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Implementation of the LADM-Based Cadastral Model for Mongolia towards Transition to a 3D Cadastre

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Abstract: Most countries have considered the adoption of the international standard ISO 19152—Land Administration Domain Model (LADM) mostly for the improvement of their cadastral systems in the context of developing the 3D cadastre. However, the adoption of LADM is yet to be considered in Mongolia. The aim of the study is to create an LADM-based cadastral data model–Country profile for Mongolia, presenting how the standard can be tailored to the cadastral systems based on an understanding of current legal and systematic requirements. We conducted this study by taking steps to understand the current cadastral system in Mongolia, the implementation of the LADM Country profile, and the LADM conformance test for the developed model. The LADM Country profile has been created based on two parts–Administrative and Spatial. The developed country profile conformed to all classes from the low and medium levels and several classes from the high level of the Abstract Test Suite provided by the standard. In addition, we provide object-instance diagrams to help understand how the developed model can be applied to real situations. The study results will be used when considering the adoption of the standard and moving towards fulfilling modern cadastral requirements (e.g., multi-dimensional cadastres) in Mongolia.

Keywords: cadastre; LADM; ISO 19152; international standards; Mongolia

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1. Introduction

A cadastre or cadastral system is established depending on the purpose of specific jurisdictions. The International Federation of Surveyors (FIG) defined cadastre as a parcel-based and up–to–date land information system that contains a record of land interests (i.e., rights, restrictions, and responsibilities, or RRRs). In particular, cadastres usually comprise a geometric description of land parcels as a series of maps or plans presenting their size and location with text records (e.g., ownership, value) that represent land attributes [1,2]. Cadastral concepts and systems have been evolving due to the introduction of new cadastre concepts such as future cadastres, i.e., "Cadastre 2014" [3], which deals with visionary statements for future cadastres at the time it was conceived. In addition, "Cadastral new vision," defined by Australian scholars, provides six characteristics for future cadastres: (i) survey-accurate cadastre, (ii) object-oriented cadastre, (iii) three-dimensional (3D) and/or 4D cadastre, (iv) real-time cadastre, (v) global cadastre, and (vi) organic (green) cadastre [4]. The International Organization of Standardization (ISO) established the "ISO 19152:2012 Land Administration Domain Model (LADM)" international standard [5] in line with supporting the implementation of these future cadastre concepts. The LADM provides a conceptual model for land administration and cadastral information that is concerned with rights, responsibilities, and restrictions (RRRs) affecting land (or water) and geometrical (geospatial) components based on people-land relationships. In addition, LADM provides a reference model that aims to support an extensible basis for the development and improvement of efficient and effective land administration (cadastral) systems

based on a model-driven architecture (MDA) and enables involved parties, both within one jurisdiction and between different jurisdictions, to communicate with the shared ontology implied by the model [5].

In contrast, Mongolia has a cadastral system supporting both legal and fiscal requirements for implementing multipurpose cadastres; in particular, the legal foundations for cadastres have been established at a certain level to provide tenure security and taxation in Mongolia. Recently, the government of Mongolia announced "Vision 2050" [6], which describes the long-term development policy of multiple national sectors. One of the document sections deals with issues relevant to cadastre and land administration development underpinning the general development direction of the sector with three main phases, including timeframe considerations. Figure 1 illustrates the implementation stages (periods) and their aims.

Figure 1. Land administration development perspective of Mongolia based on "Vision 2050."

In this document, each phase has specific purposes, particular goals, and action plans. Thus, the items relevant to the LADM standard can be listed as follows:

- Development of 3D and 4D integrated cadastral systems;
- Creation of a system of land valuation (assessment), fees, taxation, and transaction (exchange) systems based on artificial intelligence and blockchain technology;
- Development of a 3D land and real estate management system based on advanced technology;
- Mapping of the nationwide 3D topographic and underground engineering utility network;
- Establishment of innovation and partnerships implementing efficient land administration and management to ensure environmental and socioeconomic sustainability by adopting internationally accepted standards.

The LADM can be used as a basis for implementing the above items. Particularly for 3D and 4D (3D + time) cadastre implementation, LADM supports the transition towards the 3D cadastre, including 3D RRRs.

Most countries have considered the adoption of LADM mostly for the development/improvement of their cadastral and/or land information systems in the context of developing the 3D cadastre. In particular, building LADM-based profiles to solve their cadastral issues [7–13]; transiting from 2D to 3D cadastre in several countries [7,8,10,14–17] with giving emphasis on the registration of 3D strata objects, such as buildings and premises, with parcels in this context [18,19]. In addition, extending the LADM country profile was considered for agricultural land management [20], utility network cadastre [21,22], and underground land administration [23–25]. Furthermore, a review of more LADM country profiles is given in [26], including some of the profiles mentioned here.

In this study, these future cadastral concepts and the long-term vision of the country become the principal motivation for developing the LADM-based cadastral model—a country profile for Mongolia–and also take advantage of the LADM, which provides a formal language describing cadastral systems, data exchange, interoperability, and the support of the 3D cadastre.

This paper presents the implementation of the LADM-based cadastral data model for Mongolia so that the LADM-based Country profile considers the current cadastral

system and legal requirements while also ensuring conformance between the implemented Mongolian Country profile and the LADM. These processes are required to implement the LADM standard. The Country profile developed as a result of this study will serve as an essential contribution to the transition toward a multi-dimensional cadastre.

The remainder of this paper is organized as follows. Section 2 describes the study methods, and Section 3 provides a brief overview of the Mongolian cadastral system. Section 4 presents the implementation of the LADM country profile, elaborated with subsections analyzing the LADM and Mongolian LADM Country profiles. Finally, a discussion and conclusions are presented in Section 5.

2. Methods

The methodology used in this study consisted of three main parts: (1) a review of the current cadastral system in Mongolia, (2) the implementation of the LADM country profile, and (3) the LADM conformance test provided by the standard. An overview of the current situation mainly addresses the country's legal and systematic environment. The LADM country profile was developed over two essential (separate) parts: Administrative (aspatial) and Spatial. In addition, two object-instance diagrams are provided to show how the developed model can be used for real situations that could occur. Subsequently, the conformance test, indicating the application schema level for the implemented country profile, was performed. The overall research methodology is illustrated in Figure 2.

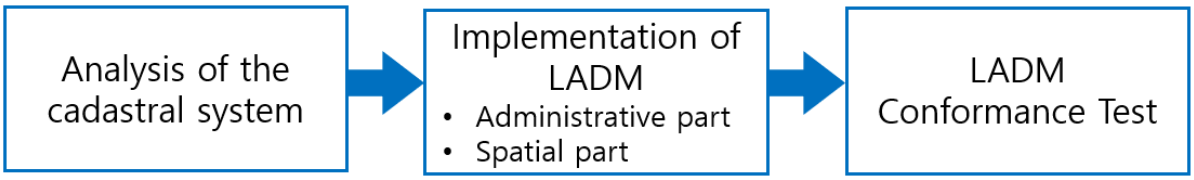

Figure 2. Research methodology flow diagram.

3. The Mongolian Cadastral System

According to the cadastral law of Mongolia, "cadastre" is defined as the comprehensive activities of determining the location, boundaries, site, volume, quantity, and conditions of land and other immovable properties, valuating condition (quality) and economic value, establishing a basis for a land fee, and confirming rights of possession, use, and ownership [27]. The basis of the digital cadastre was established in 2000 with the support of the Asian Development Bank (ADB) to implement the Cadastral Survey and Land Registration Project in Mongolia [28]. The project had two components: (1) systematic cadastral surveying and mapping—the creation of digital cadastral maps and the collection of relevant attribute data—to establish the national cadastral database, and (2) the establishment of a National Land Information System (NLIS) based on the national cadastral database resulting from the first component to form the basis for the legal description of property and property registration at national and provincial levels.

