Source, which can be translated as Record of Deed (Registry/sale deed) or Allotment File in Pakistan's context. The categorisation of PK_AdministrationSource is coded into a defined list, as shown in Figure 12.

Table 6. PK_AdministrativeSource attributes overview.

Value	Overview	Type	Multiplicity
text	Registration document content	MultimediaType	0..1
type	Document type	PK_AdministrativeSourceType	1..1

4.3. PK_Spatial Unit Package

The Spatial Unit package with a sub-package, Surveying and Representation, manages the critical information related to the property's location on the ground and its seamless

representation. The distinct details related to land and property are given in textual and/or geometric form, either in 2D or 3D form. Property location demarcation in the country is complicated, particularly in relation to urban LAS. Two distinct systems (British and contemporary) interact for property registration, mainly relying on textual information and manually drawn sketches or maps (drawings). Both systems are mutually exclusive. Considering the textual and manual nature of LAS, it is essential to adopt the technical specifications given in the Spatial Unit package and its sub-package to upgrade the existing LAS, allowing us to record the precise location of land and property ISO 19125-2:2004, Geographic information—Simple feature access—Part 2: SQL option standard define required relationships among spatial units. The details of the attributes of each class of PK_SpatialUnit Package and their coded values are given in Figure 13.

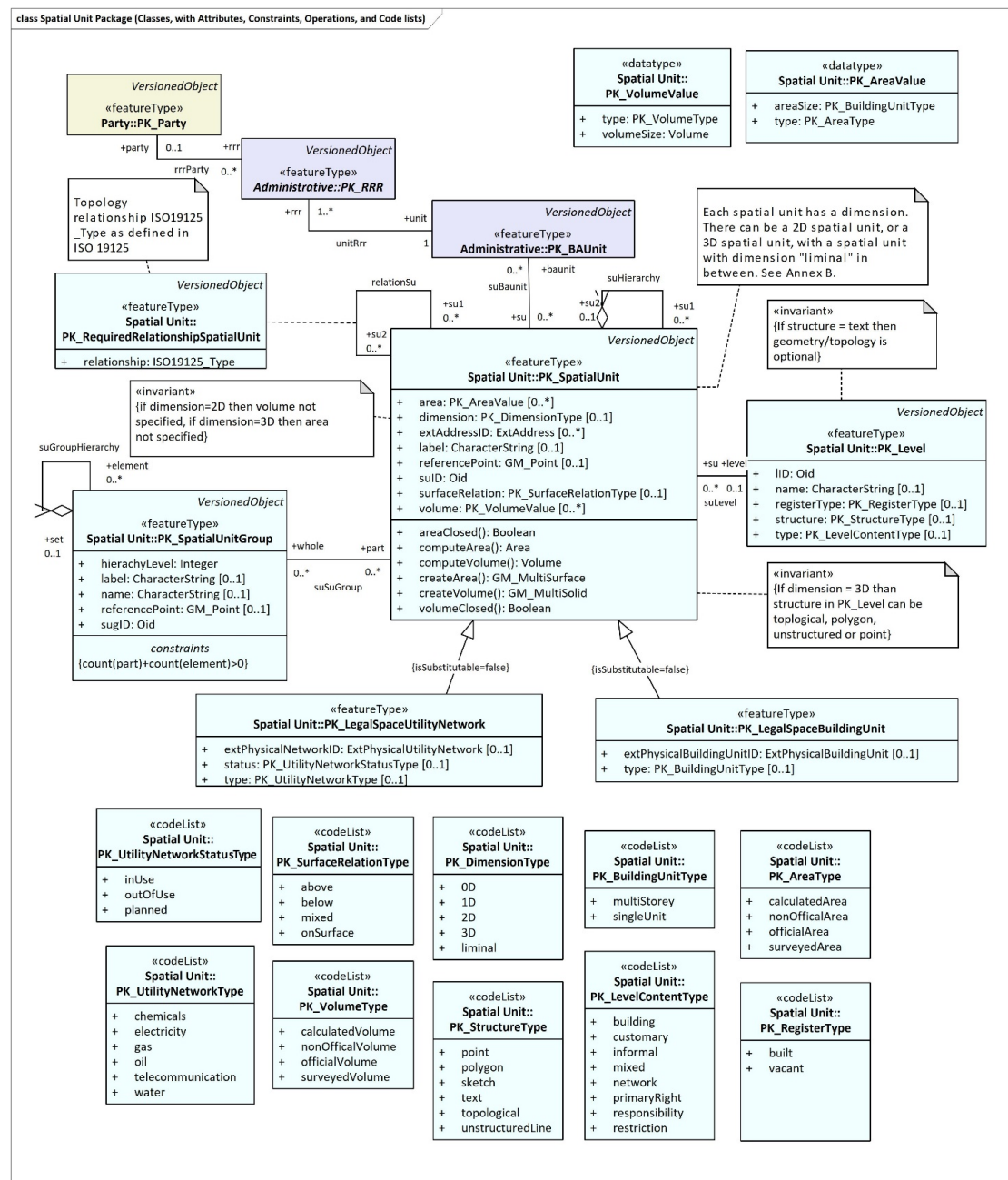


Figure 13. Classes, attributes, multiplicities, and code lists of the PK_LADM Spatial Unit package. 0..* means zero or more instances.

