Horizon 2020
European Union funding
for Research & Innovation

ITS 4 LAND
innovations for land tenure

Deliverable 6.3
Technical Report

30 April 2019

Version 1.0

Abstract:
Technical report about "Cadastre database with qualitative extended spatial reference"

Project Number: 687828
Work Package: 6
Lead: HL
Type: DEM
Dissemination: Public
Delivery Date: 30 April 2019

Contributors: Christian Timm, Dr. Mohammed Imaduddin Humayun, Stephanie Walter, Dr. Sahib Jan, Prof. Dr. Angela Schwering, Dr. Malumbo C. Chipofya

The its4land consortium consists of the following partners:

University of Twente (UT)
KU Leuven (KUL)
Westfaelische Wilhelms-Universitaet Muenster (WWU)
Hansa Luftbild AG (HL)
Institut d'Enseignement Superieur de Ruhengeri (INES)
Bahir Dar University (BDU)
Technical University of Kenya (TUK)
ESRI Rwanda (ESRI).

Executive Summary

Deliverable D6.3 focuses on the extension of LADM to handle qualitative spatial references in a cadastral database.

Land Administration Systems use general parcels as spatial reference. Parcels are defined by their boundaries. Boundaries are taken more or less as crisp demarcation defined in general by connected point features or lines.

Work package 3 has developed methods and tools that capture and model qualitatively described spatial objects. This allows the modelling of boundaries or areal objects with an intrinsic uncertainty. To make use of qualitatively described spatial objects in a cadastral database, two topics have to be clarified:

- Conceptual extension of the LADM to handle qualitatively defined spatial references in a cadastral database

- Integration of SmartSkeMa into Publish and Share so that together they can be used as a cadastral database for qualitatively described spatial objects.

This report will address both topics by introducing an LADM extension that can manage qualitative spatial data. The core of this extension is a new LADM class that extends the existing LA_BoundaryFaceString class and a corresponding spatial profile.

The report will furthermore describe two scenarios how SmartSkeMa can be used as a cadastral database:

Case 1 "Corresponding Features": The local person sketched a feature that already exists in the base map, i.e. there exists a corresponding feature in the base map with which the sketched feature can be aligned. This is typically the case for large and globally important features such as mountains, rivers, major streets, or large areas such as a marshland. These features need to be aligned with each other to provide us with reference points for the additionally sketched features. We already have the exact geometries of these features in the base map: only the non-spatial information captured in the sketch map is transferred to the corresponding feature in the base map.

Case 2 "Features without Correspondence": The local person sketched features that are not yet included in the base map, i.e. there exists no corresponding feature. This is information about new features that were gathered via the sketching exercise. This is typically the case for features with local relevance such as a boma, an olopololi, a school building, boreholes, or ranch boundaries. In this case, we aim to identify the location of the new features in the base map by describing their qualitative relations with respect to other, already aligned features.

Contents

Abbreviations

FOSS	Free Open Source Software
GDAL	Geospatial Data Abstraction Library
GRASS	Geographic Resources Analysis Support System
GUI	Graphical User Interface
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
JSON	JavaScript Object Notation
LADM	Land Administration Domain Model
LAS	Land Administration Domain Model
OAS	OpenAPI Specification
OGC	Open Geospatial Consortium
ORM	Object-relational mapping
QCN	Qualitative Constraint Network
REST	Representational State Transfer
RRR	Right, Restriction and Responsibility
SME	Small-Medium-Enterprises
TRL	Technical Readiness Level
UAV	Unmanned Aerial Vehicle
UML	Unified Modeling Language
URI	Uniform Resource Identifier
WFS	Web Feature Service
WMS	Web Map Service

1 Introduction

Its4land is a European Commission Horizon 2020 project funded under its Industrial Leadership program, specifically the 'Leadership in enabling and industrial technologies – Information and Communication Technologies ICT (H2020-EU.2.1.1.)', under the call H2020-ICT-2015 – and the specific topic – 'International partnership building in low and middle income countries' ICT-39-2015.