In 2013, a Land Manager (LM) program used by land administration offices nationwide was developed. The LM handles more than 30 types of government applications and requests related to land ownership, possession, and use. In addition, the program has 14 submodules that cope with orders (decree), contracts, certificates, cadastral maps, land payments, valuations, personal electronic files, etc., in an automated manner to deliver services to citizens. The software also has a web and mobile monitoring system for the public to monitor the processing of their applications and requests submitted to the land office and obtain information about the land they own, possess, and use in either graphical or textual form from the state register [29].

The Land Manager program for the cadastre database was fully introduced in 21 aimags (provinces), 330 soums (subunits of aimags), and nine districts of the capital city during 2017–2018 [30]. Figure 3 shows the general concept of the land management system.

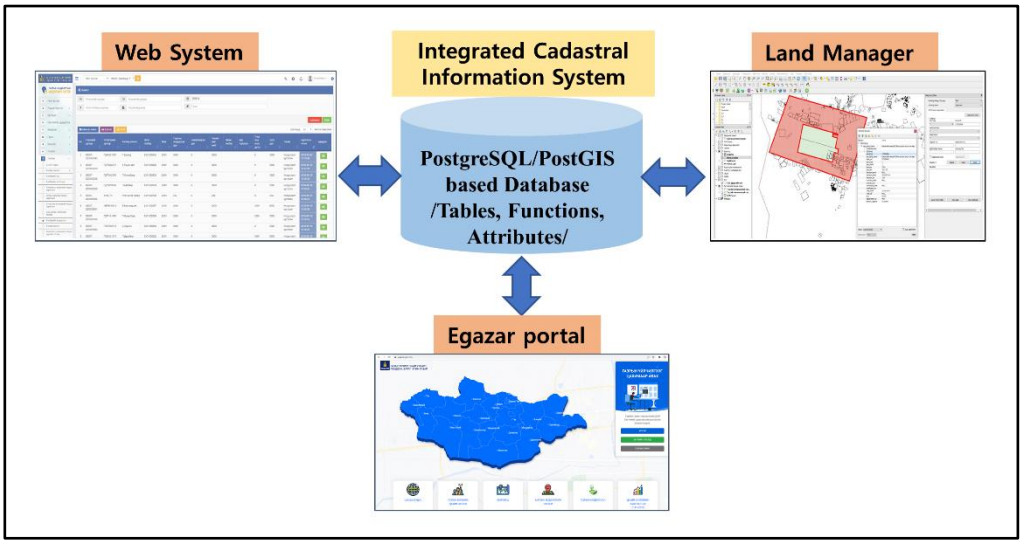

Figure 3. Overview of Land Manager program. Adopted from [31].

Furthermore, the land authority of Mongolia developed a system named "Integrated Land Administration System for Unified Land Database" in the context of smart land administration. The system consists of six main systems: planning, land exchange, valuation and taxation, cadastral, monitoring, and urban development, as well as other geodetics, addresses, and basic research supporting data collection, processing, analysis, and information distribution [32]. The integrated system covering the nation has been operating since 2020 in accordance with government decree No.110. Figure 4 shows the general concept of the system based on [32].

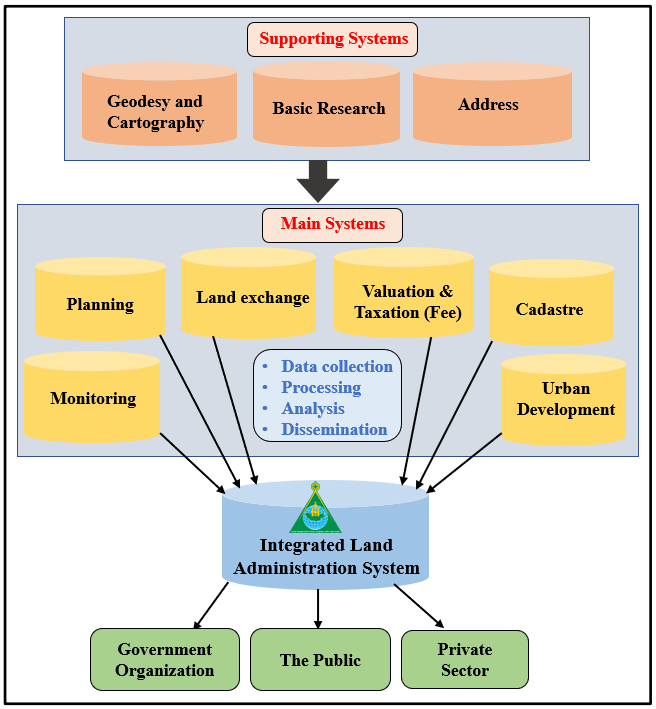

Figure 4. Integrated Land Administration System for Unified Land Database.

In contrast, the legal environment for cadastres and land administration provides tenure security in the country. In particular, both the "Law on Land" (land law) [33] and the "Law on Allocation of Land to Mongolian Citizens for Ownership" (land privatization

law) [34] were enacted in 2002, and as a result, three principal land rights have been introduced: land ownership, land possession, and land use rights. According to the land privatization law of Mongolia, any individual with Mongolian citizenship is allowed to own land. The term "owning land" or "land ownership" means using land under one's complete control (e.g., selling, renting) within the legitimacy of the law [34]. Land ownership (hereinafter, ownership) is given for two purposes: family use purposes (for a living) and for (family) business (e.g., farming) without a specific hold limitation (as a freehold). The size of the area given to these land rights differs by region (depending on the location of the land) and is defined by law.

According to the land law of Mongolia, the term "land possession" indicates the use of land in accordance with the purpose of its use, terms, and conditions specified in the respective land contracts within the legitimacy of law. Land possession (hereinafter, possession) rights are allowed for Mongolian citizens aged 18 and above, and companies and organizations may possess or use land in compliance with the land law. Land possession types or possession rights certificates are of the following types: family (household), government organizations, and economic entities (e.g., corporations), whereas "land use right" indicates land contracted with landowners and possessors using one of the beneficial qualities of the land within the legal scope. For land use rights, foreign countries, international organizations, foreign legal entities, entities with foreign investment, foreign citizens, and stateless persons may be allowed to become users of land for a specific purpose and period subject to contract conditions and in compliance with the law. Table 1 summarizes these three main land rights and their key features.

Table 1. Main types of land rights.

	Main Right Type	Subject	Remark
1	Land ownership	Mongolian citizens only	Limitless (Freehold)
2	Land possession	Mongolian citizen, local legal entity	Up to 15–60 years, extension possible for 40 years
3	Land use	Mongolian citizen, local and foreign legal entity	Up to 5 years, extension possible for 5 years

4. Implementation of LADM Country Profile

4.1. Overview of LADM

LADM provides an abstract and conceptual schema, and it serves the following goals: (1) the establishment of a shared ontology implied by the model, which could support communication between involved parties within one and different countries, and the development of spatial data infrastructures (SDA) as a core data model; (2) support for the development of the application software for cadastral systems, which could enable MDA-based efficient and effective software development for the cadastre; and (3) facilitation of cadastral data exchange with and from a distributed land administration system, which could support combinations and integration of cadastral data with other data sources, such as cadastral legal data, and physical objects such as roads, buildings, or utilities. In addition, this type of data exchange can be performed between cadastre-related organizations within the country and between different countries; and (4) support for data quality management in the Land Administration, which could support the avoidance of data inconsistency between different organizations. In addition, a standardized data model can help detect existing data duplications [35].