4.3.1. PK_SpatialUnit

The PK_SpatialUnit (can also be referred to as ‘parcel’) is the main class for recording the location of land or property in the form of text, point, line, area, or volume. In the PK_SpatialUnit class, area and volume are the two data types used to represent 2D and 3D spatial units. PK_SpatialUnit allows for certain operations like computeArea, createArea, etc., see Table 7.

Table 7. PK_SpatialUnit attributes overview.

Value	Overview	Type	Multiplicity
area	Parcel area	PK_AreaValue	0..1
dimension	Parcel dimension	PK_DimensionType	0..1
label	Parcel short description	Text	0..1
referencePoint	Point inside the parcel	GM_Point	0..1
suID	Parcel identification	Oid	1..1
surfaceRelation	Parcel above or below the surface	PK_SurfaceType	0..1
volume	Parcel volume	PK_VolumeValue	0..*

0..* means zero or more instances.

4.3.2. PK_SpatialUnitGroup

PK_SpatialUnitGroup class (see Table 8) organises spatial units into administrative zones. For Pakistan, the administrative zoning is based on the hierarchy level where level 0 is country, level 1 is province/territory, and so on, as given by [43].

Table 8. PK_SpatialUnitGroup attributes overview.

Value	Overview	Type	Multiplicity
hierachyLevel	Administrative subdivision level	Integer	1..1
label	Short description of the PK spatial unit group	Text	0..1
name	Name of the group	Text	0..1
referencePoint	A point location within the PK spatial unit group	GM_Point	0..1
sugID	Spatial unit group identification	Oid	1..1

4.3.3. PK_Level

PK_Level consists of spatial units with a geometric or thematic consistency. The PK_Level class organises spatial units into different thematic levels (built or vacant) [86]. PK_Level can further be described through register type, structure type, and content level type (Table 9) having unique code lists, see Figure 13.

Table 9. PK_Level class attributes overview.

Value	Overview	Type	Multiplicity
IID	Identification no. of the PK level	Oid	0..1
name	Name of the PK level	Text	0..1
registerType	Type of registration of the level	PK_RegisterType	0..1
structure	Type of structure of the level	PK_StructureType	0..1
type	Type of content of the level	PK_LevelContentType	0..1

4.3.4. PK_LegalSpaceUtilityNetwork

The PK_LegalSpaceUtilityNetwork is a subclass of PK_SpatialUnit that records utility networks such as electricity, gas, telecommunication, etc., see Table 10.

Table 10. PK_LegalSpaceUtilityNetwork class attributes overview.

Value	Overview	Type	Multiplicity
extPhysicalNetworkID	Identification no. of the utility network	ExtPhysicalUtilityNetwork	0..1
status	Utility network existing status	PK_UtilityNetworkStatusType	0..1
type	Utility network type	PK_UtilityNetworkType	0..1

4.3.5. PK_LegalSpaceBuildingUnit

The PK_LegalSpaceBuildingUnit is another subclass of PK_SpatialUnit to record building unit types, such as single building units or multistorey buildings, see Table 11.

Table 11. PK_LegalSpaceBuildingUnit class attributes overview.

Value	Overview	Type	Multiplicity
extPhysicalBuildingUnitID	Identification no. of the building unit	ExtPhysicalBuildingUnit	0..1
type	Building unit type	PK_BuildingUnitType	0..1

4.4. Surveying and Representation Sub-Package

The British introduced surveying for LAS maintenance consisting of boundary marks, such as Tri-Junction pillars, Corner Stone pillars, and Baseline Stone pillars, to identify revenue estate boundaries, parcel boundaries, and angular changes in parcel boundary lines, respectively. The boundary marks were established during the land settlement process without the inclusion of any written information, primarily in the British era. However, these marks may no longer be present in the terrain, or could have been disrupted by natural calamities like floods or deliberate actions such as the unauthorised occupation of another's property over an extended period. It is important to note that no numerical information about the marks' angle or location was recorded on cadastral maps or field book registers during the land settlements. The boundary mark's accurate placement is crucial to converting cadastral maps to digital format and resolving land disputes. References [43,44] suggest the extensive use of geospatial technology and a participatory approach to improve accuracy and upgrade the quality of existing LAS data. The details of the attributes of each class of PK_SurveyingAndRepresentation Sub-Package and their coded values are given in Figure 14.

4.4.1. PK_Point

PK_Point is the main class for recording the LAS survey-related information, and serves as a key reference to describe the parcel's location through PK_SpatialUnit class. There is flexibility in the model, such that if the information in 2D and 3D is not currently available in the system, the textual information can also be incorporated without any geometry, see Table 12.

Table 12. PK_Point class attributes overview.

Value	Overview	Type	Multiplicity
interpolationRole	The function of a point within the composition of a line	PK_InterpolationType	1..1
monumentation	Type of monument	PK_MonumentationType	0..1
originalLocation	Location derived from measurements and observations	GM_Point	1..1
pID	Point identification no.	Oid	1..1
pointType	A list of types of a PK point	PK_PointType	1..1
productionMethod	Lineage of a PK point	LI_Linear	0..1
transAndResults	Transformation and transformed location	PK_Transformation	0..1

