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Refining the survey model of the LADM ISO 19152–2: Land registration

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ABSTRACT

Cadastral surveying involves the delineation of property boundaries and the extent and documentation of easements and restrictions (imposed by private or public law), forming the foundation for Land Administration (LA). Survey models and processes constitute vital parts of Cadastres and Land Administration Systems (LASs). However, these models are often inadequately documented and lack standardization in practice. To address the global diversity and complexity of legal and administrative challenges in LA, standardization efforts have yielded the ISO 19152:2012 (ISO, 2012) Land Administration Domain Model (LADM), the Global Land Tool Network's (GLTN) Social Tenure Domain Model (STDM), and the OGC LandInfra/InfraGML standard. The current edition of the LADM focuses on standardised conceptual modelling of LA-related information, including a dedicated sub-package for Spatial and Surveying representation. As part of the ongoing LADM revision, a refined survey model is being developed to support a broad range of surveying and data acquisition approaches and levels of accuracy. Recognizing that surveying technology is not bound by national practices and regulations, this paper focuses specifically on the surveying aspect of LADM. It illustrates that the proposed refined survey model is applicable not only to conventional real property formation but also to participatory land rights recordation processes. The approach adopted in this research is technology-neutral, accommodating the ongoing evolution of surveying technology. It offers support for a broad range of surveying and data acquisition approaches, with varying levels of accuracy. *As the demand for high-precision positioning has been persistent within the land mapping and surveying community, particularly since the initial adoption of GPS, aiming to achieve centimetre-level accuracies (initially confined to local services), the paper addresses the fundamental principles of the High Accuracy Service (HAS) concept within the proposed model.* The main results presented in this paper are the conceptual model of the refined survey model of LADM Edition II (ISO19152–2), as well as an abstract, reference, cadastral surveying workflow following the principles of the proposed model.

1. Introduction

The primary purpose of a Land Administration System (LAS) is to support the processes of recording and disseminating information about the ownership, value and use of land and its associated resources (UNECE, 1996). Despite the great diversity of LASs that exist worldwide, they do present commonalities in terms of data, components, processes, and structure. One of these is the structure of the survey-related information and process, which lead to the description and delineation of natural and artificial features on the earth.

People-to-land relationships are dynamic. This results in a need for subdivision or merging of spatial units, as well as the re-establishment of existing boundaries where their location is ambiguous or disputed. All those cases require documentation of the respective boundaries. In case of a cadastral survey, the boundaries recorded are the boundaries of spatial units against which homogeneous land rights are associated ISO. ISO 19152, 2012. The rights can be formal, informal, or customary (FIG, 2010). Not all these rights are recognized in all countries, however, similar surveying techniques can be applied for boundaries between spatial units covered by these rights.

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Cadastral surveying is usually described through survey models and relevant processes, which differ from country to country. Those models are an important component of any land administration system. They are not always documented in detail. Due to the rapid advances in technology and geoinformation they need to be revised quite often.

Conventionally, data collection for land administration is carried out by specialists (licensed land surveyors). They use sophisticated survey equipment and elaborate attribute forms, in many cases serving several purposes (COST et al., 2000). However, in recent years, an approach raised where right holders themselves join in the data collection process in participatory methods. Those approaches are under the supervision of surveyors and/ or other land professionals (Morales et al., 2021). In that case, the use of advanced equipment with complex user interfaces combined with composite data forms is not suitable and not possible to perform.

Therefore, the required changes in data acquisition procedures pose a significant challenge, where upgrading of the data acquisition methodology and technology is concerned. Simple-and-robust technology to support the data collection either by professionals or citizens needs to be described together with a sophisticated set of algorithms to post-process collected data.

To support the above-mentioned issues, as well as to enhance the surveying functionality of the LADM, the survey model of its first edition is proposed to be enriched in the context of its ongoing revision. The second edition of the standard will consist of six parts: five parts as conceptual models (see Fig. 1) and one part that standardises the technical implementations.[1] The refined survey model is included in Part 2 – Land Registration.

This paper presents, describes and discusses the proposed components of the refined survey model for LADM Edition II – Part 2. This model is expected to support state-of-the-art techniques on data acquisition, alignment with other standards (e.g., OGC LandInfra[2]), as well as participatory methods in surveying. Apart from the conceptual data model that describes the data organisation, the process that is followed during a cadastral survey plays an important role. Therefore, in line with the conceptual model, a reference cadastral workflow has been developed. This workflow is presented in the next chapters. It is validated using implemented cadastral surveying processes from Greece, Denmark and Colombia.

In this paper, first the research methodology is presented in the next Section. Background information is derived from a literature review on developments in the cadastral surveying domain as introduced in Section 3. This review includes results of previous research by the authors. Furthermore, in Section 4, cadastral surveying practices across different institutional contexts are presented, resulting in the proposed reference workflow for cadastral surveying. This workflow is validated using existing and implemented cadastral survey processes from three countries. Then, Section 5 presents the refined survey model of LADM. Lastly, the conclusions and topics for future analysis are in Section 6.

2. Research methodology

The research methodology followed in this paper is presented in Fig. 2. First literature with documentation on LADM country profiles is investigated. This concerns relevant literature that enriched the surveying-related part of the standard. Furthermore, literature is investigated that describes the respective technological advances in other standards, in ongoing projects and in good practices from various countries around the world. In parallel, experts in the surveying industry (equipment manufacturers) are consulted, specifically for the inclusion in the model of support for High Accuracy Services and participatory methods.

From this review, the needs and requirements that need to be addressed in LADM Edition II – Part 2 have been formulated as presented in Kara et al. (2023). ISO standards should include the requirements that form the basis of the scope of the standard, while they are also used to specify an abstract test suite. In the context of this paper, those requirements have been validated and used through the model design in the next steps of the methodology.

Following, the components of the refined survey model have been designed. Outcomes of previous research (Shnaidman et al., 2019; Kalogianni et al., 2021a) have been taken into consideration in this design process. The versions of the LADM survey model that have been developed and revised during the standardisation process are assessed and further refined. This includes -among others- support for participatory surveying. The needs of the citizen and the requirements from the surveying process are handled simultaneously. It should be noted that the conceptual survey model has been discussed and evaluated by the ISO/TC211 LADM development team.

Taking into account all those sources and the relevant standards and ongoing projects (Section 3), a generic cadastral workflow aligned with the refined survey model is designed. The proposed workflow is validated using cadastral processes from Denmark, Greece and Colombia.

3. Literature review

The first Edition of the LADM included a simple survey model based on the ISO 19156:2011 Observations and Measurement Standard (ISO 19156:2011). The model is abstract, as at the time of the release of the first Edition, focus is given on describing the people-to-land relationships through the detailed documentation of Rights, Restrictions and Responsibilities (RRRs) associated with spatial units. In this context, the need for functionality to clearly represent a broad range of spatial units is recognised and supported by Edition I of the LADM. Spatial units are the areas of land (below and above)/ water and can be represented either as a text, a sketch, a single point, a set of unstructured lines, a surface, or a 3D volume (Lemmen, 2012; Lemmen et al., 2015; van Oosterom and Lemmen, 2015; Kalogianni et al., 2020b). A RRR applies to a basic administrative unit, consisting of zero or more spatial units.

The LA_SpatialUnit class allows for the description and inclusion of any type of spatial unit, while there are two sub-classes or specialisations: one devoted to the legal spaces of utility networks (LA_LegalSpaceUtilityNetwork) and the other to the legal spaces of building parts (LA_LegalSpaceBuildingUnit). In Annex E, named 'spatial profiles', a description of surveying and representation alternatives is included.

The Surveying and Representation sub-package in LADM Edition I includes basic concepts for modelling the bounding elements for spatial units. These include points (LA_Point), 2D boundaries/ linestrings (LA_BoundaryFaceString) and 3D boundaries/ volumes (LA_BoundaryFace), based on available standards, such as ISO 19107:2019.

Sub-Section 3.1 lists the most important developments in cadastral surveyring as implemented through various LADM country profiles. Following, survey and design sources are taken into consideration when developing the refined survey model. A reference cadastral workflow is introduced. Finally, Sub-section 3.3. briefly provides relevant literature with regards to cadastral survey processes.

3.1. Surveying functionality of country profiles based on LADM Edition I

From the various county profiles that have been developed, only a minority used the survey model, while some of them further extend it to support the needs of the respective country. From an analysis made on them (Kalogianni et al., 2021b), it is noted that most of the designers of the profiles further enriched the spatial package and/ or surveying and representation sub-package when they are focusing on modelling of the underground infrastructure. Such developments have been carried out in order to support explicitly and in detail the needs of a country with regards to those aspects.