Its4land aims to deliver an innovative suite of land tenure recording tools that respond to sub Saharan Africa's immense challenge to rapidly and cheaply map millions of unrecognized land rights in the region. ICT innovation is intended to play a key role. Many existing ICT-based approaches to land tenure recording in the region have failed: disputes abound, investment is impeded, and the community's poorest lose out. Its4land seeks to reinforce strategic collaboration between the EU and East Africa via a scalable and transferrable ICT solution. Established local, national, and international partnerships seek to drive the project results beyond R&D into the commercial realm. Its4land combines an innovation process with emerging geospatial technologies, including smart sketch maps, UAVs, automated feature extraction, and geocloud services, to deliver land recording services that are end-user responsive, market driven, and fit-for-purpose. The transdisciplinary work also develops supportive models for governance, capacity development, and business capitalization. Gender sensitive analysis and design is also incorporated. Set in the East African development hotbeds of Rwanda, Kenya, and Ethiopia, its4land falls within TRL 5-7: 3 major phases host 8 work packages that enable contextualization, design, and eventual land sector transformation. In line with Living Labs thinking, localized pilots and demonstrations are embedded in the design process. The experienced consortium is multi-sectorial, multi-national, and multidisciplinary. It includes SMEs and researchers from 3 EU countries and 3 East African countries: the necessary complementary skills and expertise are delivered. Responses to the range of barriers are prepared: strong networks across East Africa are key in mitigation. The tailored project management plan ensures clear milestones and deliverables, and supports result dissemination and exploitation: specific work packages and roles focus on the latter.

1.1 The Publish and Share platform in its4land

Publish and Share combines the tools and methods developed in *Draw and Make, Fly and Create* and *Automate it* in a technical platform (see **Error! Reference source not found.**).

The Publish and Share platform can be considered on the one hand as a runtime environment for the tools developed in its4land and on the other hand as a provider of data and information for existing land administration systems (LAS) or other tools. The platform will be accessible via service interfaces based on standards from Open Geosptial Consortium (OGC) and Word-Wide-Web Consortium (W3C). The modelling of the interfaces follows the concepts introduced by Land Administration Domain Model (LADM). External systems like LAS or planning systems can use the service interfaces to integrate data into their own processes, based on specific national rules. The usage scenarios and workflows to combine the its4land tools with land administration systems will be defined and implemented to a prototype level.