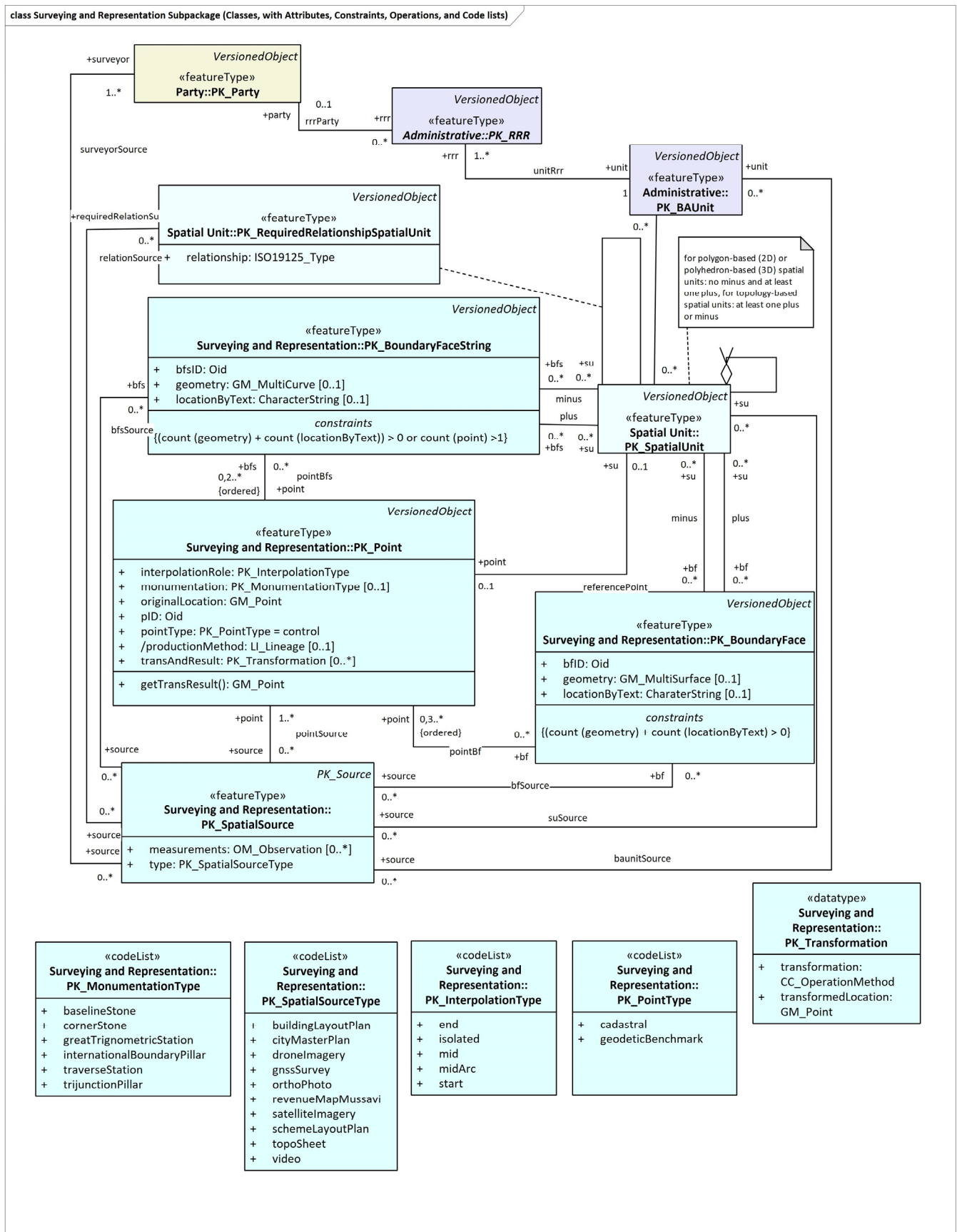


Figure 14. Classes, attributes, multiplicities, and code lists of the PK_LADM Survey and Spatial Representation Sub-Package. 0..* means zero or more instances.

4.4.2. PK_BoundaryFace

The PK_BoundaryFace class is linked with PK_Point to record 3D representation (as a vertex of each side of a 3D parcel). The designated geometry of the class is Multi Surface for volumetric representation, see Table 13.

Table 13. PK_BoundaryFace class attributes overview.

Value	Overview	Type	Multiplicity
bfiD	PK boundary face identification no.	Oid	1..1
geometry	3D surface to represent parcel boundary	GM_MultiSurface	0..1
locationByText	Textual representation of boundary	Text	0..1

4.4.3. PK_BoundaryFaceString

The PK_BoundaryFaceString class is linked with the PK_Point class to record 2D representation (in the form of vertex of 2D parcel boundary) in point form. The geometry of the class is Multi Curve, see Table 14.

Table 14. PK_BoundaryFaceString class attributes overview.

Value	Overview	Type	Multiplicity
bfiD	PK boundary face identification no.	Oid	1..1
geometry	2D surface to represent parcel boundary	GM_MultiCurve	0..1
locationByText	Textual representation of boundary	Text	0..1

4.4.4. PK_SpatialSource

The PK_SpatialSource class records measurements (distance, GPS Coordinate, or bearing) which may be based on GNSS survey, housing scheme layout plan, etc. The PK_SpatialSource establishes associations with the Party (surveyor) who will be responsible for obtaining the measurements of land or property, see Table 15.

Table 15. PK_SpatialSource class attributes overview (0..* means zero or more instances).

Value	Overview	Type	Multiplicity
measurements	Measurements and observations	OM_Observation	0..*
type	Type of the spatial source	PK_SpatialSourceType	1..1

0..* means zero or more instances.