[1] https://www.iso.org/standard/51206.html

[2] https://www.ogc.org/standard/infragml/

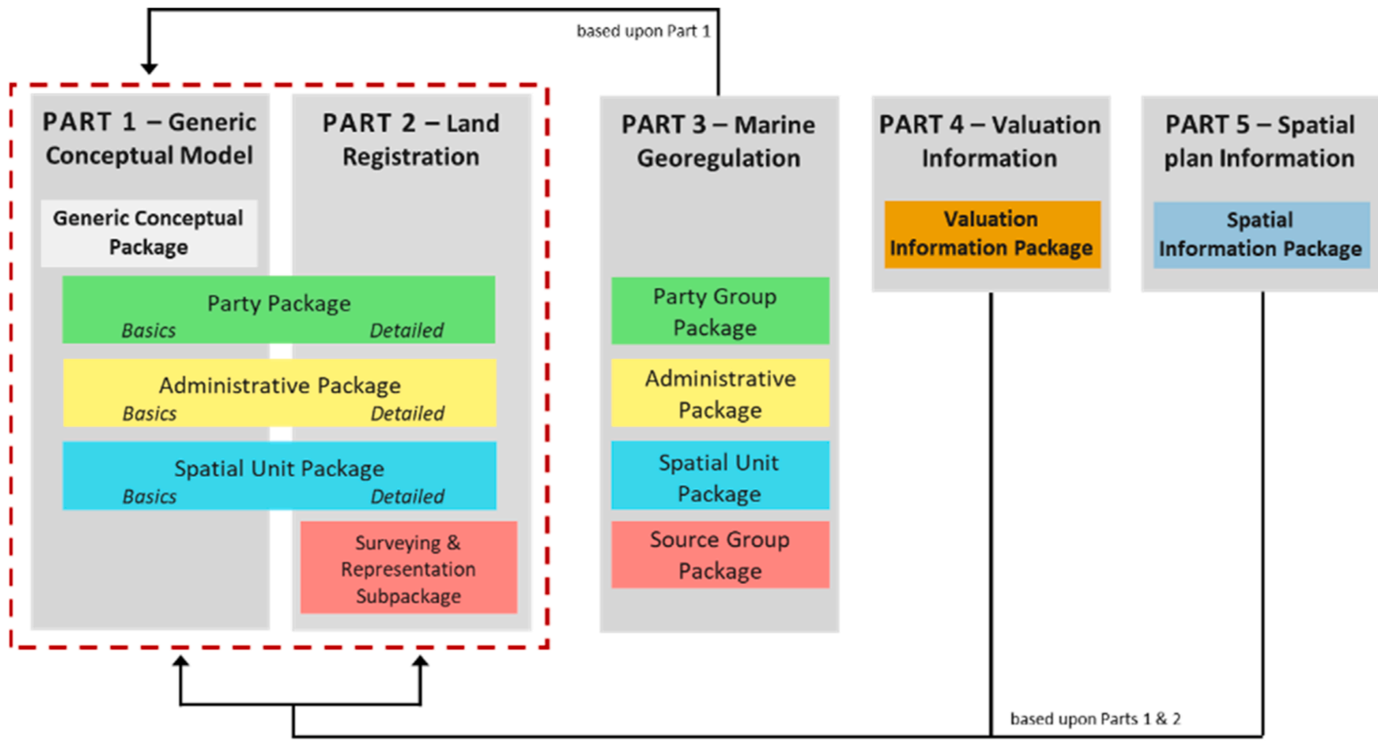

Fig. 1. Overview of the packages of all the Parts of the LADM Edition II – focus is given to Part 2 in this paper (Kalogianni et al., 2023).

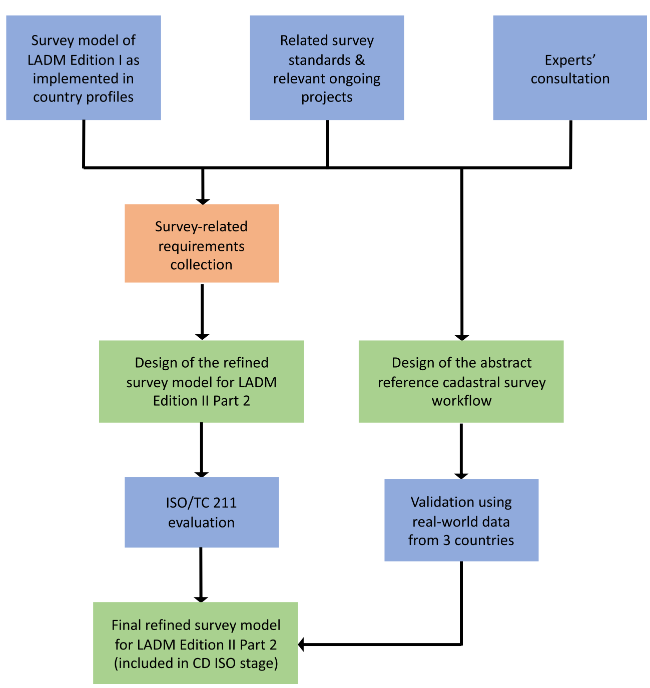

Fig. 2. Research methodology followed in this paper.

Kim et al. (2017)) developed a detailed cadastral data model for Korea 3D underground data based on LADM, proposing a 3D underground cadastral surveying and mapping package. Radulović et al. (2019) in the extended country profile for Serbia, focus on the utility network cadastral data, introducing the Serbian Utility Network Model providing a detailed structure and code lists. Aditya et al. (2021) introduce a LADM-compliant field data collector for cadastral surveys in Indonesia by examining possible collaborative efforts (top-down information and bottom-up field recording and validation) using a mobile application designed for both spatial and legal/administrative data simultaneously.

3.2. *Surveying functionality of other standards and projects*

Currently, there are multiple standards and/ or encodings that provide functionality to model, store and/ or exchange survey-related information. LADM Edition II aims to facilitate interoperability with other standards.

Two main categories of sources are identified: one related to the surveying and one related to design, for example designed spatial units in a spatial plan. The focus of this paper is on the surveying sources.

3.2.1. *Surveying sources*

The *OGC Land and Infrastructure Conceptual Model* (LandInfra, OGC, 2016) is the proposed successor of LandXML. Landinfra is based on a subset of LandXML functionality. It is based on a UML conceptual model and implemented based on GML. LandInfra has a package to model survey information (LandInfra Survey) to represent infrastructure facilities in compliance with interests in land (OGC, 2016). The Survey package provides access and processing options to all survey information specified under an umbrella with "header" information about a survey, such as the purpose, type, and surveyor. It is composed out of sub-packages with information on observations, equipment, and results. Overall, LandInfra is more focused on infrastructure surveys combined with cadastral surveying. There is less emphasis on the legal and administrative aspects of land development.

The *OGC MUDDI (Model for Underground Data and Integration)* is a conceptual multipart and modular model, including implementation specifications, and mapping options 'to/from' other models for geospatial data representing underground infrastructure assets (OGC, 2019). The MUDDI approach emphasises the definition of common concepts and terminologies that mediate between elements in existing data models and can be used to integrate underground data from disparate sources (Lieberman et al., 2020). Underground Infrastructure

Information can be linked directly to measurements, sensor observations, and supporting evidence. Its quality can be determined, using the 'iSurveyed' interface referring to position and measurements.

The *Singapore's Digital Underground project* is a collaboration between Singapore Land Authority and the Singapore-ETH Centre that aims to establish a digital twin of all subsurface utilities in Singapore (Singapore - ETH Centre, 2019). Reliable information on subsurface utilities requires an integrated approach including the survey and mapping of the subsurface utilities with precise information of the underground space. Therefore, Phase 2 of the Digital Underground project developed a broad set of recommendations on data governance, data capture, data management, and capacity development and established the Digital Underground Connect community of practice. Those include also the 'Standard and Specifications for Utility Survey in Singapore', Version 1.1 (SLA, 2021). Those specifications provide descriptions of procedures from acquisition to production of utility information/data covering the two major elements of the utility survey process. That is the data capturing and the data presentation. For data capturing Global Navigation Satellite Systems (GNSS) are covered in the document as a tool to capture high quality data output to produce 3D models with well-defined absolute and relative accuracy. Surveyors should determine appropriate equipment to satisfy user's requirements (Yan, 2021).

Currently, there is an ongoing Australian-New Zealand project on building the *Intergovernmental Committee on Surveying and Mapping (ICSM) Conceptual Model for 3D Cadastral Survey Data Model and Exchange (3D CSDM)* with a standardised way of transferring cadastral survey datasets in all Australian states and territories and in New Zealand. This solution is adopted by the survey software suppliers operating in the Australian and New Zealand market. The surveying community has actively provided comments and feedback during the development of the standard. A progressive transition from lodging paper-based documents or PDF files to fully digital data for surveyors could be organised. The harmonised data model will cover all cadastral survey data components required by the responsible cadastral agencies, including 2D and 3D elements (Haanen, 2021).

Another project carried out in *Colombia* presents a data model based on LADM and STDM that supports *participatory data collection* (Morales et al., 2021). Grassroot surveyors collect the boundary data together with citizens under supervision of professional surveyors. The process starts from the field data collection stage up-to the post-processing to identify and properly position the property boundaries. Perimeters of spatial units are walked in the field and observed as polygons, this means that each boundary is observed from two sides. Topology is calculated during post processing of the observations. A field survey module is developed, in collaboration with Esri, to adhere to the stated requirements. The field survey module is based on the ArcGIS Collector app (Morgenthaler, 2020) and, consequently, the module takes advantage of the cloud infrastructure on which the Collector app operates. It is important to note that the fit-for-purpose approach that is proposed has been tested during several case studies in regions of Colombia with different land rights structures, ranging from formal to indigenous or social. See Morales (2021) and Lemmen (2019)).

*HAS is a novel service developed by Galileo with the aim to enable positioning performance in the order of 20cm using Precise Point Positioning (PPP) approaches. While primarily broadcasted for PPP correction services, several studies (*Angrisano et al., 2023*) explore its advantages on alternative positioning methods, such as Single-Point Positioning (SPP). These investigations focus on evaluating the improvements in position accuracy that HAS can provide to these different techniques. Moreover, a* H2020 project 'Galileo Improved Services for Cadastral Augmentation Development On-field Validation' (GISCAD-OV) (H2020 GISCAD-OV, 2023) investigates the mapping of Galileo HAS measurements and 3D Land Administration Systems in the context of the ongoing development of LADM Edition II.