LADM is divided into three main packages and one subpackage. The Party package is related to parties (e.g., people and organizations); the Administrative package represents basic administrative units, rights, responsibilities, and restrictions (e.g., ownership); the Spatial Unit package is associated with spatial units (e.g., parcels, buildings), and one subpackage of the Spatial Unit package: The Surveying and Representation subpackage is

related to spatial sources (e.g., surveying), and spatial representations (e.g., geometry and topology) [5].

The core classes of LADM are LA_Party (with party as an instance) from the Party package, LA_RRR and LA_BAUnit from the Administrative package, and LA_SpatialUnit (with spatial units as instances) from the Spatial Unit package. Figure 5 shows these core/basic classes of the LADM.

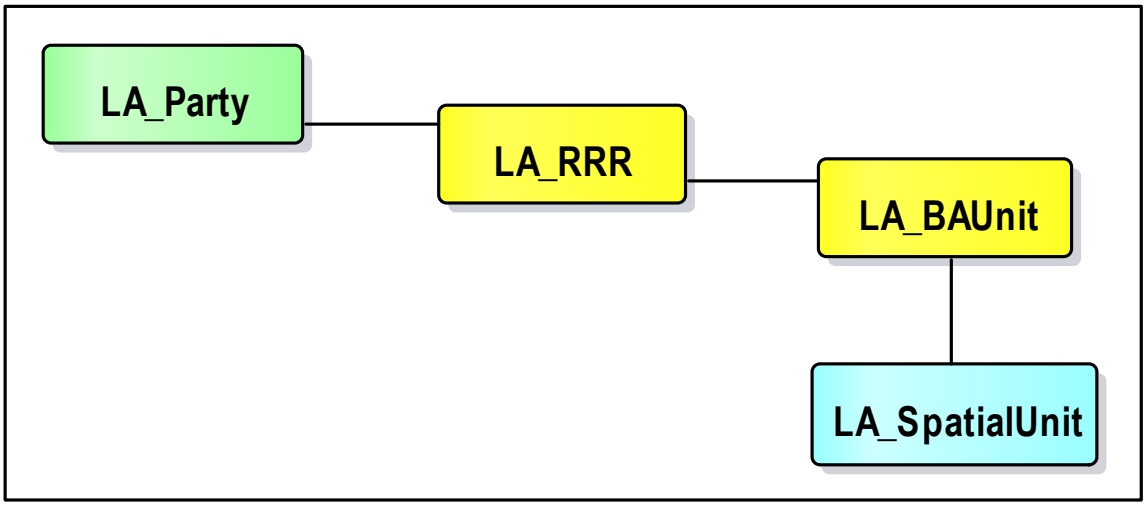

Figure 5. The LADM basic classes.

LA_Party has a specialization, LA_GroupParty, with a group party as an instance. LA_RRR is an abstract class with three specializations: LA_Right (with rights as instances), LA_Restriction (with restrictions as instances), and LA_Responsibility (with responsibilities as instances). LA_BAUnit is an abbreviation for "basic administrative units," which considers basic administrative units as instances. Spatial units have two specializations: LA_LegalSpaceBuildingUnit (with building units as instances) and LA_LegalSpaceUtilityNetwork (with utility networks as instances). In addition, the Surveying and Representation subpackage includes classes such as LA_Point (with points as instances), LA_SpatialSource (with surveying documents as instances), LA_BoundaryFaceString (with boundary face strings as instances), and LA_BoundaryFace (with boundary faces as instances). The classes LA_BoundaryFaceString and LA_BoundaryFace were used to represent 2D and 3D representations of spatial units.

4.2. Mongolian LADM Country Profile

The LADM Country profile was developed in two parts: Administrative (aspatial) and Spatial. The Administrative part includes the Party and Administrative packages, while the Spatial part includes the Spatial Unit package and Surveying and Representation subpackage. The LADM cadastral model–Country profile implemented in this study used some previous research results [13], i.e., the cadastral data model as a reference and extended and improved them.

4.2.1. Administrative (Aspatial) Part

In the country profile, the Administrative part comprised two parts: Party and Administrative packages. The "MG_" prefix, representing Mongolia as MG, was used for the LADM country profile implementation.

The Party package contains the classes MG_Party, MG_GroupParty, MG_PartyMember, MG_NaturalPerson, and MG_LegalEntity. The Administrative package includes MG_BAUnit, MG_RRR, MG_Right, MG_Restriction, MG_Responsibility, MG_Mortgage, MG_AdmninistrativeSource, MG_BuildingMap, MG_LandFeeDecision, MG_LandPermissionApplication, MG_LandRegister, and MG_CadastralMap.

The MG_Party class generalizes the MG_NaturalPerson and MG_LegalEntity classes. The MG_NaturalPerson class describes the personal information of a party as a natural person, mainly as a registration number, name, phone number, address, and identification information. The MG_LegalEntity class denotes a company or organization's information as a legal entity and contains attributes such as registration number, entity name, contact information, address, and entity certificate. The attribute "address" for both of these classes has ExtAddress type, which represents a class for an external registration of addresses (an address being a direction for finding a location) as documented in "Annex K" of the LADM. MG_GroupParty is a subclass of MG_Party and can consist of many (two or more) MG_Party classes. The MG_GroupParty class has one attribute that indicates the type of Group party. Group parties can be associations, families, or in the form of joint ventures.

The MG_Party class has two codelists: MG_PartyRoleType and MG_PartyType. The attributes of MG_PartyType are naturalPerson (e.g., a person) and legalEntity (e.g., an organization). Attributes of MG_PartyRoleType describe parties involved in land administration as natural person types, including certified surveyors, citizens, employees, farmers, notaries, etc., whereas parties as a legalEntity could be a company, taxOrganization, technicalCouncil, consulate, etc.

The MG_BAUnit class has the MG_BAUnitType attribute, which can be a building, parcel, or rightOfUseUnit. A BAUnit is an administrative entity, subject to registration (by law) or recordation rights, consisting of zero or more spatial units against which (one or more) unique (an RRR is held by one or more parties for the whole BAUnit) and homogeneous (an RRR affects the whole BAUnit) rights, responsibilities, or restrictions are associated with the whole entity in a land administration system [5].

The MG_RRR class is an abstract class that generalizes MG_Right, MG_Restriction, and MG_Responsibility classes. According to LADM, a right provides a formal or informal entitlement to own or do something and comprises two types of rights: real and personal rights. Real rights are rights over or with respect to spatial units (e.g., ownership or usufruct). Personal rights are rights that parties have (e.g., fishing rights, grazing rights, or use rights). A restriction is a formal or informal obligation to refrain from doing something; for example, building within 200 m of a fuel station is banned, or servitude or mortgage as a restriction to ownership rights. A responsibility is a formal or informal obligation to do something, e.g., to clean a ditch, keep a snow-free pavement, or maintain a monument.

According to the "General Law on State Registration of Mongolia" [36], types of state registration of property rights include, in addition to three main types of (real) land rights–ownership, possession, and land use rights, ownership rights of property, right to construct a building on another person's land, servitude, hypothec, usufruct, lease, right of financial leasing of watercraft or aircraft, guarantee, and right to possess and use land. The MG_RightType codelist covers various right types, such as ownership, possession, landUseRight, servitude, hypothec, usufruct, mining, and undergroundUseRight.