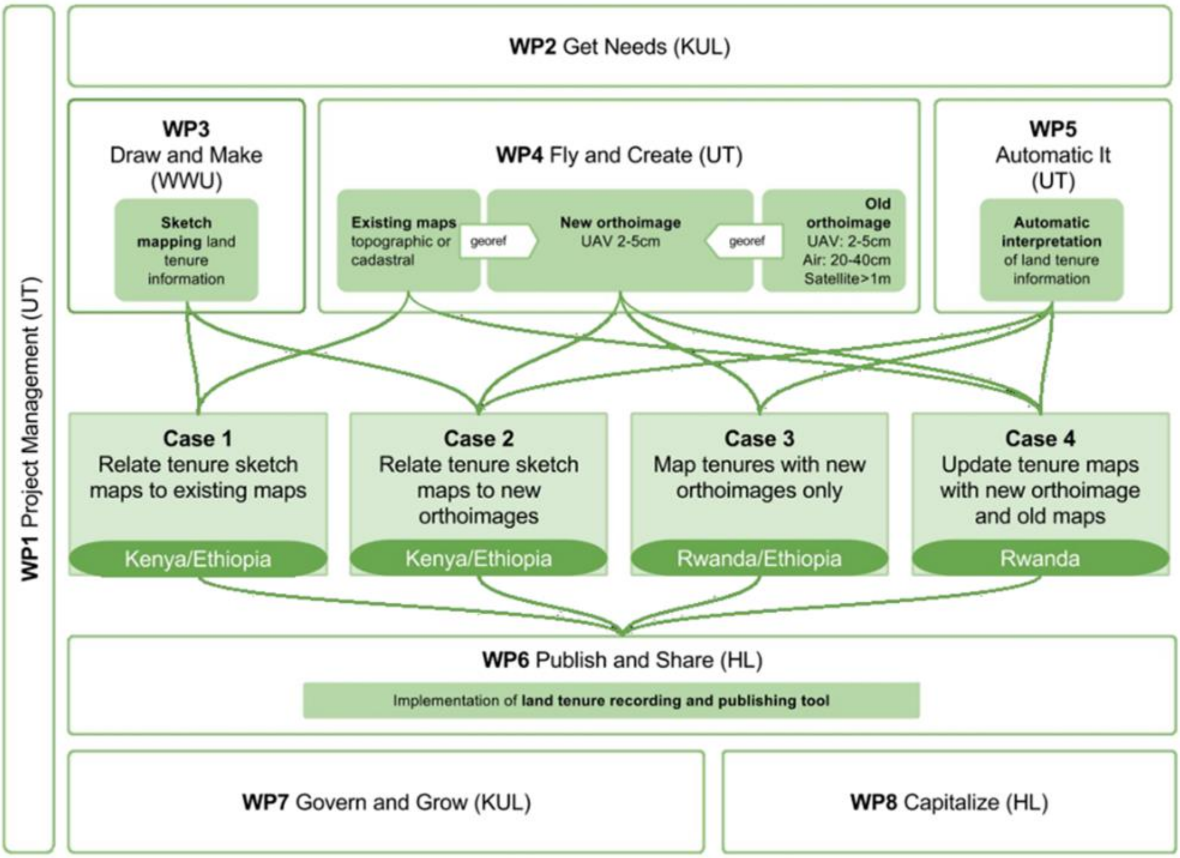

Figure 1: Overview of the its4land work packages

The implementation of the Publish and Share platform follows a toolbox approach and will provide a framework of common APIs and services used by all its4land tools. From this toolbox, a user can select those its4land tools fitting his tasks best.

As per the paradigm of geocloud, the tools will be implemented as services accessible via an Application Programming Interface (API) based on web standards. Tools which are capable of calling a REST API can make use of any kind of Publish and Share service, like public APIs or storage services. For 3rd party tools developed outside the scope of its4land, it is the responsibility of the 3rd party tool vendor or creator to adapt their tools to Publish and Share.

Its4land's claim is the development of state of the art methods for recording land rights with special consideration of the needs of local stakeholders in developing countries. To achieve a close integration of local stakeholders, adopting needs and land tenure concepts is required.

2 Overview/Problem description

2.1 Qualitative spatial objects

Land Administration Systems use general parcels as spatial reference [1]. Parcels are defined by their boundaries. Boundaries are taken more or less as crisp demarcation defined in general by connected point features or lines [2]. This definition of parcels corresponds with the ISO/TC211 standards ISO 19107:2003 Geographic Information — Spatial schema [3] and ISO 19111:2007, Geographic Information — Spatial referencing by coordinates [4]. Both standards are a fundamental part of the Open Geospatial Consortium set of standards and therefore the guiding principle of nearly all-available GI-System implementations.

This strict quantitative view on spatial reference for cadastral databases leads to some limitations. Since it considers the spatial reference as being crisp, it also considers the boundary between land rights as crisp. Uncertainty is treated predominantly as positional uncertainty. This approach is useful in the case of clearly defined rights, based on a surveyed parcel reference, as you find it, e.g. in European countries. However, this does not take other concepts about land and land access into consideration. These alternative concepts often lead to an unclear demarcation of land rights. The spatial reference has an intrinsic uncertainty. This uncertainty has to be handled by the cadastral database.