3.2.2. Design Sources

An OGC LandInfra dataset based on the Land Division (OGC, 2016) package may refer to boundaries delimiting ownership in land. This provides context for fieldwork with measurements and boundary marking. Ownership rights in land (as specified by a PropertyUnit in LandInfra) include buildings and fixtures on the land parcel. However, lawful processes may establish units of real property which are not bound to the surface of the Earth, namely in terms of CondominiumUnits through a *condominiumScheme*, or in terms of *superficieObjects* through an encumbranceScheme (OGC, 2016). There is a class Condominium in LandInfra providing information about a condominium. Condominium is defined as a concurrent ownership of real property that has been divided into private and common portions and it is expected that it could be a valuable source of information.

Further, research has been done by (Atazadeh et al., 2017; Oldfield et al., 2017; 2018, Meulmeester, 2019; Kalogianni et al., 2020a; Broekhuizen et al., 2021; Ramlakhan et al., 2021; Alattas et al., 2021; Guler and Yomralioglu, 2022; Guler et al., 2022) in reusing 3D digital models, specifically *Building Information Model (BIM)* for Land Administration applications. This is a rich source of geometrical information and semantics, which can support the identification of property units accurately, with the visualisation of complex buildings into detail (Sun et al., 2019; Kalogianni et al., 2020a). Information from BIM/ IFC models may be needed for cadastral registration, further an initial detailed IFC model should be created with information on spaces, georeferenced attributes, etc.

3.3. Cadastral surveying processes and workflows

Cadastral surveying processes are described for a number of European countries in the context of the COST action G9: *Modelling Real Property Transactions* (COST, 2000). Drawing on Alistair Cockburn: 'Basic Use Case Template', such processes have been outlined for Denmark, Finland, Hungary, The Netherlands, Slovenia, and Turkey. A more elaborated presentation is prepared for Greece (Arvanitis et al., 2004), and as outcome of a Short-Term Scientific Mission, the property transactions of Greece and Sweden have been compared (Koukopoulou, 2005). The issue is further developed, e.g. through the report: 'Property formation in the Nordic countries' (Kort og Matrikelstyrelsen, 2006).

World-wide, cadastral surveying is performed as part of land administration endeavours and during the last decades also in the context of participatory land right recordation processes. The selection of terminology appears challenging. The term 'process' conventionally refers to a sequence of activities, which complies with a statute or statutory instrument. Williamson et al. (2009) thus define land administration as 'The processes run by government using public- or private-sector agencies related to land tenure, land value, land use, and land development'. Yet also the term 'workflow' is frequently used for describing land administration processes. However, where the term is defined, the context is resource management and efficiency (Van Osch et al., 2004), and this is out of the scope of this paper. For the purpose of this paper a workflow is defined as a computer implementation or automation of a business process. A system that fully defines, manages and executes workflows through performing activities whose order of execution is defined by the workflow logic is called a 'Work Flow Management System' (WFMC, 1995; Vranić et al., 2021).

4. Cadastral surveying in institutional context

Each country has cadastral surveying workflow(s) developed in accordance with specific needs, legislative framework, organisational land administration structures and mandates, and agreed with parties involved. Depending on the technological maturity of the systems those workflows are quite different, but some key-activities can be identified in them and constructive conclusions can be derived to form a generic approach.

At this section a first version of a generic cadastral surveying workflow is presented as an aspect of the refinement of the survey part in LADM. To abstract beyond these conceptions, a reference workflow is proposed in terms of a sequence of activities in sub-Section 4.1. Next (sub-Sections 4.2.1–4.2.3) the Danish, Hellenic and Colombian practices are described based on Kalogianni et al. (2021a) and Morales et al. (2021).

4.1. A generic, reference cadastral surveying workflow

This subsection presents a generic, reference cadastral surveying workflow, including both the administrative and the surveying part aiming to align the main activities with the refined survey model of LADM Edition II.

The following describes a sequence of activities which are to be performed to document rights in land. This concerns the effort to describe the present status during initial data acquisition, or the effort to change this status in case of transactions. This may be achieved through documents which refer to spatial objects, which can be identified by holders of the right(s). Where needed this can be supplemented by placing specific marks (monuments) in the field. Reference systems are important as means to achieve the documentation.

The objective of the generic workflow is stated in terms of rights on spatial units, with agreement between all involved parties (e.g., surveying professionals, citizens and neighbours, etc.) The model that describes the proposed workflow comprises the following activities:

- previous boundary-related sources (e.g., fieldwork, maps, records, etc.) are collected, if available, as needed, and eventual permissions are obtained;
- the boundaries of spatial objects where rights apply are identified, possibly marked/staked out, and finally surveyed relative to a national reference system and local, well-defined points. Results of aerial surveys can be used;
- the documentation of the boundary surveys is edited in appropriate formats. Parties confirm the documentation where possible;
- the involved agency/ies approve(s) the documentation and record(s)/archive(s) it; and:
- the parties involved close the effort.

Fig. 3 presents the overview of the proposed cadastral surveying workflow.

First the “case” or project or survey activity needs to be identified. Then the workflow starts with the planning for the data acquisition process in a defined area, which can be a project area for initial data collection or a (set of) spatial units where data maintenance will be applied. Depending on the purpose of the survey, the size of the area of interest and the equipment that will be used, the number of teams that will work in the field for the initial data collection and/ or maintenance and/or setting out of designed spatial units or boundaries is decided. The team(s) proceed to collect and/or maintain and/or simultaneously set out the spatial data and collect the administrative/legal data in the area. During fieldwork or during post processing, the observations are adjusted to existing coordinates of points and/or transformed into topologically correct representations of the spatial unit. The last step is the recordation or registration in the (official) cadastre and land registry.

Fig. 3 depicts the generic steps that are being followed during cadastral survey. It does not describe in detail the data collection process or the process of setting out of boundary positions. Fig. 4 illustrates the activities that serve as a reference workflow for cadastral surveying, covering the main stages followed in such a process, and in alignment the proposed LADM refined survey model.

The process starts either with the definition of new, unique, identifier (s) for newly created spatial units that will be surveyed or set out. Or, if they already exist, for the retrieval of the existing ones. Similar for party identifiers. Those spatial unit identifiers make it possible to execute administrative data collection and spatial data collection independently and merge them back later in the survey process. In case the spatial unit already exists, the related information can be retrieved, either from a design source (i.e. a BIM model, spatial plan or land consolidation plan) or from a survey source (i.e. from a cadastral database/ registry). This can be aligned to the two new subclasses of the class “LA_SpatialSource” of the LADM Edition II-Part 2, namely “LA_DesignSource” and “LA_SurveySource” (see Section 5). This introduces the concept of reusing information from multiple sources.

Following, there are three processes that can run in parallel (optional): the collection of administrative information, the collection of spatial information (by a professional or, in a participatory way by communities) and setting out designed coordinates in spatial plans.

The first optional choice is where relevant administrative information is being collected on parties and/or rights. This concerns all possible cases: when there is an existing design source available, when there is an existing cadastral registration for the spatial unit, and when there is no available data at all and all the data-attributes on parties and (shares in) rights have to be initially documented. Note: administrative data may be distributed in case of spatial planning.

The second optional choice concerns spatial data collection, where the source of the spatial unit includes documentation from the survey process. Regardless of the existence or not of associated sources, the data acquisition process can be executed in two different ways: either as a community-based (participatory) spatial data collection process under the supervision of a professional surveyor (i.e. a crowdsourcing approach), or executed directly by professional surveyors (using one or more of surveying methods, that can be represented in the subclasses of the LA_SurveySource).

The third option concerns setting out designed boundary descriptions (ranging from coordinates to physical features and other spatial descriptions). Depending on various factors, but mainly the regulations and legislative framework of each country/ jurisdiction the result is validated, whether it is included within the respective tolerance. In case the validation is not possible a redesign can be made.

The last step for the second (spatial data collection) and third option (setting out coordinates from the design process) is the creation of new spatial unit(s) or updating of the existing one(s). They are used to either update the existing one(s) or to generate new ones.

The notations used in Figs. 3 and 4 are explained in Table 1 (OMG, 2011):

4.2. Comparing of the proposed reference workflow with existing workflows

In the following subsections, the Danish, Hellenic and Colombian cadastral surveying workflows that have been earlier presented by Kalogianni et al. (2021a) are compared with the proposed reference workflow presented in Sub-Section 4.1, in order to assess it in terms of consistency and to identify potential issues related to the LADM survey model components.

4.2.1. Implementation regarding the cadastral surveying workflow for parcel subdivisions in Denmark

The organization of cadastre in Denmark and the general outline of a subdivision process is rendered in the report Property Formation in the Nordic countries (Kort og Matrikelstyrelsen, 2006). Fig. 5 below renders the surveying aspect of the subdivision process.