In both land privatization and land law of Mongolia, responsibility is cited as an obligation for landowners. This encompasses protecting geodetic points on owned land (property), not taking any action that harms the legal rights and interests of the land rights holders and negatively affects the health of the population or the environment on the property, and not causing deterioration in the condition and quality of the land.

Land possessors and land users have responsibilities, some of which usually overlap with land ownership obligations. However, some articles cite the responsibility of paying a land fee (land-use tax), carrying out the state inspection and assessment of the land condition and quality following established procedures (which, in the case of ownership, should be done every five years), and registering at the state registry if the certificate is to be transferred or put up as collateral (this only applies to land possession). The MG_ResponsibilityType codelist, therefore, includes monumentProtection, parcelTax, tenancyFee, landFee, purposeUse, and stateInspection.

According to the land privatization law of Mongolia, Article 33 deals with contents of servitude, including passing through the area (e.g., right of way), demarcation of land

boundary and geodetic surveying points and markers on the site (e.g., monument), performing work to reduce swamping, and implementing other land administration duties. Public servitude and/or easement can be permanent or temporary. As stated in the Land Law of Mongolia, there is an article relevant to restrictions as servitude and/or easement, and it states a limited use of land in possession or in use for entering and crossing (passing) purposes. For instance, if land in possession or in use is not specifically protected by erected fences or posted warning signs prohibiting entry and crossing, any person may enter or cross this land without causing damage. Moreover, in relation to the easement, use, and property protection, owners of immovable property shall have the right to demand a limited use of land possessed or used by others to construct roads, power, communication, and engineering lines through that land, transit points, and for other purposes. Therefore, the MG_RestrictionType codelist contains the attributes of the monument, servitude, hypothec, easement, and passage. The MG_Mortgage class has an MG_MortgageType, which includes types of hypothec (e.g., apartment loans), levelPayment, etc.

The MG_BuildingMap, MG_CadastralMap, MG_LandFeeDecision, MG_LandPermissionApplication, and MG_LandRegister classes are modeled as subclasses of the MG_AdministrativeSource class, showing various sources such as documents supporting (zero or more) MG_BAUnit and MG_RRR. The MG_AdministrativeSource class has two codelists: MG_AdministrativeSourceType and MG_AvailabilityStatusType. The MG_AdministrativeSourceType codelist contains attributes such as landCertificate, landPermission Act, and landRegister. The MG_AvailabilityStatusType codelist shows whether a document is available or not, e.g., incomplete, unknown, or available.

The MG_BuildingMap and MG_CadastralMap classes in this section support the registration of the RRRs and BAUnits based on the AdministrativeSource class. The MG_CadastralMap class has two codelists: MG_LandRightType and MG_LandGradeType. MG_LandRightType comprises three main types of rights: ownership, possession, and landUseRight. The MG_LandGradeType codelist deals with the general condition of the land, i.e., good or bad.

The MG_LandFeeDecision class expresses a decision on land fees incurred by using or possessing the land, and it has attributes relevant to land taxation, decision number, and start and due dates. MG_LandPermissionApplication indicates an application for obtaining land for a specific use (e.g., ownership). This class has two codelists, MG_LandRightType and MG_LandUseType. The MG_LandUseType codelist includes the purposes of land use, e.g., residential, business, educational, and health. The MG_LandRegister class describes the information of the application–accepted land or permitted land, and it has MG_LandRightType and MG_LandGradeType codelists.

The VersionedObject class was introduced in the LADM to manage and maintain historical (temporal) data, and it has a value type of DQ_Element from ISO 19115 and CI_ResponsibleParty from ISO 19115. In the Administrative part, the classes MG_Party, MG_GroupParty, MG_PartyMember, MG_NaturalPerson, MG_LegalEntity, MG_BAUnit, MG_RRR, MG_Right, MG_Restriction, MG_Responsibility, and MG_Mortgage are subclasses of the VersionedObject in direct and indirect inheritance.

Figure 6 shows the developed or proposed country profile of the Administrative part (Party package in green and Administrative package in yellow) for Mongolia with their corresponding codelists (in gray).

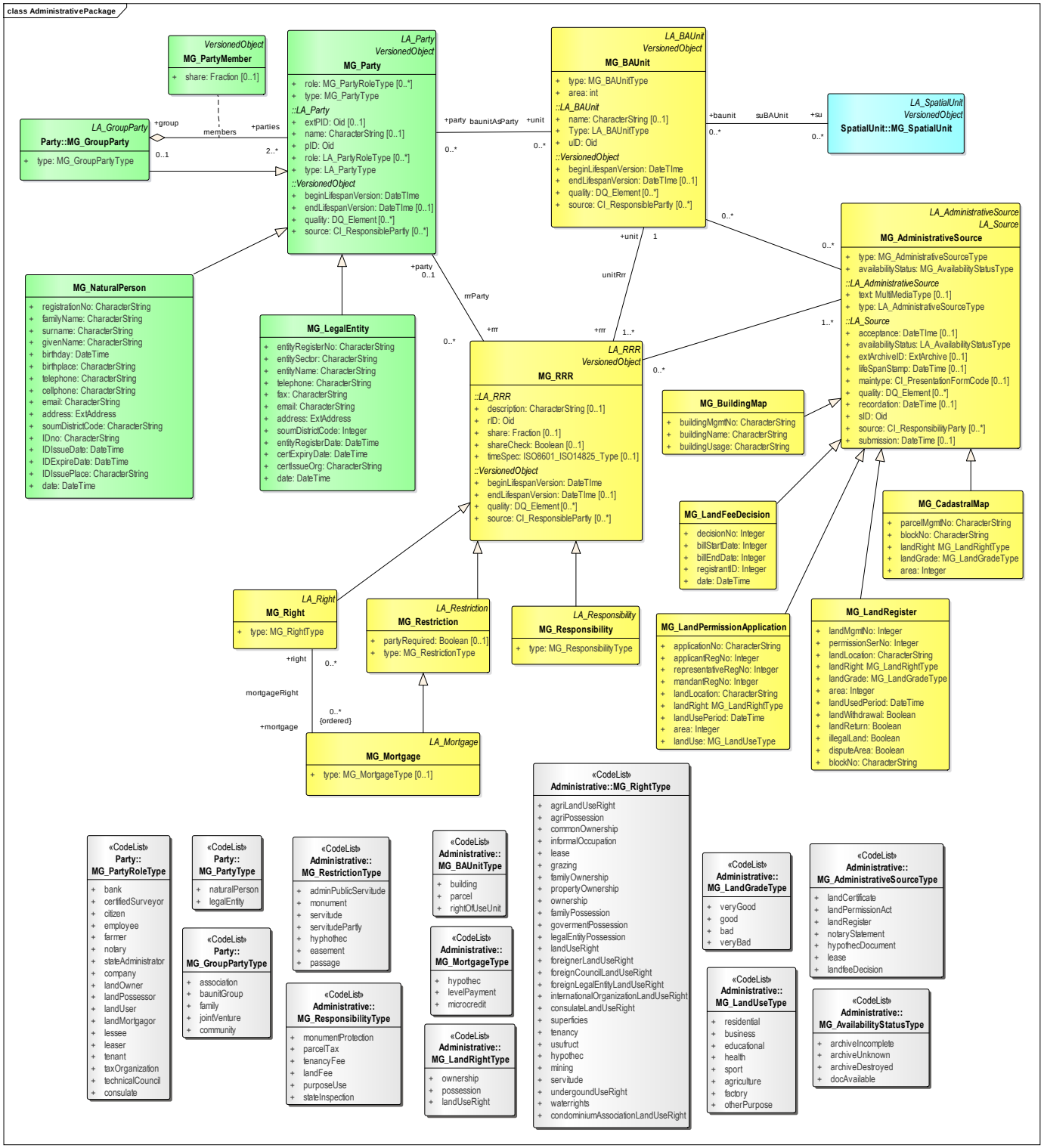

Figure 6. Administrative (Party and Administrative package) part of the Mongolian LADM Profile.