In work package 3 (Draw and Make), we have developed methods and tools that capture and model qualitatively described spatial objects. This allows the modelling of boundaries or areal objects with an intrinsic uncertainty. To make use of qualitatively described spatial objects in a cadastral database, two topics have to be clarified:

- Conceptual extension of the LADM to handle qualitatively defined spatial references in a cadastral database

- Integration of the SmartSkeMa tool into Publish and Share so that together they can be used as a cadastral database for qualitatively described spatial objects.

This report will on the one hand describe a conceptual extension of the LADM for qualitative spatial data (see also D3.4 and D3.6 for LADM extension for non-standard land tenure systems [5] [6]) and on the other how SmartSkeMa can work together with Publish and Share as a cadastral database.

2.2 LADM and Cadastral databases

For a general introduction to LADM, see [7] [8]. In this chapter, we will only consider that part of LADM, which is directly relevant for a cadastral database. In our context, we define a cadastral database as the sum of all spatial objects, which form the spatial reference for the registration of interest in land. Our definition does not determine the spatial representation.

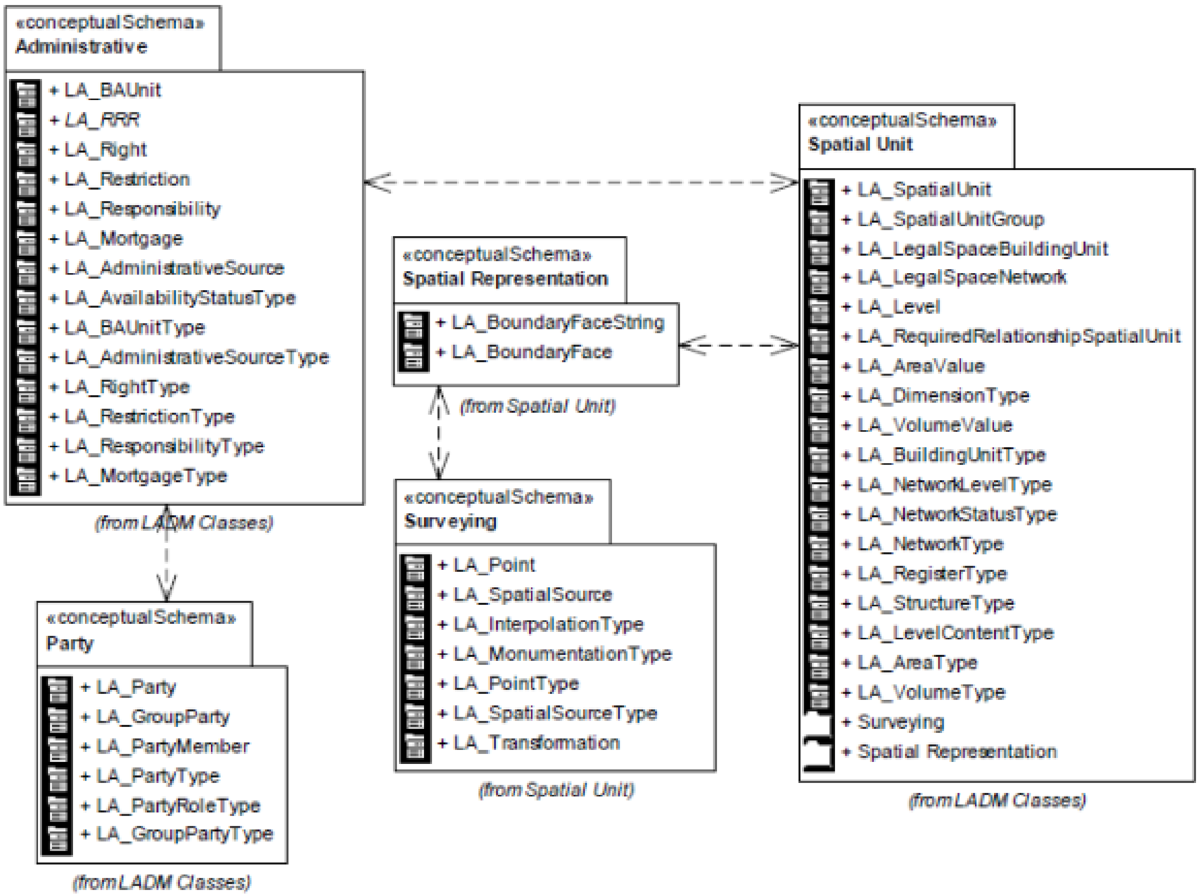

Figure 2: Overview of the LADM [8]

Figure 2 shows the complete LADM with all three main packages (Administrative, Party and Spatial Unit), as well as the two sub-packages of Spatial Unit (Spatial Representation and Surveying)

Only the Spatial Unit and its two sub-packages are relevant for our definition of a cadastral database. The cadastral database in our context is the sum of all LA_SpatialUnit class instances.

The LA_SpatialUnit is defined as “single area (or multiple areas) of land […] and/or water, or a single volume (or multiple volumes) of space” [8]. The spatial unit itself does not specify the spatial representation. The spatial representation is defined by the two classes LA_BoundaryFaceString and LA_BoundaryFace in the spatial representation sub package:

- LA_BoundaryFaceString: defining the boundary between a spatial unit and the outside in 2D by a 1-dimensional topological primitive. A boundary face string can have multiple appearance (see spatial profiles below).

- LA_BoundaryFace: defining the boundary between a spatial unit and the outside in 3D by combining 2-dimensional topological primitives. A boundary face can have multiple appearances (see spatial profiles below).

LADM identifies six different types of spatial units.

Table 1: LADM spatial profiles [8], [9]

Spatial Profile	**Description**
sketch based	A sketch (a quick drawing of a group of spatial units) is available, e.g. sketch maps (survey sketches), and photographs, in the absence of any better identification.
point based	A point based spatial unit identifies an area by a point within the area. This profile is typically used when only the location and the size is known.
text based	A text based spatial unit is used when an area is entirely described by text. The spatial unit is in general associated with one or more boundary face strings, with their location described by free text. No geometry is used in this kind of spatial unit.
unstructured (line) based	An unstructured (line) based spatial unit references boundary face strings. The boundary face string is represented by a polyline. This profile is used, when inconsistencies, such as hanging lines and incomplete boundaries are allowed.
polygon based	A polygon based spatial unit has exactly one link to a polygon. Every spatial unit is treated as a separate entity without topological connection between neighbouring spatial units. Standard GIS supports this profile by default.
topological based	A topological based spatial unit is encoded by referencing boundary face strings. In opposite to the unstructured line or polygon profiles, the boundaries are topologically connected and consistent. Adjacent spatial units share a boundary face string as a joint boundary. The boundary face strings of a spatial unit form a closed loop. The topological profile can be best compared with the node-edge-face model.

The profiles “unstructured line”, “polygon” and “topological” can be defined in 2D or 3D.