In the surveying company, a case identifier is established. Next step is the retrieval of relevant data, in terms of existing cadastral identifiers, boundaries, and areas, as well as archived measurements of existing boundaries. Together with the owner request, the data are elaborated into a survey design. Then, the new boundaries are set out by referring to existing control points and other locational cadastral evidence, e.g. in terms of boundary marks, which appear undisturbed since their

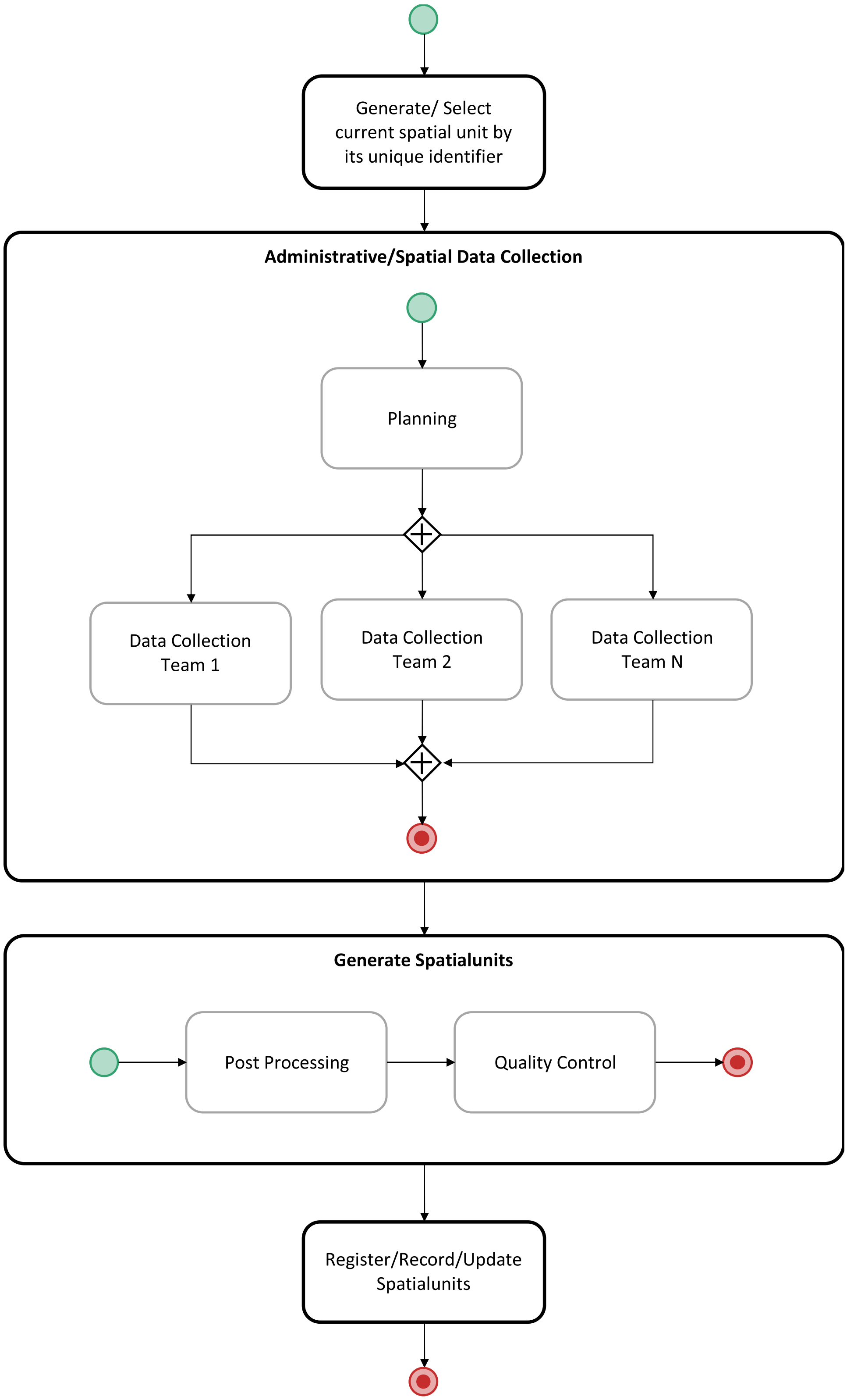

Fig. 3. Proposed reference cadastral surveying workflow based on the refined survey model of LADM.

establishment, house corners, and other well-defined spatial features. New boundary points are marked, and the spatial data collection is completed.

Back in the office, the account of cadastral changes is detailed, and the changes are validated against requirements. Due to the focus on surveying, no details are presented in the workflow concerning party confirmations, or requirements arising by spatial planning, environmental, and other land use aspects, and regulations, including consultation with municipality, easements and settling of other liabilities.

Finally, the case is submitted to the Danish Geodata Agency, which verifies that the relevant requirements are met and approves the proposed changes to the cadastre.

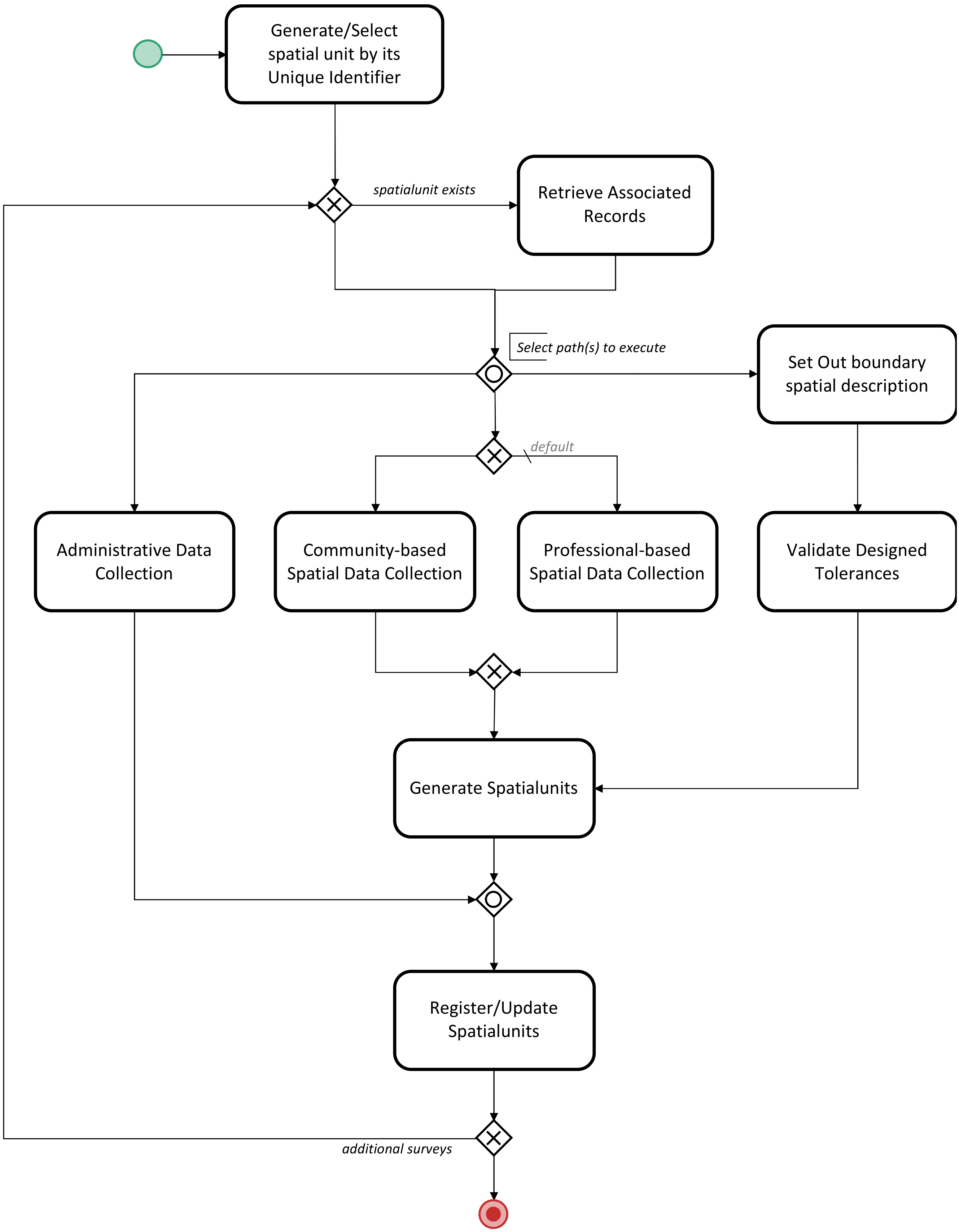

Fig. 4. Data collection process as part of the proposed reference cadastral surveying workflow.

Table 1
Notations used in the activity diagrams describing the proposed reference cadastral workflow.

	An ***inclusive gateway*** allows multiple sequential flows to evaluate to true hence enabling the process to follow various paths depending on the evaluation of the gateway criteria for each process instance.
	An ***exclusive gateway*** always leads to the activation of exactly one sequential flow. If none of the gateway's conditions evaluates to true, then the default path is activated.
	A ***start event*** represents the point at which a process instance or a sub-process starts.
	An ***end event*** represents the point where the process or sub-process is considered to be completed successfully.
	An ***activity*** corresponds to a process step that can be atomic or decomposable into a sub-process.

4.2.2. Implementation regarding the cadastral surveying workflow for parcel subdivisions in Greece

The Hellenic Cadastre (HC) is a property-based system that registers and maintains the technical (location and boundaries) and legal information of real properties, linked via a Unique National Cadastre Code Number (KAEK) (Kalogianni et al., 2021a). In case a registrable fact results in a geometric change (merges, subdivisions etc.), the cadastral surveying work is performed by a licensed surveyor in contact with the (local) cadastral authorities who provide the necessary information and guidance in accordance with the local requirements and regulations. The process is described in Fig. 6.