4.2.2. Spatial Part

The spatial unit package is to support the creation of basic administrative units. The developed spatial unit package contains MG_SpatialUnit, MG_SpatialUnitGroup, MG_RequiredRelationshipSpatialUnit, MG_Level, and MG_LegalSpaceBuildingUnit, along with MG_Parcel and MG_Building, two newly added classes. The Surveying and Representation subpackage includes MG_Point, MG_SpatialSource, MG_BoundaryFaceString,

and MG_BoundaryFace. The MG_Point class can be a point—a 0-dimensional geometric primitive that represents surveying points or monuments (control points) to determine the position of a spatial unit. In addition, the point can represent the geometry of a parcel or building.

In the Mongolian cadastre, the MG_SpatialUnit class can exist as a lot or parcel or as a building for a basic administrative unit (e.g., house or apartment). MG_SpatialUnit specializes in the MG_Parcel class and contains parcel information on the cadastral map. The Cadastral law of Mongolia [27] defines "parcel" as an allotted land or building or a part of an allotted land or building under the same use and with the same boundary and identifying number to be included in the cadastre having the same owner, possessor, user, and proprietor. The MG_Parcel class is modeled using attributes such as parcelID, owner, and address. In addition, this class has an MG_LandRightType codelist (Administrative part), which defines a type of cadastral map.

The MG_LegalSpaceBuildingUnit class describes the legal space for a building unit, includes information about buildings, and has an MG_BuildingUnitType codelist indicating whether a building is individual or shared. The MG_Building class inherits from the MG_LegalSpaceBuildingUnit class and can describe more information about a building. This class has two additional (proposed) codelists: MG_BuildingUseType, describing a building use category, e.g., residential, business, educational, and health; and MG_BuildingType, indicating the building type as an apartment, building, ger (traditional Mongolian housing), etc.

In practice, MG_BuildingMap and MG_CadastralMap (showing the parcel boundaries) are depicted as 2D maps/plans. A cadastral map is usually drawn on a scale of 1:1000 in urban and settlement areas [11]. The MG_BuildingMap class depicts a building inside the MG_CadastralMap class, i.e., a building inside a parcel (surrounded and/or erected by fences). Figure 7 illustrates a typical cadastre map [37] with the corresponding annotations added.

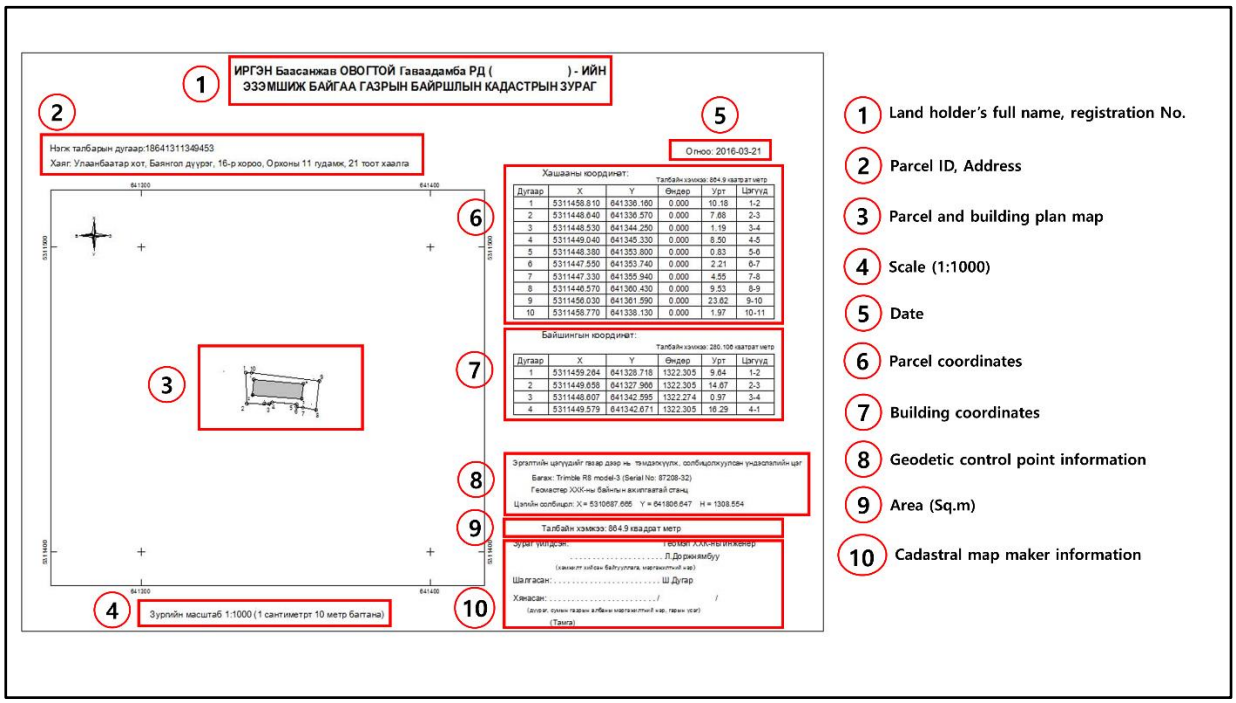

Figure 7. Typical cadastral map of Mongolia.

A spatial unit can include another spatial unit inside it or be covered by another, such as a spatial unit consisting of zero or more spatial units. This relationship was adjusted with the support of the MG_RequiredRelationshipSpatialUnit class, which has

an ISO19152_Type codelist. Alternatively, several spatial units can be grouped into larger spatial units (i.e., spatial unit groups). MG_SpatialUnitGroup is a group of spatial units forming an administrative zone (e.g., a section, canton, municipality, department, province, or country) or within a planning area. An MG_Level class is a collection of spatial units with geometric, topological, and/or thematic coherence.

MG_LegalSpaceUtilityNetwork describes the legal space (e.g., access or repair of a cable or pipeline) in the topology of utilities. In addition, a utility network can act as a BAUnit. It has two codelists: MG_UtilityNetworkStatusType and MG_UtilityNetworkType. MG_UtilityNetworkStatusType is used to show the status of a utility as in use, out-of-order, or planned. MG_UtilityNetworkType indicates the utility type, such as electricity, gas, or heating. According to the "Law on Urban Development of Mongolia" [38], especially for urban cadastre-related articles, the urban cadastre shall include engineering utilities such as power, water and sewerage, roads and road facilities, and communication.

Generally, all codelists from the LADM standard apply to the Mongolian Country profile and all types of spatial unit package codelists. The proposed codelists of the Spatial unit package are MG_RegisterType, MG_LevelContentType, MG_StructureType, MG_AreaType, MG_DimensionType, MG_SurfaceRelationType, MG_VolumeType, MG_BuildingUseType, and MG_BuildingUnitType.

In the case of the Surveying and Representation subpackage, points can be acquired in the field by surveying methods or with aerial images. A survey is documented with spatial sources (MG_SpatialSource), which includes surveying processes (observation) and methods involved in measurement, e.g., fieldSketch or gnssSurvey methods, as included in the MG_SpatialSourceType codelist. Additionally, the Spatial unit class can be associated with zero or more spatial sources.