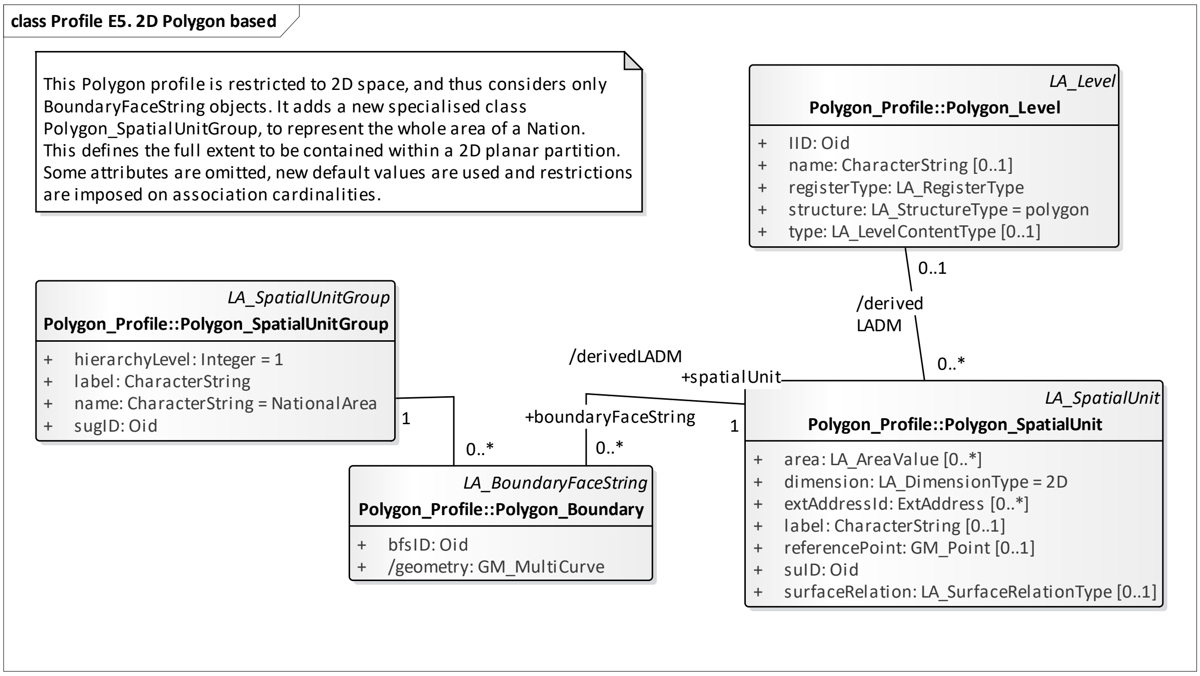

Figure 3: 2D polygon based spatial profile [8]

Figure 3 shows the modeling of a spatial unit based on the 2D polygon based spatial profile. The 2D polygon profile is the most widely used one. The 2D polygon profile can be directly mapped to today’s standard GI-Systems and the OGC simple feature specification, since it is based on ISO 19107:2003 [3].