As a first step it is important to select the cadastral number(s) of the specific parcels or area under change in the specific case. The cadastral number is a unique identifier assigned to each parcel of land in the Hellenic cadastral system. With the cadastral number, the surveying workflow can be tailored to the specific parcel/ spatial unit and its corresponding cadastral records, ensuring compliance with local regulations and procedures.

The surveyor needs to obtain the existing cadastral survey diagram of the spatial unit from the cadastral authorities, also gathering existing necessary documents (such as cadastral maps, historical records, and deeds, if needed). So, the surveyor requests and the cadastral office issues and grants the cadastral survey diagram, including information about the existing parcel. The first page of the cadastral diagram represents the parcel of the application to scale, the area according to the Cadastre data, and the value of the linear distortion in EGSA87 (the national reference system), while the second page includes the table of coordinates and the respective areas. The information about the control points used in the survey (trigonometric and urban network points) is available online through the official website[3] and the e-CADASTRE electronic services portal.

Following, the spatial data collection in the field takes place by professional licensed surveyors. On-site collection of accurate measurements and data, locating existing boundaries, landmarks, and physical features are executed using the necessary surveying equipment. Based on the results of the field work, new boundaries of the spatial unit are determined, ensuring compliance with zoning regulations. Following, the surveyor designs the new/ updated topographic diagram depicting the geometric changes that have occurred due to the spatial change (depending on the type, different updates will occur at the topographic diagram). The diagram is then submitted along with the applications for the registration of acts and the relevant correction/ update of geometric data to the cadastral office.

Following, the verification of the application is carried out by the cadastral office. The final step leads to the "Under Final Registration" status of the spatial unit (depending on the result of the verification -rejection or conversion to updated spatial unit), to be further processed following the steps for each distinct type of spatial change.

4.2.3. Implementation regarding the cadastral surveying workflow for parcel subdivisions in Colombia

This sub-section provides an example case for Colombia where participatory mapping has been applied and tested, see Morales et al. (2021). The Colombian test of land rights recordation is two-levelled, initiated by a group of national agencies (Land, Mapping and Registry), who determine which areas should be surveyed (with unique use case identifiers), and followed by local socialisation and training events.

The objective is to document an unspecified type of right, called a consideration, the identity of the person, who holds this tenure relationship, as well as the unit of land, the parcel, for which the consideration is valid. In the test grassroot surveyors, land professionals, university staff, and employees from the group of agencies are engaged in the local activities, which are organised involving leaders of the local community/ communities (as presented in Fig. 7). In parallel, available data sources, existing cadastral records, and adequate orthophotos and/ or satellite images are collected and provided by the agency group.

Claimants of interests in land identify the location and the approximate area of their interest, first in a planning phase on a base map (using an orthophoto or a high-resolution satellite image), next accompanied by a grassroot surveyor in the field. The grassroot surveyor measures the boundaries of land units in terms of VertexPoints and AnchorPoints (as presented by Morales et al., 2021), and non-private objects, e.g. a river or road, in terms of ReferenceObject. Corresponding evidence on existing rights in terms of documents and photos are recorded as well.

The surveyed data are transformed into topologically correct representations of parcels, and an analysis of the various classes of rights is made and is compared with existing government registers when applicable. The processed results are presented to the community in a public forum for approval. Signatures are collected as validation of the results, which indicate agreement between the parties. Then, the parcel data that is approved by authorities and the community is submitted to the national agencies for processing. They proceed to analyse the data so that official documents can be generated for the various holders of right. In some cases, the right can be immediately formalised leading to a land title. In other cases, which fall into different categories of rights, a different procedure applies, but they can potentially lead to titles too. The sequence of activities thus appears as open- ended, as presented in the following figure.

5. The proposed refined survey model of the LADM Edition II - PART 2

The proposed refined survey mode of the LADM Edition II - Part 2, and its main UML diagrams and concepts are presented in this section. Starting from the need to support the description of a wide range of types of spatial units, the categories of the (legal spaces of) cadastral objects supported in Edition I (LA_LegalSpaceBuildingUnit and LA_LegalSpaceUtilityNetworkElement) are further specified. In this respect, two subclasses are introduced: the LA_LegalSpaceCivilEngineeringElement and the LA_LegalSpaceParcel. Those subclasses describe the legal spaces of infrastructure elements (bridges, tunnels, etc.), as well as traditional land parcels (see Fig. 10).

Apart from this, the most extended refinement concerns the 'source concept' based on two pillars:

- The concept of Integrated Source. This is modelled as an association between the Administrative and the Spatial source classes. The different source types are represented via assignments of multiplicity (Fig. 8).

[3] www.ktimatologio.gr

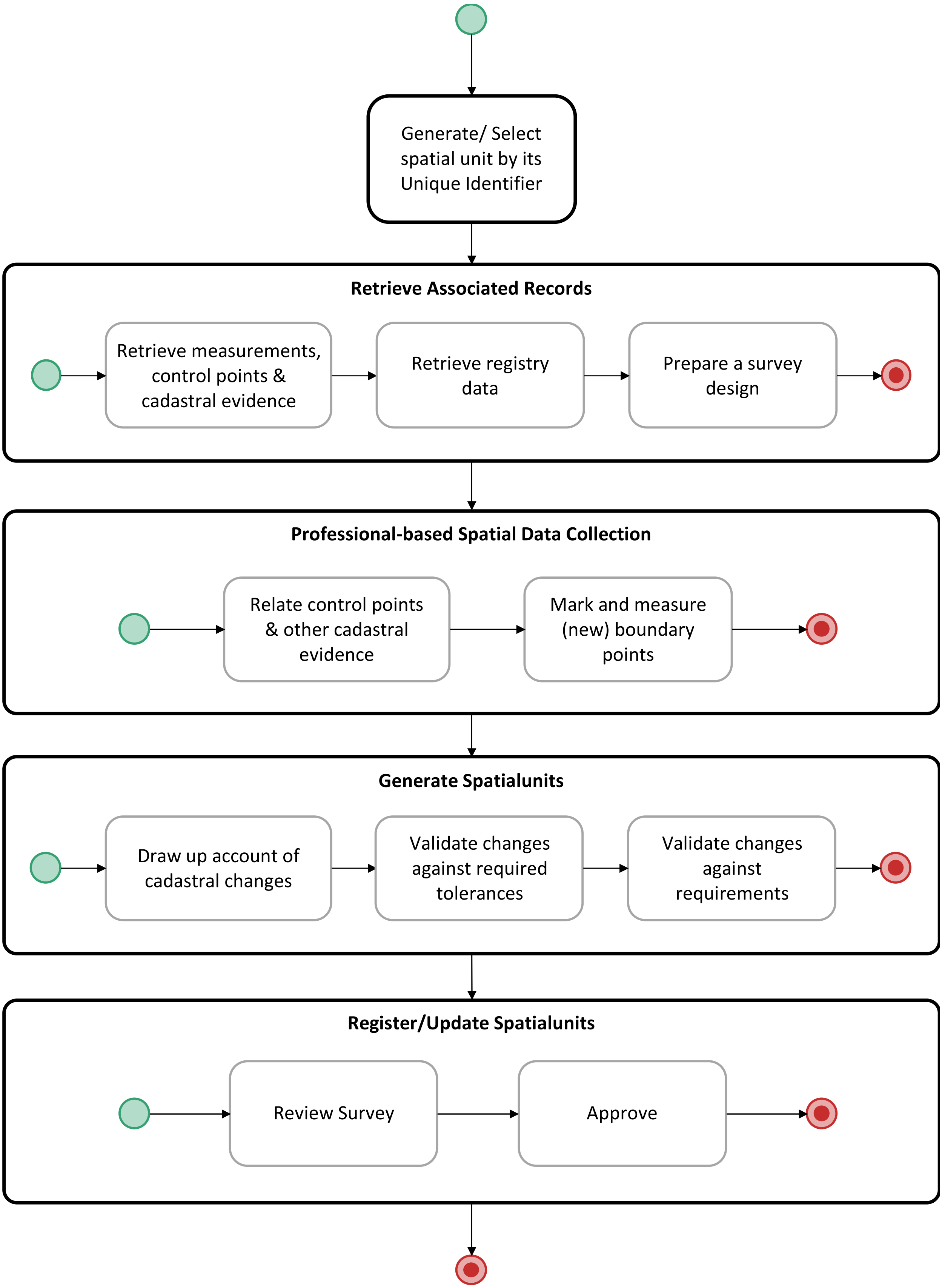

Fig. 5. Implementation of the proposed reference cadastral surveying workflow for Denmark.