A point may be used to define one or more boundary faces—2-dimensional topological primitives—or boundary face strings (e.g., 1D line). The MG_BoundaryFaceString can represent the boundaries of spatial units by line strings in 2D. It is associated with classes MG_Point and MG_SpatialSource to record the origin of the geometry. A boundary face string should be defined as having two or more [2..*] points (e.g., the beginning and end of a straight line). The MG_BoundaryFace can be used for the 3D representation of the boundary of a spatial unit. It is associated with the classes MG_Point and MG_SpatialSource to depict the origin of the geometry. A boundary face should be defined as having three or more [3..*] points (i.e., a face as a triangle as the minimum is defined by three points).

The MG_Point class can be adapted to the Mongolian cadastral system, both as a reference point for surveying and as a point to express the boundary line of a lot. In addition, to record information about cadastral surveying, the MG_Point and MG_Spatial Source classes were modeled and/or included in the proposed model. A 3D cadastral parcel or building can be represented using the classes MG_BoundaryFace and MG_BoundaryFaceString with the support of MG_Point and MG_SpatialSource.

In this spatial part, classes MG_SpatialUnit, MG_SpatialUnitGroup, MG_RequiredRelationshipSpatialUnit, MG_Level, MG_LegalSpaceBuildingUnit, MG_LegalSpaceUtilityNetwork, MG_Parcel, MG_Building, MG_Point, MG_BoundaryFaceString, and MG_BoundaryFace are subclasses of the VersionedObject in the way of direct and indirect inheritance.

The proposed codelists of the spatial unit package include MG_PointType and MG_SpatialSourceType. The possible codelists are MG_MonumentationType (surveying reference point type), MG _Point Type (with or without a reference point), MG_SpatialSourceType (spatial data acquisition method), MG_InterpolationType (interpolation method type), and MG_Transformation (coordinate transformation). Figure 8 shows the developed or proposed Country profile of Mongolia's Spatial part (Spatial Unit package in cyan and Surveying and Representation subpackage in pink) with their corresponding codelists (in gray).

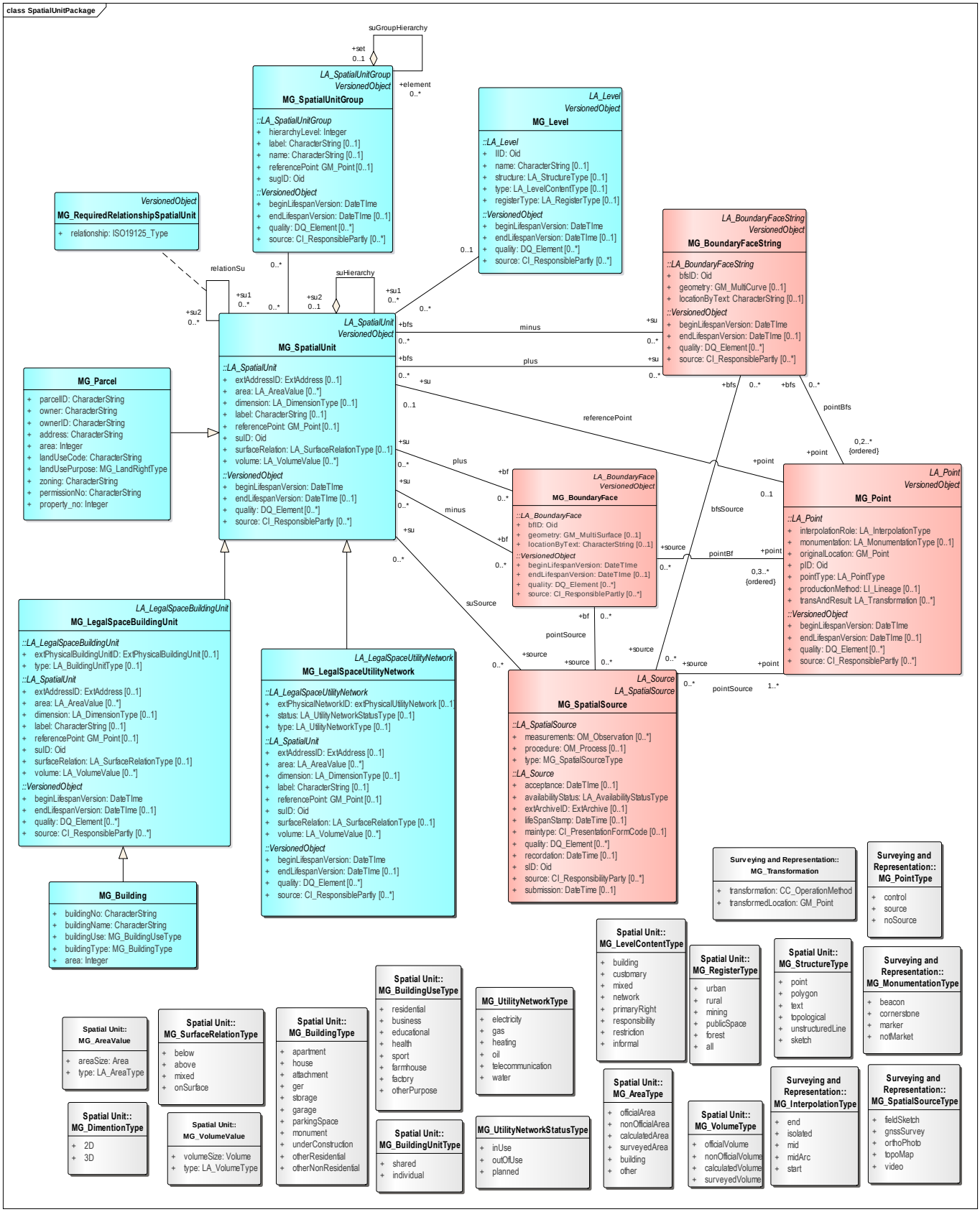

Figure 8. Spatial (Spatial Unit and Surveying and Representation Subpackage) part of the Mongolian LADM Profile.

4.3. Object Instance Diagram for the LADM Country Profile

Instance-level diagrams were created to show how the developed model could be used in a possible real-life scenario and/or use case. We created two cases/diagrams that would help understand the standards and consider their adoption. Thus, detailed elaborations are as follows:

Case 1, registering 3D parcels: In this case, persons 1 and 2, as naturalPerson, compose a family and have the responsibility to pay land fees and the right to possess the land for 15 years. In addition, they were responsible for protecting the surveying monument on their land, and simultaneously, it became a restriction not to harm the monument. The state, MG_Party, controls surveying monuments. The BAUnit is a parcel (uID = 1461502546) having homogeneous rights, restrictions, and responsibilities that affect the whole basic administrative unit. MG_BAUnit was supported by the Spatial unit of the MG_Parcel class. The parcel described in this case is defined as having suID = 10,001, 700 square (sq.) meters, and is above the surface and used for housing (living) and 3D, with a volume of 4056 cubic meters. The 3D parcel is expressed using MG_BoundaryFace classes, which use GM_Surface as the geometry. Figure 9 describes the case thoroughly, with the color indications being the same as in the developed LADM Profile.