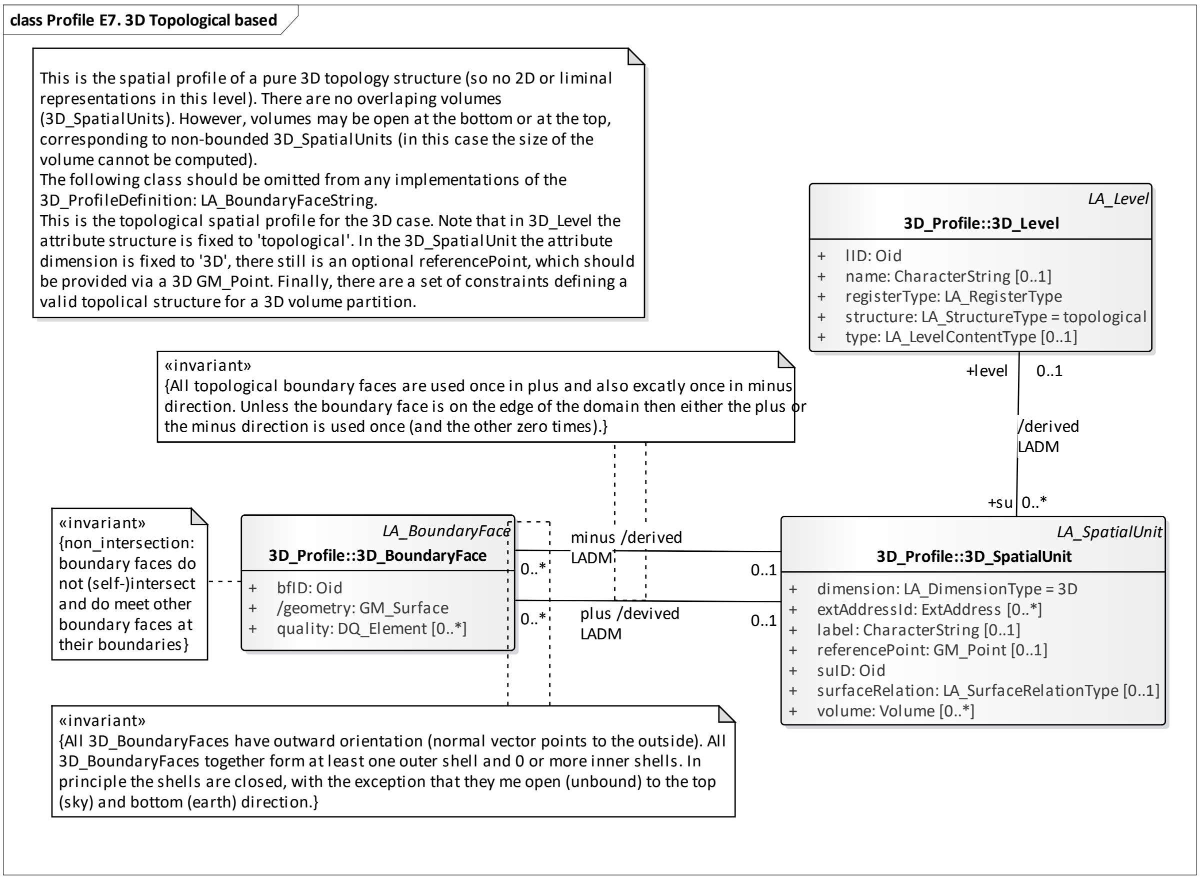

Figure 4: 3D topological based profile [8]

Figure 4 shows a model of a spatial unit based on the 3D topological based spatial profile. This kind of modelling will create spatial volume model for the spatial unit, without overlap between spatial units and shared LA_BoundaryFace as boundaries between spatial units.