4.5. PK_External Package

The information related to the land or property land use, land valuation, and additional information related to the party's identification and address are recorded in the external package. For example, the PK_ExtParty class allows for the recordation of the information related to the fingerprint, photo, and signature necessary for the land and property registration. For ExtAddress the ISO 19115:2003, Geographic information—Metadata specification are used, whereas currency specification in ExtValuation and ExtTransaction use ISO 4217:2008, Codes for the representation of currencies and funds in the ISO/TS 19103:2005, Geographic Information—Conceptual schema language standards. The details of the attributes of each class of PK_External Package and their coded values are given in Figure 15.

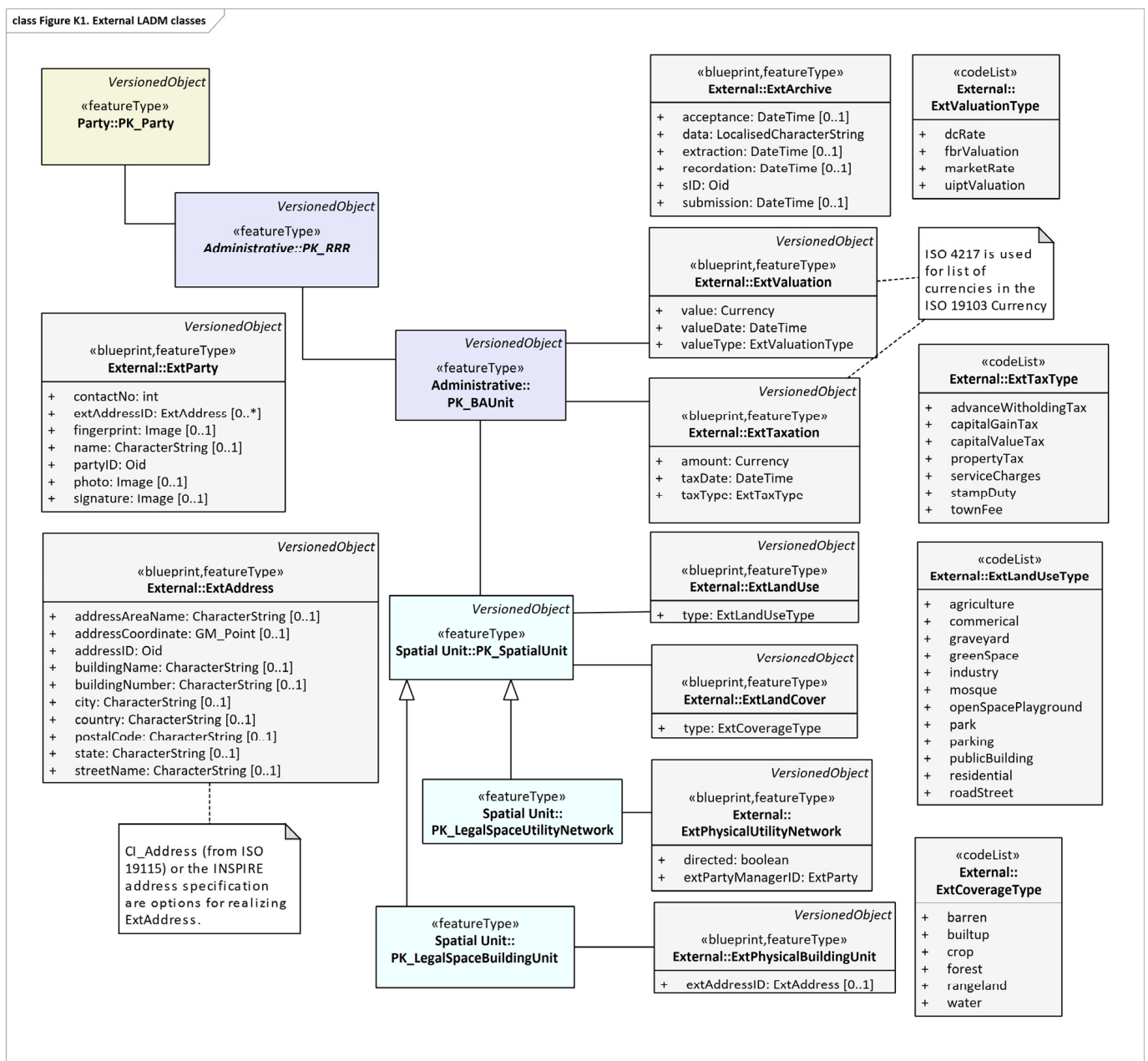


Figure 15. Classes, attributes, multiplicities, and code lists of PK_LADM external classes. 0..* means zero or more instances.

4.6. Validation

A conformance test given in Annex A of LADM is performed on the PK_LADM, and the country profile is fully conformant to the specification established by ISO/TC211 [78]. The conformance test validates the model at three levels, i.e., low, medium, and high, where PK_LADM qualifies for high conformance (level 3).

A panel of experts from LAS organisations and academia was identified to consult and validate the developed PK_LADM profile. The proposed PK_LADM profile and its related key discussion points were shared with the experts through an online questionnaire, summarised below. A follow-up consultative workshop was conducted online to discuss the following critical components of the profile.

- Proposal to develop existing Registration, Allotment, and File system into a standardised, integrated, and unified system based on LADM standard or a paper-based manual system.
- Requirement to develop 3D LAS for Pakistan.
- Clarity and communication of Rights, Restrictions, and Responsibilities in existing LAS.
- Ambiguities and overlaps in existing LASs, and further requirements for re-organisation.
- Suggestion to implement inter-organisational workflows to facilitate customers/end-users.
- Suggestion to implement the PK_LADM profile, and its feasibility to adopt a centralised system managed by a single organisation/authority or distributed among organisations.
- Feasibility and adoption of technology to implement the Spatial Unit Package and Surveying and Spatial Representation Sub-Package.