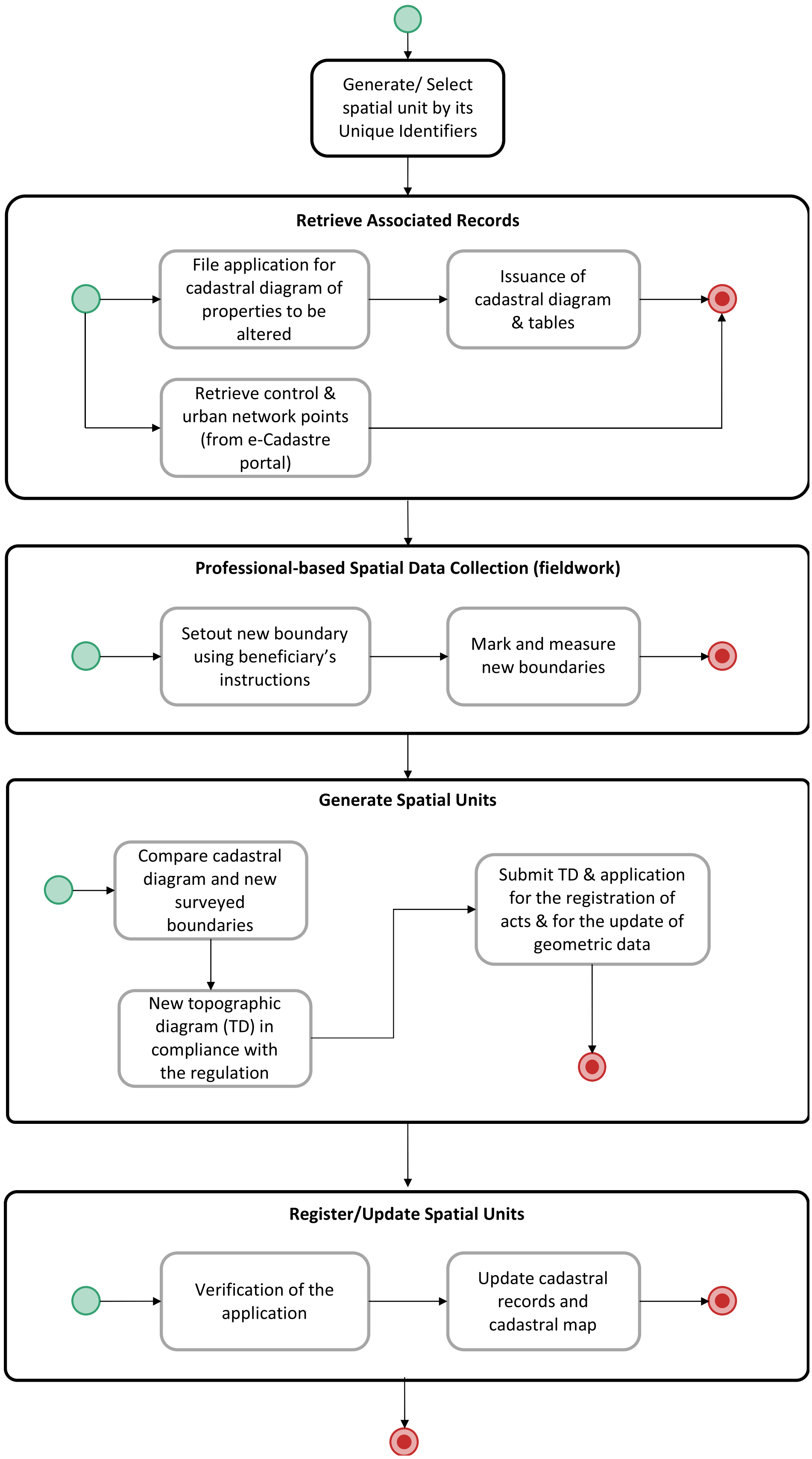

Fig. 6. Implementation of the proposed reference cadastral surveying workflow for Greece.

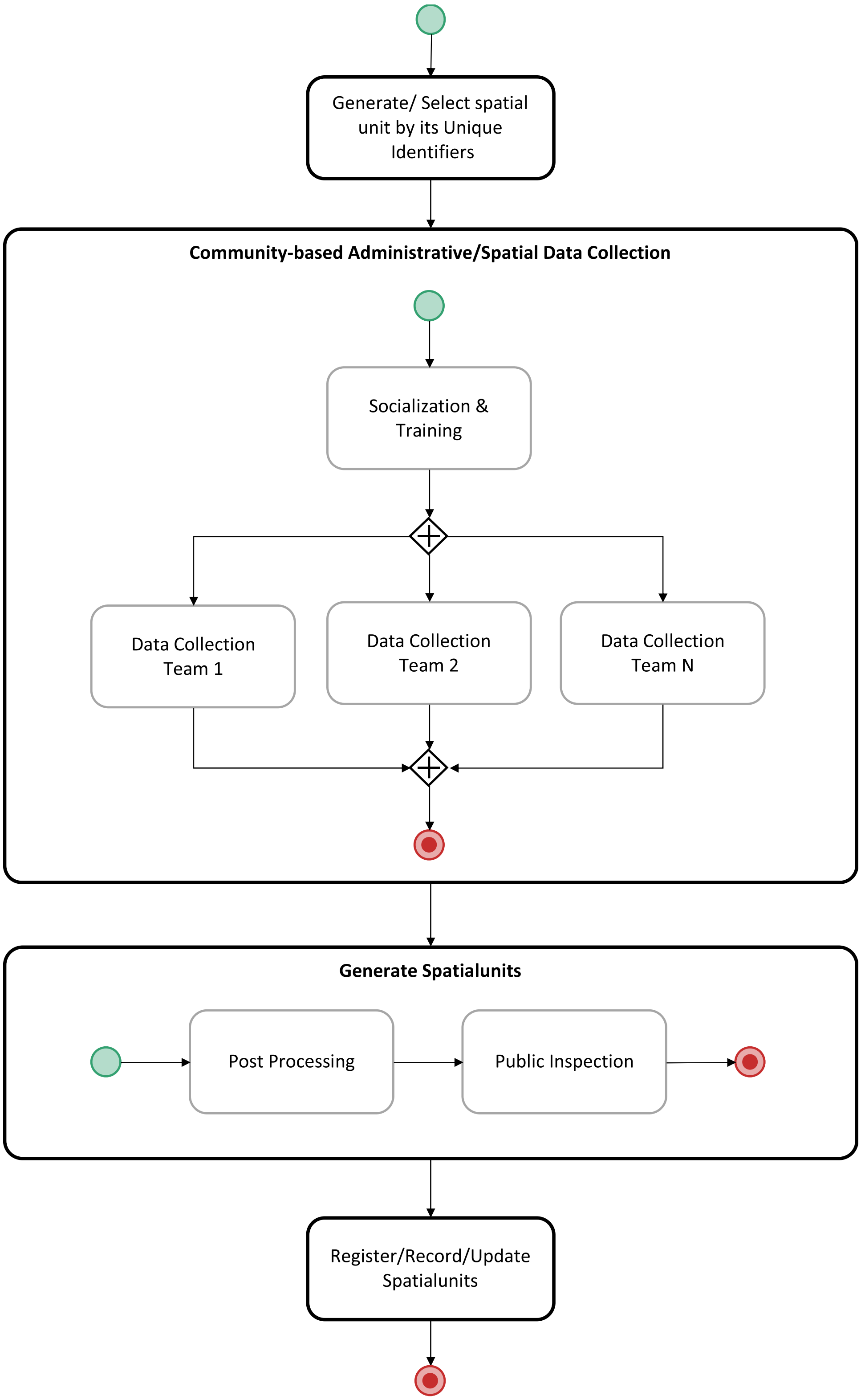

Fig. 7. Implementation of the proposed reference cadastral surveying workflow for Colombia.

- The subclasses LA_SurveySource and LA_DesignSource (Fig. 8) added at the LA_SpatialSource class. Those classes provide the option to describe into detail the source that is being used in the cadastral survey process. The sources can be either related to a data acquisition survey or can be based on a design. In this way, the concept of reusing information from other sources and previous stages of the lifecycle of an object is supported.

The basic classes of Surveying and Representation Sub-package as proposed in ISO19152–2 are presented in Fig. 9 and Fig. 10.

Additionally, in order to explicitly express the purpose of the survey,

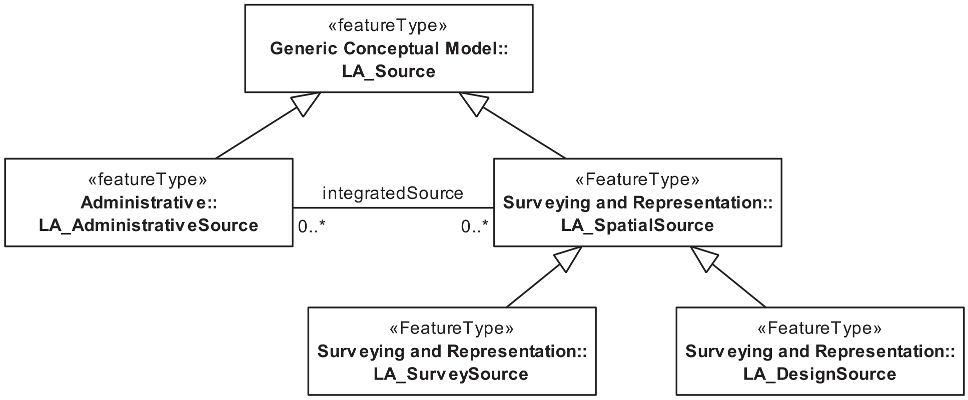

Fig. 8. Classes and subclasses of the LA_Source and integrated source.