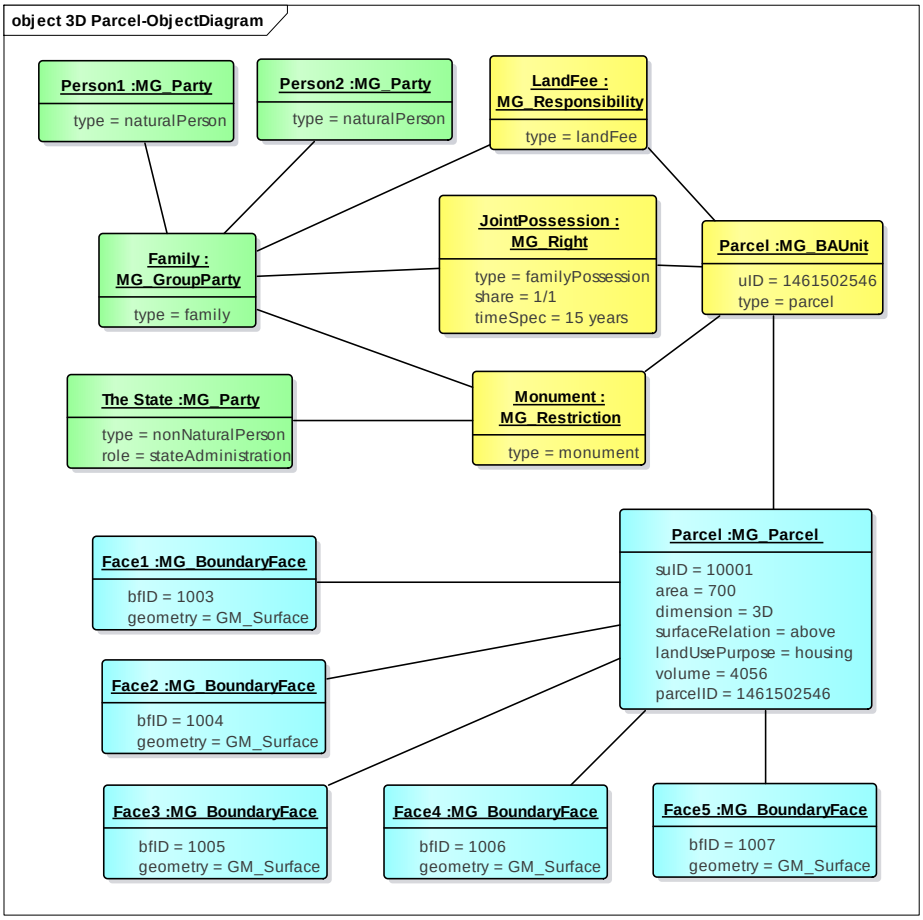

Figure 9. Instance Diagram of Party, Administrative, and Spatial Unit (3D Parcel) Package.

Case 2: cadastral registration (parcel and building) involving surveying activities: four people (naturalPerson) as a citizen consisting of a family and having FamilyOwnership over a parcel (uID = 1461502547) and PropertyOwnership over a building (uID = 0111906728), and these two rights have no specific time limit. The parcel and building are regarded as a BAUnit and are supported by the Spatial unit class as MG_Parcel and MG_Building classes, respectively. The MG_RequiredRelationshipSpatialUnit class is used to adjust the topological relationship between two classes, a building inside a parcel. The parcel of the

MG_Parcel class has an area of 700 sq. meters and has a parcelID, which is the same as the uID from BAUnit. The building of the MG_Building class is described in 2D and has an area of 50 sq. meters for individual and residential use. MG_Parcel is depicted in lines (MG_BoundaryFaceString) in 2D and thus in the MG_Building class.

The family, as MG_GroupParty relates to Doc3000 (MG_SpatialSource), is the name of an example document that contains surveying information (e.g., gnssSurvey method) on the land they possess. In addition, the surveyor MG_Party executes surveying work over the land that has been possessed by parties. The MG_SpatialSource class relates to the MG_Point class as the surveying point (monument), which has been used as a control/reference point for geodetic work. MG_BoundaryFaceString relates to MG_Point to describe the beginning and end of a line depicting a parcel. Figure 10 illustrates Case 2 thoroughly, with the color applied the same as the developed LADM profile.

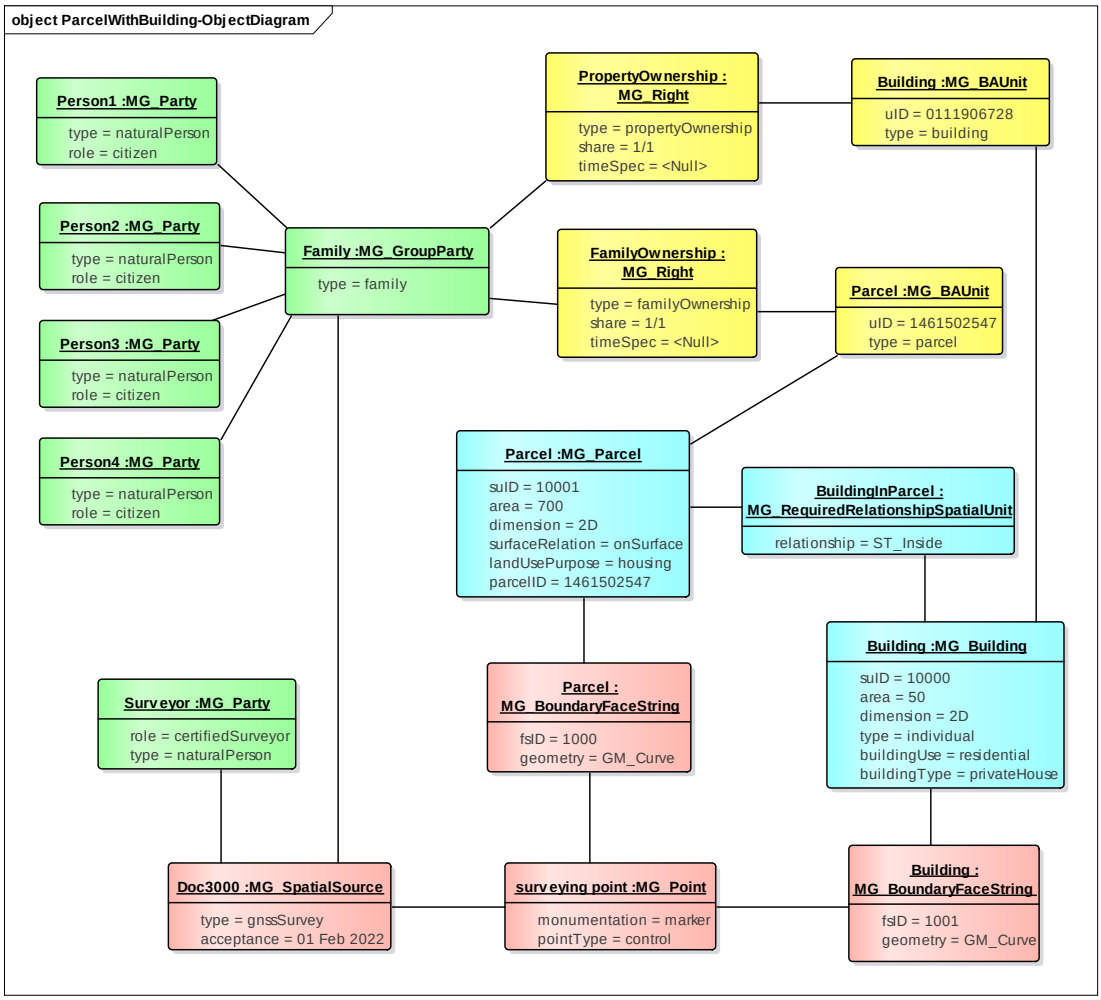

Figure 10. Instance Diagram of Party, Administrative, Spatial Unit (Parcel with Building), and Surveying and Representation Subpackage.