The experts strongly recommended the development of an integrated, standardised, and unified digital LA system. They emphasized that it was a good idea and a need for the hour to achieve transparency and interoperability. Regarding the development of 3D LAS, the experts suggested developing 2D first, and then scaling it towards 3D in the future. The experts also noted that the existing RRRs needed more clarity, awareness, and communication. They suggested amending existing legislation and guidelines in the context of complexities arising due to rapid urban infrastructure and vertical development. The existing LAS also required re-organisation to avoid overlapping and promote clear responsibilities related to the LAS function. The experts recommended the LADM, and it shows feasibility in being deployed in the centralised environment adopted by LAS organisations to develop inter-organisational workflows. However, the experts recognized the associated legal and administrative challenges, including poor legislation and their low implementation for urban LAS, lack of conclusive land record (a piece of land owned by one person having a vertical building with multiple shops/apartments owned by many), bringing disintegrated LASs into the centrally coordinated system and outdated land record (particularly sketch maps) to accurately demarcate ownership on the ground. They considered it a crucial success factor to overhaul the manual survey and mapping practices by adopting technology and utilising the LADM Spatial Unit package and the Surveying and Representation sub-package.

5. Phase-3: Implementation

ISO/TC211 [78] introduces a special class of Versioned Objects in the LADM to capture time dimensions related to LAS transactions. Most of the LADM classes maintain temporal versions of their designated datasets as soon as a change happens in any recorded data through the Versioned Object. The details of all LADM classes enabled with version history, data types used in LADM, and the attributes of PK_VersionedObject are given in Figure 16. A further test run is required that uses field data to implement the conceptual PK_LADM.

5.1. PK_LADM Impact Evaluation to FELA and SDGs

The evaluation criteria for the PK_LADM are based on the FELA and SDGs. The authors of this research already identified vital challenges of existing LAS in Pakistan using FELA [30], including the development of conclusive and reliable LAS using (3D) geospatial technology, reforming and implementing laws and policies, as well as avoiding corruption and malpractices.

Figure 17 identifies the SDGs' targets that are crucial milestones for designing and developing the integrated urban LAS in Pakistan, and Table 16 offers a way forward to achieve the SDGs using the PK_LADM.

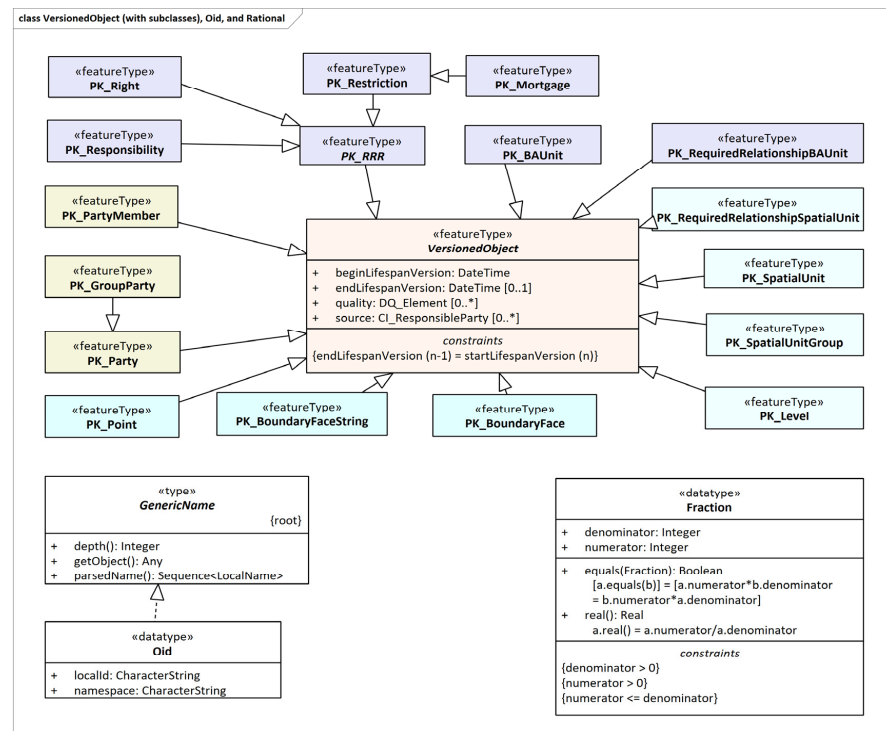


Figure 16. Details of PK_LADM versioned classes and data types used in PK_LADM.