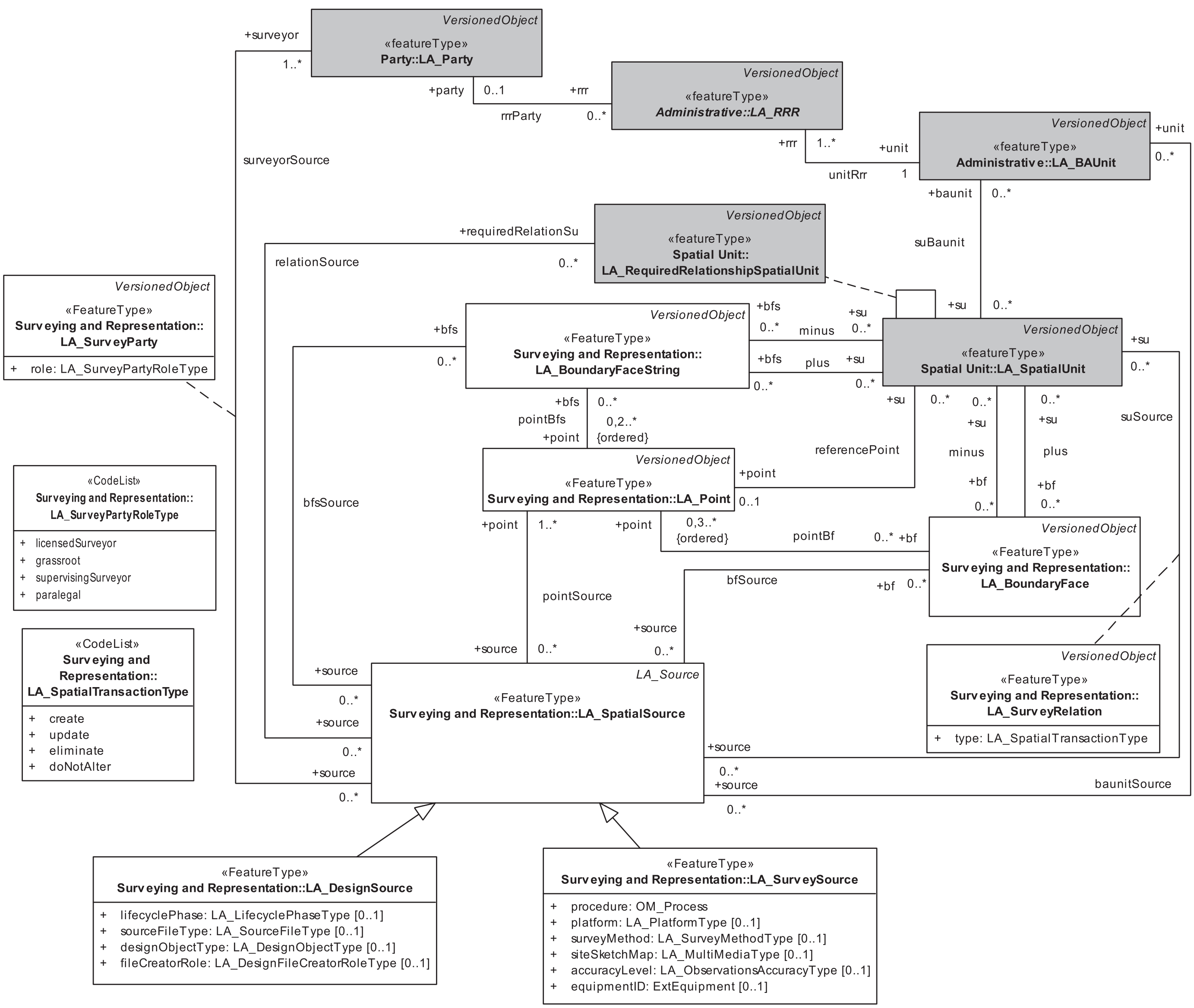

Fig. 9. Basic Classes of Surveying and Representation Sub-package of ISO19152-2, as submitted in CD of ISO19152-2 (1).

an association class LA_SurveyRelation is proposed between the LA_SpatialSource and LA_SpatialUnit, as presented in Fig. 9.

Survey-related information is documented in spatial sources and specifically, a set of measurements with point observations is an attribute of LA_SpatialSource of the LADM Edition I. However, as the types of measurements used around the world for cadastral survey are not

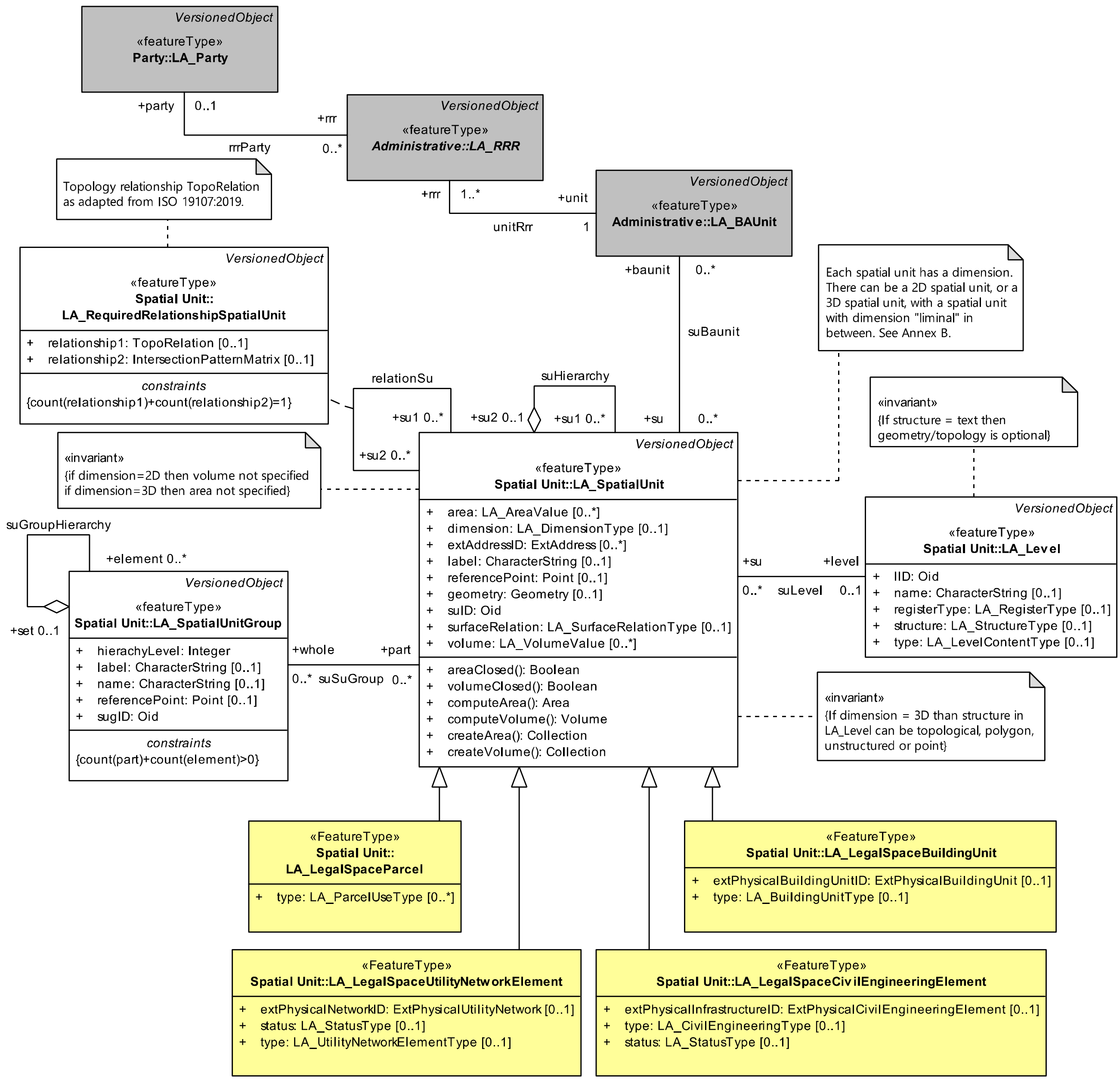

Fig. 10. Basic Classes of Surveying and Representation Sub-package of ISO19152-2.

limited to point observations (and therefore coordinates), other, commonly used observations for measurements and boundary descriptors (distance, height difference, GNSS, etc.) are introduced now in the refined survey model of the second edition of the standard.

Therefore, the LA_SpatialSource class as defined in LADM Edition I, is being extended (yellow-coloured classes in Fig. 10), see also Kalogianni et al. (2023). A spatial source may be official, or not (i.e., a registered survey plan, or an aerial photograph) and therefore, the proposed model is flexible and supports both formal and participatory surveying acquisition methods. Paper based documents (which may be scanned) can be considered as an integral part of the land administration system.

The spatial source can be a survey, which becomes a specialisation of the class OM_Observation as defined in ISO 19156:2011 (ISO, 2011), describing a set of measurements that may be obtained through various survey techniques. Recent developments have seen a new edition of 19165. At the time of developing LADM Edition II (specifically Parts 1 and 2), this updated edition of Observation & Measurements was not yet accessible. Consequently, the concepts used from 19156 for this edition of LADM remained unchanged. (OM_Observation - Observation inferface, OM_Process - Survey Procedure). Future editions of LADM will align with the updated edition of 19156:2023.

To provide this additional functionality at the standard nine subclasses are added to the LA_SurveySource, representing the different methods for observations' acquisition (Fig. 11). For each one of the subclasses, relevant attributes and code lists have been designed to address the most common observation characteristics for each one of the methods.