4.4. LADM Conformance Test

Annex A, the abstract test suite of the ISO 19152 standard, defines whether a specific application of the LADM profile is consistent with the LADM application schema (package and level) [5]. A conformance test was specified for each package of the LADM, and three conformance levels were specified per (sub)package: level 1 (low level), level 2 (medium level), and level 3 (high level). Level 1 tests require the application schema (profile) to include at least one of the basic classes of the LADM. Level 2 further contains more common classes, and level 3 includes all other classes of the LADM, in addition to levels 1 and 2. The

conformity test method is described in "Annex A," where a specific application (schema) is tested as follows: (1) show an inherited structure between the LADM and the tested model (elements), or (2) show a mapping of elements between the LADM and the tested model. Table 2 shows the mapping of the LADM classes and Mongolian LADM country profile classes. The Mongolian country profile conforms to all classes from the low and medium levels and several classes from the high level of conformance. In particular, while classes derived from the cadastral system generally meet the low level, classes defined by the legal requirements conform to medium and high levels. In Table 2, the "derived from" column shows how profile classes are derived, i.e., CS for cadastral systems and LR for legal requirements.

Table 2. LADM conformance test, including corresponding classes of the Mongolian cadastre.

LADM Class	Corresponding Class (Attributes)	Profile Class	Derived from	Conformance Level
Special Classes				
VersionedObject	-	Partially occurs in some classes	CS	1
LA_Source	-	LA_AdministrativeSource	CS, LR	1
LA_Source	-	LA_SpatialSource	CS, LR	1
Party Package				
LA_Party	-	MG_Party	CS	1
LA_Party	Natural person	MG_NaturalPerson	CS	1
LA_Party	Legal entity	MG_LegalEntity	CS	1
LA_GroupParty	Family, Joint venture, Community	MG_GroupParty	LR	2
LA_PartyMember	Family member	MG_PartyMember	LR	2
Administrative Package				
LA_RRR	-	MG _RRR	LR	1
LA_Right	Ownership, Possession, Land use right	MG _Right	CS, LR	1
LA_Restriction	Hypothec, Servitude	MG_Restriction	LR	2
LA_Responsibility	Monument protection, Land fee payment	MG_Responsibility	LR	3
LA_BAUnit	Parcel, Building	MG_BAUnit	CS, LR	1
LA_Mortgage	Hypothec	MG_Mortgage	CS, LR	2
LA_AdministrativeSource	Land (right) certificate	MG_AdministrativeSource	CS, LR	1
LA_ RequiredRelationshipBAUnit	-	-	-	-
Spatial Unit Package				
LA_SpatialUnit	-	MG_SpatialUnit	CS	1
LA_SpatialUnit	Parcel	MG_Parcel	LR	1
LA_SpatialUnitGroup	Section, District	MG_SpatialUnitGroup	LR	2
LA_LegalSpaceBuildingUnit	Building	MG_LegalSpaceBuildingUnit	LR	3
LA_ LegalSpaceUtilityNetwork	Engineering utilities	MG_ LegalSpaceUtilityNetwork	LR	3
LA_Level	Urban, rural, mining	MG_Level	LR	2
LA_ RequiredRelationshipSpatialUnit	-	MG_ RequiredRelationshipSpatialUnit	LR	3

Table 2. *Cont.*

LADM Class	Corresponding Class (Attributes)	Profile Class	Derived from	Conformance Level
Surveying and Representation Subpackage				
LA_Point	Geodetic control point, Benchmark	MG_Point	LR	2
LA_SpatialSource	Field surveying, Orthophoto	MG_SpatialSource	LR	2
LA_BoundaryFaceString	-	MG_BoundaryFaceString	LR	2
LA_BoundaryFace	-	MG_BoundaryFace	LR	3

5. Discussion and Conclusions

This study was motivated by the current requirements of the long-term vision of Mongolia in the context of implementing future cadastres. This paper presents the implementation of the LADM-based cadastral data model–the Country profile for Mongolia consisting of Administrative and Spatial parts, showing how the standard can be adapted to the local cadastral system.

We improved and extended the previously developed model by revisiting and reexamining the cadastral system on the one hand, and on the other hand, we analyzed the legal environment for the country to derive the required classes for the proposed LADM data model. The developed Country profile conformed to all classes of the LADM from the low to the high level, particularly, while classes derived from the cadastral system generally met the low level, classes defined by the legal requirements conformed to medium and high-level classes. In addition, we provide object-instance diagrams to help understand how the developed model can be used in real situations.

In contrast, the adoption of LADM would require a holistic approach to consider all aspects relevant to cadastral systems, which may impact existing organizations and their operations, the scope of cadastral information, cadastral database structure, and cadastral information management [39]. The authorities responsible for cadastral affairs in Mongolia (i.e., Agency for Land Administration and Management, Geodesy and Cartography) may consider a roadmap for the LADM adoption [39]. Steps in this roadmap would include organizational motivation, institutional arrangement, information interpretation, data organization, governance and engagement, and capacity building. These steps are necessary for the successful application of LADM. In addition, when adopting the standard, after the cadastral data scope is defined, data collection and updates will gain importance. The LADM-compliant field data collector, the mobile application essential for these purposes, has already been developed and tested [40]. Therefore, these types of applications may also be considered for adopting LADM.

When the standard is adopted, the study result–the developed model would enable the use of the functionalities the LADM provides, including a formal language describing cadastral systems, i.e., shared ontology for communicating with one and different regions, standard-based efficient and effective software development for the cadastre. In addition, it will also facilitate cadastral data exchange between one and different regions, data integration with other sources, and cadastral data quality management to ensure data consistency and remove duplications.

The study is limited to the development of conceptual modeling—a platform-independent model, as the standard provides. The current version of the standard does not provide specific practical guidance for the implementation of LADM [5,15]. One way towards implementation could be the encoding of a unified modeling language (UML)-based LADM data model into an extensible markup language (XML) [41]. However, a platform-specific implementation (e.g., database development) for the developed Country profile will be vital to verify and test the application schema.

This paper presented a method for transitioning to a multi-dimensional cadastre reflecting the real world by taking advantage of the LADM, emphasizing the record of RRRs. In contrast, other solutions could exist to implement future (3D) cadastres, such as LandInfra (InfraGML), CityGML, and Building Information Modeling (BIM). However, as the legal aspects that the LADM highlights are considerable, cadastral 3D transitions should be based on the LADM or possibly with the combination with the CityGML [42], and data conversions and/or transformations between LADM-based models and other (physical) models should be enabled without data/information loss.

From the modeling perspective, further modeling and exploration of the LegalSpaceUtilityNetworks class and its specialization for the Country profile is required to implement an urban cadastre where the management of utility networks is important. The Surveying and Representation subpackage should also be further modeled considering local (legal)

requirements and relevant documents. In addition, a refined survey model [43] coming with the LADM edition II can be considered.

Furthermore, considering the country's characteristics (e.g., vast territory and pastoralism), the introduction of a subversion of the LADM–Social Tenure Domain Model (STDM) will be indispensable. This is because as many people engage in livestock farming/ranching for their livelihoods, securing pastureland or grazing land/area rights become a vital issue along with the increasing land degradation and desertification. Thus, the inclusion of informal land rights may be the point to consider when adopting the LADM standard to secure these pastoralists' rights and ensure efficient land use.

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