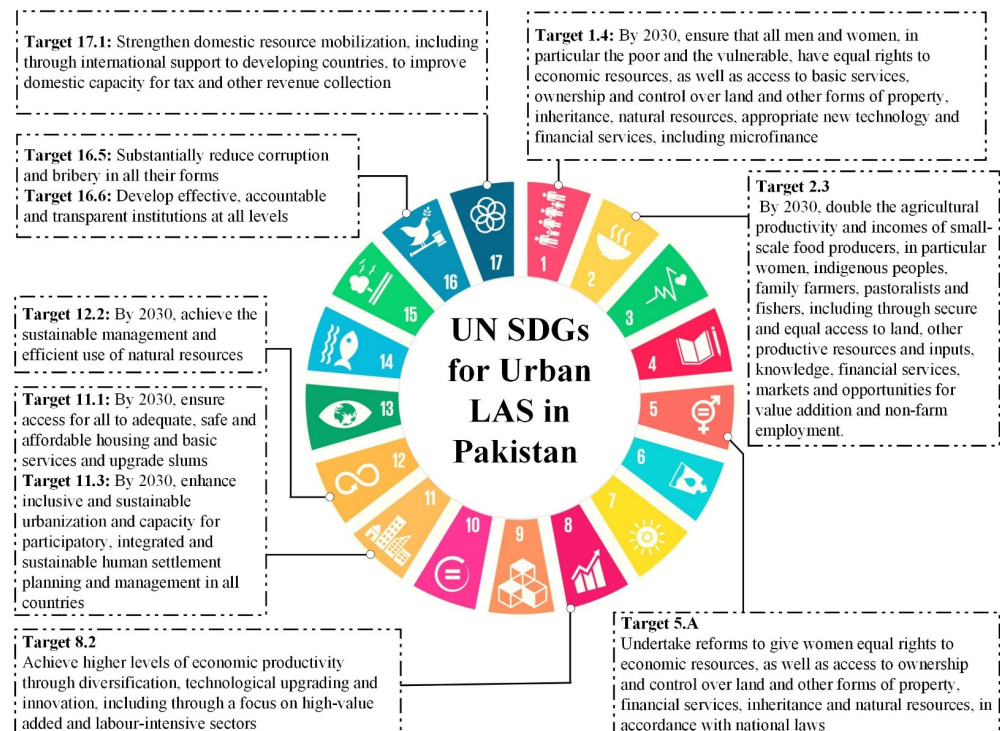


Figure 17. Overall 17 SDGs goals are: No Poverty (1), Zero Hunger (2), Good Health and Well-being (3), Quality Education (4), Gender Equality (5), Clean Water and Sanitation (6), Affordable and Clean Energy (7), Decent Work and Economic Growth (8), Industry, Innovation and Infrastructure (9), Reduce Inequality (10), Sustainable Cities and Communities (11), Responsible Consumption and Production (12), Climate Action (13), Life Below Water (14), Life on Land (15), People, Justice and Strong Institutions (16), and the Partnerships for the Goals (17). The identified SDGs goals and targets are critical for the development of LAS in Pakistan.

Table 16. Achieving SDGs goals by adopting PK_LADM.

SDG Goal	SDG Target	Achievement by Adopting PK_LADM
1—No Poverty	1.4	To achieve the target of property ownership, inheritance rights, and new technology adoption, the PK_LADM profile for Pakistan is anticipated to provide a transparent and open framework to access land and property information with the possibility of its online availability.
2—Zero Hunger	2.3	To achieve secure and equal access to land, the PK_LADM will greatly support the traceable (versioned) digital transaction and easy accessibility of land records through PK_LADM.
5—Gender Equality	5.a	Women (especially rural women), being a marginalised segment in Pakistani society, suffer from mandatory property ownership rights under Muslim inheritance laws [108]. To achieve equal rights for women to get access to ownership and control over land and property, PK_LADM offers integrated and digital support [109].
8—Decent Work and Economic Growth	8.2	The goal of economic development through innovation and technology upgradation can be met through the implementation of PK_LADM in the LAS sector. Tax and revenue collection in a developing country, Pakistan, is very important; however, currently, the country falls behind in achieving the targets and unlocking the potential for economic growth [35,63,64,110].
11—Sustainable Cities and Communities	11.1	Access to safe and affordable housing for all can be achieved by introducing LADM, as the currently manual nature of LAS has loopholes and issues in locating suitable land for affordable housing [46,71,111].
	11.3	For integrated, sustainable urbanisation and planning, it is crucial to upgrade existing manual LAS [29,31] into a sophisticated and integrated LAS by implementing PK_LADM.
12—Responsible Consumption and Production	12.2	The alarming depletion of natural resources amid rapid urbanisation [112–115] underscores the significance of PK_LADM as a practical solution for effective management and rational planning of natural resources.
16—Peace, Justice and Strong Institutions	16.5	The conventional cadastre and land administration has been notorious due to corruption, where officials mainly exploit the manual nature of LAS [77,116]; however, the PK_LADM can help reduce corruption and bribery.
	16.6	Developing effective, accountable, and transparent institutes, including LAS organisations in the country, is critical [117]. The LAS stakeholders are facing issues, especially those dealing with organisations under government control [30,118].
17—Partnership for the Goals	17.1	The potential for tax and revenue collection in the country is high. However, the achievements are too low [63,110]. To improve the domestic tax and revenue collection by mobilising local resources in an integrated manner, it is critical to strengthen the current manual LAS using PK_LADM.

5.2. PK_LADM into 2D/3D LAS

The adoption of LADM by each LAS organisation is pivotal to integrating and digitalising the manual LAS in the country. The existing manual processes involved in the LAS require redefinition. The LAS processes are to be augmented with an LADM-compliant central database. The existing manual forms and application procedures should be replaced with online ones for better service delivery.

The growth rate of urban areas in Pakistan is twice that of rural areas, and particularly vertical urban development is being encouraged at the national level [56,119–121]; see Figure 18. In the LADM Spatial unit package and sub-package, the dimension of space can be recorded both textually and spatially. Depending on the existing LAS setup, textual, 0D (point), 1D (line), 2D (polygon), and 3D (volume) can be captured in the LADM [122]. An overview of different Level of Detail (LOD) is given in Figure 19. The housing society layout plan given in Figure 5 can be used to create LOD 0.0, whereas the house plan given in Figure 6 helps create further detailed LODs for 3D. Currently, no LiDAR (Light Detection and Ranging) data or Drone images are available with LAS organisations in the country to create the seamless 3D model; however, ongoing rapid urban development (see Figure 18) needs careful attention in this regard.