Overall, the approach and model presented in this paper is technology neutral, *capturing (3D) coordinates along with their associated uncertainties. This is supported by the number of sub-classes that are introduced (*Fig. 11*) representing the different methods for observations' acquisition. These range from simple distance measuring techniques, such as tape measurements, to more advanced methods including total station (TPS observations), GNSS, and point cloud data collection. Additionally, the model allows*

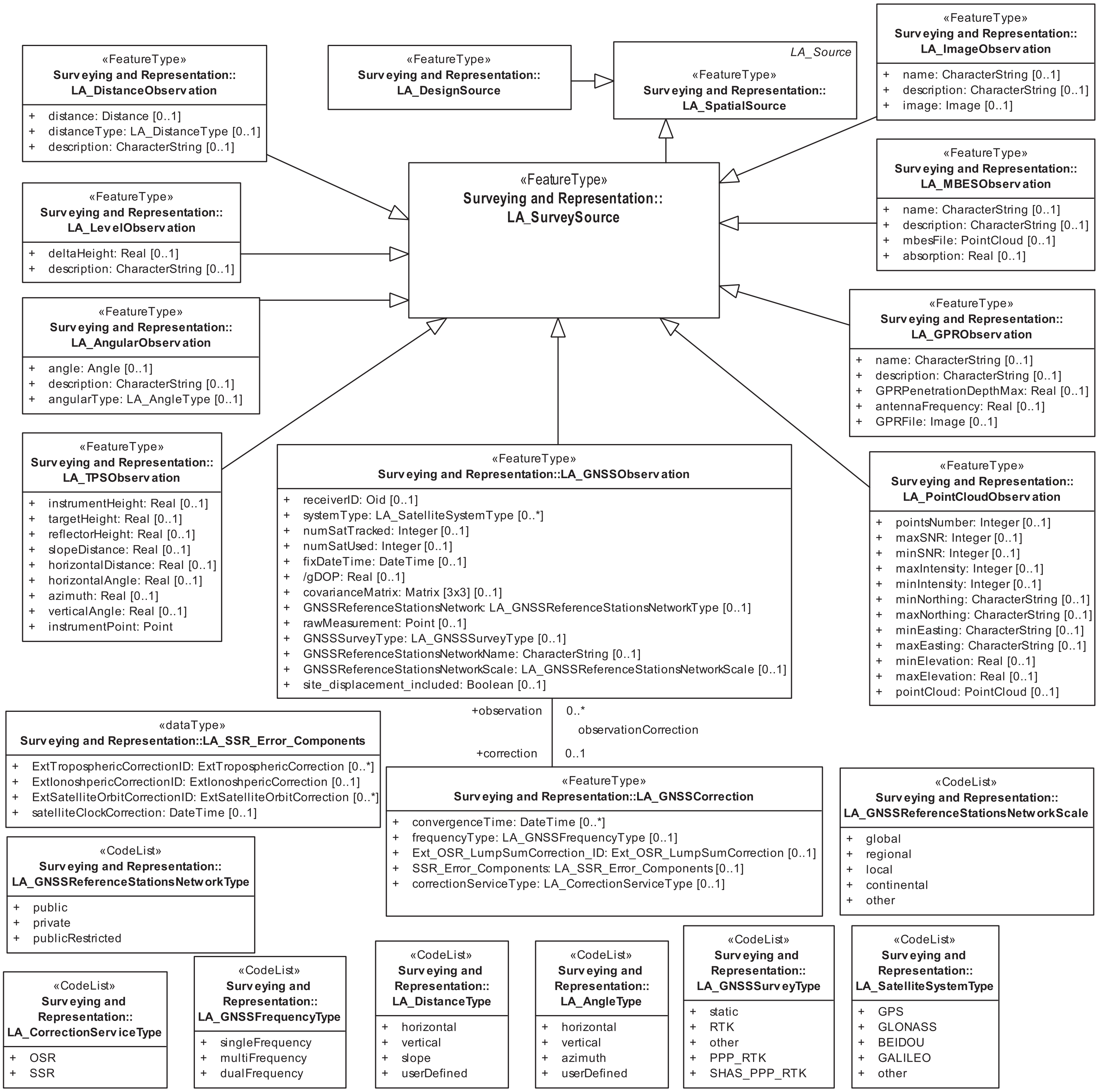

Fig. 11. The sub-classes of LA_SurveySource of the Surveying and Representation Sub-package of ISO19152-2, as submitted in CD of ISO19152-2 (2).

for the optional recording of coordinate or vector uncertainties and their related metadata, using the LA_GNSSCorrection class. This proposed class is designed to allow the modelling of High Accuracy Service components in a generic way, through five attributes:

- *convergenceTime, where the convergence time of GNSS observation is recorded. Provision is made to register more than one convergence time in case this is needed (for instance when recording Galileo HAS observations);*
- *frequencyType, where the frequency range of GNSS corrections is stored with predefined values from the code list LA_GNSSFrequencyType;*
- *correctionServiceType, where the category of the corrections' concept used is defined, acode list LA_CorrectionServiceType is available here;*
- *the Ext_OSR_LumpSumCorrection_ID, serves as an external link to the source were the lump sum of corrections of Observation Space Representation (OSR) is stored and:*
- *the SSR_Error_Components, with the values of the components of corrections of State Space Representation (SSR) can be defined. In order to support the need to define the various SSR components, a new data type has been created: LA_SSR_Error_Components.*

The corrections of GNSS observations are included as an optional class in the model, as HAS is anticipated to become a valuable tool for land *administration applications, given the fact that precise satellite corrections are provided to users globally (in this moment) for free, it is financed by the EU.* [4]

*HAS, presently, offers corrections for precise positioning for GPS and Galileo systems tailored for use in Precise Point Positioning (PPP) algorithms. Currently, various GNSS systems are either in the process of developing or have already developed similar services. For example, the QZSS (Quasi-Zenith Satellite System) provides MADOCA-PPP (Multi-GNSS ADvanced Orbit and Clock Augmentation—Precise Point Positioning), which delivers corrections for GPS, GLONASS, and Galileo (*Angrisano et al., 2023*). The same authors claim that HAS could enhance Single-Point Positioning (SPP). In this perspective, the LA_GNSSCorrection class is designed to support the modelling of HAS components in a generic way, encompassing the idea of providing corrections to improve the accuracy pf satellite navigation signals.*

Finally, the second subclass of class LA_SpatialSource is the class LA_DesignSource which refers to a source from the design phase of the lifecycle that enables information reuse (see Fig. 11). A design document (e.g., BIM/IFC, DXF) is documented with design sources, instances from class LA_DesignSource.

6. Discussion and future work

This paper outlines, in a methodological way, the components of the refined survey model of LADM Edition II. It reviews current surveying, infrastructure, and land administration standards, incorporating (i) best practices from various countries, (ii) country profiles based on LADM with a focus on standard's surveying functionality, (iii) relevant ongoing projects, and (iv) earlier versions of LADM survey models for evaluation.

Initially, the paper introduces a conceptual framework, featuring updated and detailed UML diagrams and concepts for the LADM Part 2: Land Registration. The aim of this refined survey model is to shed light on survey processes, the methods used in surveying, and the accuracy and quality of the observations. *Throughout the modelling process, there is a focus on integrating the basics of High Accuracy Services, which offer precise satellite corrections, as well as including participatory methods in data collection, supervised by professionals. HAS are crucial for the Land Administration sector to carry out traditional services like parcel subdivision, boundary determination, map updates, and coordinate reference system updates. Its integration into ISO19152–2 is anticipated to further support these processes.*

Additionally, the paper introduces a reference workflow for cadastral surveying that includes both administrative and surveying aspects. This workflow is designed to align with the conceptual refined survey model of ISO19152–2 and supports the needs for participatory surveying.

This conceptual survey model and workflow are applicable to a range of spatial units, from basic land parcels to underground infrastructure and buildings. They lay the groundwork for further specialization to meet the specific needs of countries and jurisdictions. Furthermore, the successful implementation of the proposed cadastral workflow in three national cases, demonstrates its consistency and applicability across different countries.

Future research may explore the application of the proposed refined survey model to develop methods for transitioning between country profile versions (e.g., from a country profile modelled in LADM Edition I to Edition II), based on the LADM country profile methodology (Kalogianni et al., 2021b).

What is more, the general cadastral surveying workflow needs further real-world testing to identify any gaps and to incorporate roles of involved parties. The validation of the workflow is expected to highlight interoperability requirements, addressing the implications of the findings of this research for the broader field of land administration and its impact on policy and practice. Challenges encountered in different countries should be documented to develop a general framework addressing issues like missing spatial references, incorrect coordinates, or inaccuracies in legal parcel descriptions. Additional processes, like boundary reconstruction or the utilization of various data types (point clouds, images), could also be examined.

Finally, implementing the conceptual model through different encodings is a critical next step. This is in line with ongoing research by Kalogianni et al. (2022), focusing on survey encodings to support LADM Edition II, considering technological advancements such as web services, cloud storage, big data, AI, and ML. The conceptual and implementation phases of the refined survey model should be validated through practical use cases.

[4] https://www.geopp.de/ssr-vs-osr/

CRediT authorship contribution statement

Efi Dimopoulou: Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Eftychia Kalogianni:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Conceptualization. **Christiaan Lemmen:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Javier Morales:** Writing – original draft, Conceptualization. **Erik Stubkjær:** Writing – review & editing, Writing – original draft, Conceptualization. **Hans-Christoph Gruler:** Writing – original draft, Conceptualization. **Peter van Oosterom:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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