Figure 18. Ongoing urban vertical development in Islamabad, Pakistan (2022).

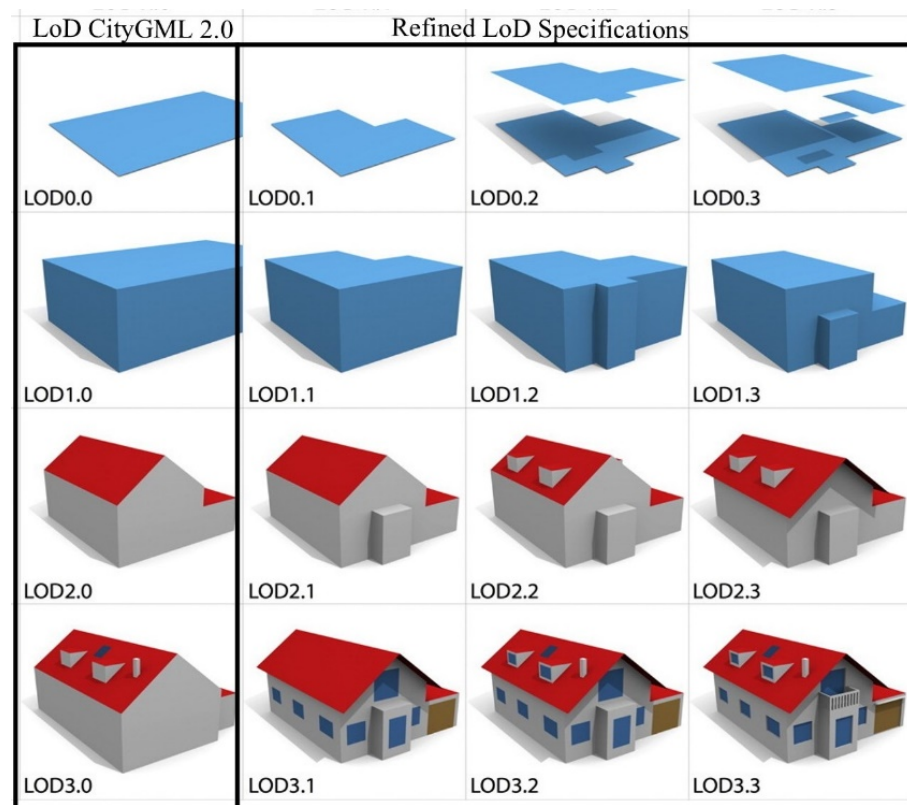


Figure 19. Level of detail for the development of parcel (spatial units) [122].

6. Discussion

This Discussion Section addresses the specific questions posed during this study, focusing on the semantics and ontologies of existing LASs, identifying and overcoming existing gaps, developing the LADM profile for 2D/3D LAS, and supporting SDG targets. Moreover, it provides an analysis of the key findings, interpreting how the objective of the study to develop an integrated, sustainable, and standardised LAS country profile for Pakistan is achieved.

Record of Rights (RoR) and Property Information Report (PIR), as well as surveying/mapping related procedures (defined through Laws and explained through Rules), provide a foundation for the development of LADM profile semantics and ontology for Pakistan. The operational relationship among existing manual LAS elements and classes is captured effectively in the LADM.

The British Colonial and contemporary urban LASs are interconnected in terms of policy, administration, and management. However, a critical observation is that these systems operate independently within their respective domains. The lack of effective information sharing and integration imposes a burden on property owners and buyers, who must navigate through redundant procedures and forms, exacerbating bureaucratic challenges and manual processes. Punjab province's LRMIS-P achieved success in digitalising revenue-related attribute records, but the initiative falls short in addressing the manual aspects of property Record of Deed (registry) and mapping of LAS. The ongoing second phase of the LRMIS-P project (known as Punjab Urban Land System Enhancement-PULSE) signals a need for careful attention and systematic development. Joint ownership, particularly governed by the Muslim Personal Law (1962), poses complexities, leading to disputes. The rarity of official delineation in cases of inheritance transfer contributes to uncertainties, with family members vying for valuable portions of the property. Spatial components, including revenue estate sketch maps, housing scheme layout plans, and individual house layout plans/drawings, are integral to LAS, but are currently managed with limited technological integration. Surveying practices lack a coordinate system and angular information,

contributing to the challenges in quality spatial data production and management. The specificity and effectiveness of recorded Rights, Restrictions, and Responsibilities (RRRs) in addressing diverse LA needs are still evolving in the country.

Keeping in view the manual nature of urban LAS in the country, LADM offers conceptual guidelines to organise the existing LAS into a standardised form. The LADM profile encompasses three key packages, each contributing to the static LAS elements in Pakistan and offering a significant role in improving them. The PK_Party Package plays a pivotal role in capturing information about individuals and organisations involved in land administration. Efforts are made to categorise parties based on their roles in LAS, with specific attention to the legal interests of property owners. While the National Database and Registration Authority (NADRA) issues unique identification numbers (CNIC) for citizens, the lack of integration with a central database poses challenges. The ongoing efforts to record fingerprints and photos, especially in Islamabad, signal a move towards modernisation, yet real-time verification with NADRA remains a non-mandatory requirement. The Administrative Package is crucial for managing Rights, Restrictions, and Responsibilities (RRRs), mortgage information, and overall land administration in Pakistan. The BAUnit, representing the smallest administrative control unit, is associated with RRRs, allowing for efficient management. The challenges lie in the broad and vague classifications, particularly for taxation purposes in urban areas. The need for precision in land use categories is highlighted as a critical aspect of the modernisation of LAS. The Spatial Unit Package, including a sub-package for Surveying and Representation, addresses the complexities of property location demarcation. The existing dual systems (British and contemporary), relying on textual information and manually drawn sketches, create challenges. The PK_SpatialUnit class is identified as the main component for recording location, with specialisation for building and utility networks. The incorporation of 2D and 3D spatial units, along with hierarchical grouping, aims to enhance the precision and modernisation of location data. The Surveying and Representation sub-package sheds light on historical surveying practices introduced during the British era. Boundary marks, essential for cadastral maps and resolving land disputes, lack numerical information on location and angular changes. The PK_Point class, along with linked classes, provides flexibility by allowing for textual information in the absence of geometric data. The incorporation of PK_SpatialSource establishes an association with survey information, acknowledging the importance of sources like layout plans and drone images. The PK_External Package records additional information related to land use, land valuation and party details. The PK_ExtParty class captures crucial information such as fingerprints, photos, and signatures for land and property registration, emphasising the importance of comprehensive external data in the LAS.

The implementation of the LADM country profile in Pakistan holds considerable promise in advancing the nation's progress toward key SDGs. Through its anticipated transparency and accessibility, the LADM is poised to address multiple SDG targets. For SDG target 1.4, LADM's commitment to providing a transparent and open platform aligns with the target of ensuring property ownership, inheritance rights, and the incorporation of new technologies. This not only fosters economic empowerment, but also contributes to poverty eradication. SDG target 2.3 is addressed through LADM's support for secure and equal access to land, facilitated by digital transactions and increased accessibility, thereby contributing to zero hunger by enhancing efficient land use practices. Moreover, the LADM stands as a catalyst for achieving SDG target 5.a—Gender Equality, recognising women's entitlement to property ownership under Muslim inheritance laws, and aiming to ensure equal rights for women in accessing and controlling land and property. In tandem, SDG target 8.2 is advanced as the LADM promotes economic development by emphasising innovation and technology upgradation, aligning to foster decent work and sustainable economic growth. Addressing SDG targets 11.1 and 11.3, the LADM tackles the imperative of safe and affordable housing for all by rectifying the existing loopholes and transparency issues in LAS, thereby promoting integrated, sustainable urbanisation and planning. Furthermore, LADM's contribution to SDG target 12.2 is evident, as it emerges as a viable

solution for achieving efficient natural resource management amid rapid urbanisation, aligning with responsible consumption and production practices. The LADM's impact extends to SDG target 16.6—Peace, Justice, and Strong Institutions—as it supports realistic tax and revenue collection, which is crucial for a developing country like Pakistan. By bridging the gap between potential and current achievement levels, LADM strengthens institutions, ensuring effective, accountable, and transparent land administration organisations. Lastly, for SDG target 17.1—Partnership for the Goals—the LADM's role in improving domestic tax revenue underscores the importance of strengthening the current manual LASs and fostering partnerships for sustainable development. In essence, the LADM country profile emerges as a transformative force, aligning with the broader SDGs and contributing significantly to Pakistan's pursuit of sustainable development, as is also noted by [89,91].

7. Conclusions and Recommendations

Overall, the achievement of the study objective to develop the PK LADM represents a transformative force that significantly contributes to Pakistan's efforts in achieving the SDGs for LAS. The anticipated outcomes of PK_LADM adoption extend beyond technical specifications, encompassing economic development, gender equality, and the establishment of transparent and effective institutions. This holistic approach positions PK_LADM as a catalyst for positive change in Pakistan's LA landscape. The overlap and ambiguities among organisations involved in LAS highlight the need for a comprehensive and inclusive approach coupled with PK LADM for effective urban LAS in Pakistan. The integration of spatial components, modernisation of party identification, and detailed recording of administrative and external information in PK_LADM mark significant strides towards a more efficient and precise LAS. Challenges, particularly in integrating external data sources and ensuring real-time verification, underscoring the need for continued efforts in advancing LAS modernisation in Pakistan. As Pakistan moves forward in its LAS modernisation journey, further research and implementation efforts can explore the realistic land valuation, integrated ownership, and its verification with external databases, enhancing the precision of property location and addressing challenges in the historical survey and ownership data. Additionally, exploring mechanisms to streamline the transition from manual to digital practices, ensuring the compatibility of existing data and promoting wider stakeholder adoption will be crucial for the sustainable development of urban 2D and 3D LAS, as well as the development of a smart city and its digital twin in Pakistan. It is also recommended that the PK_LADM undergo test runs and its further extension to new packages (Valuation Information, Marine Georegulation, and Spatial Plan Information), as recently presented in LADM II.

Author Contributions: As part of his research study, M.S.A. did conceptualisation, methodology, visualization, investigation, writing—original draft preparation, and formal analysis of the research. E.H., C.L., M.C.C. and J.M. did supervision and writing—review and editing of the research. J.Z., S.A., M.K. and Z.A. did conceptualization and supervision. All authors have read and agreed to the published version of the manuscript.

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