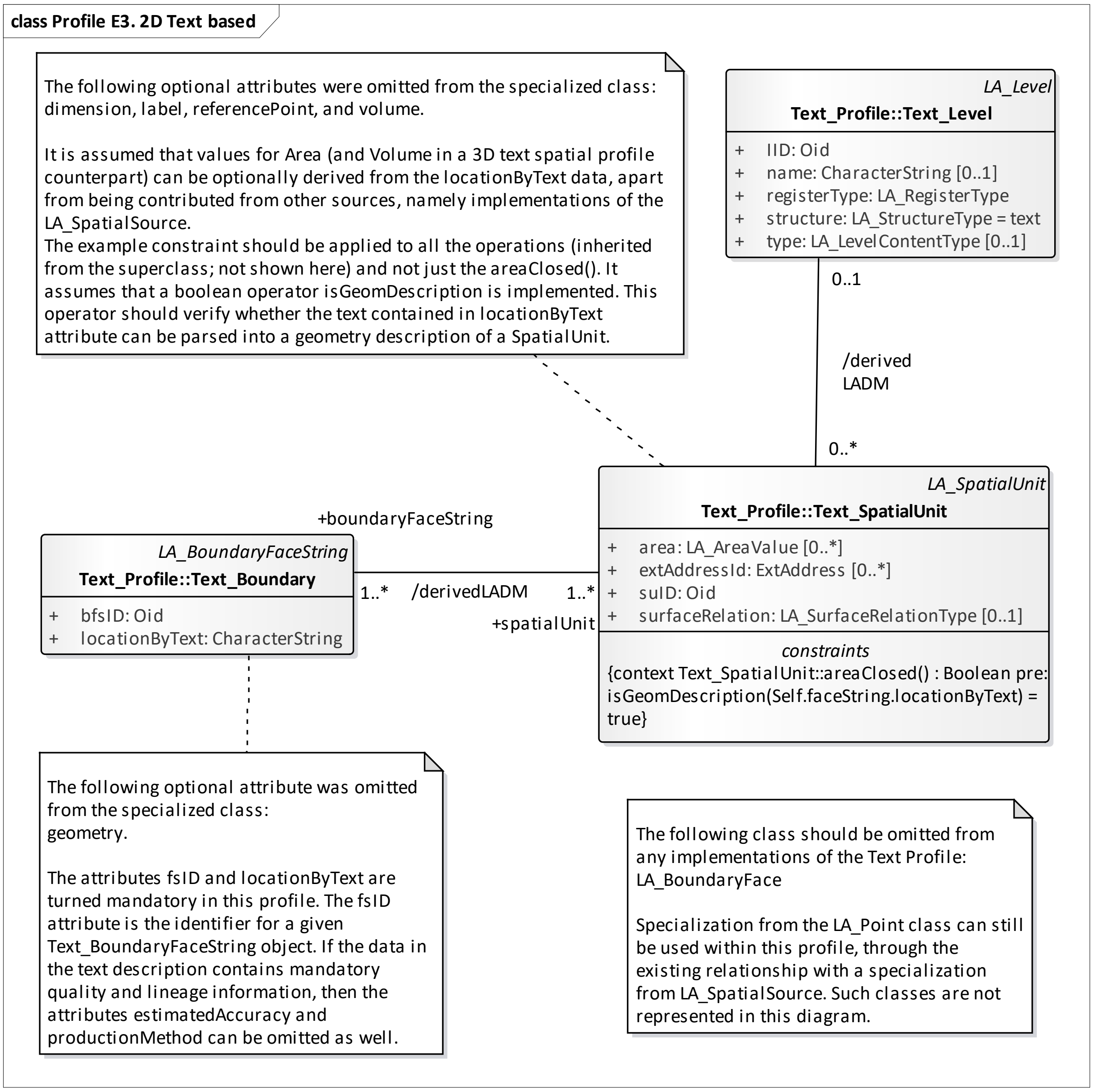

Figure 5: text based spatial profile [8]

Figure 5 shows the model of a spatial unit based on the text based spatial profile. In this case, the boundary, its location and shape are described entirely in a textual way. This profile does not allow spatial operations on the spatial unit.

None of the existing spatial profiles is able to handle qualitative descriptions of spatial objects in such a way that they can express the uncertainty of boundaries and also allow spatial operations on them. The text based spatial profile would allow a qualitative description, but not spatial operations.

In chapter 4, we will introduce a spatial profile to handle qualitative spatial data.

3 Cadastral Database and qualitative spatial information

Today's standard land administration systems accept as spatial reference for boundaries, only quantitative descriptions based on exact geometries. As explained in D3.6 [6], SmartSkeMa extends these standard land administration systems to handle qualitative descriptions of spatial units. With the SmartSkeMa we implemented a proof of concept that,

(i) extends the data model and the application to handle formalized but *qualitative* descriptions of boundaries and
(ii) includes them into the existing land administration workflows.

SmartSkeMa compares spatial features in the sketch maps with spatial features in the base map and aims to align them. We distinguish two cases:

Case 1 "Corresponding Features": The local person sketched a feature that already exists in the base map, i.e. there exists a corresponding feature in the base map with which the sketched feature can be aligned. This is typically the case for large and globally important features such as mountains, rivers, major streets, or large areas such as a marshland. These features need to be aligned with each other to provide us with reference points for the additionally sketched features. We already have the exact geometries of these features in the base map: only the non-spatial information captured in the sketch map is transferred to the corresponding feature in the base map.

Case 2 "Features without Correspondence": The local person sketched features that are not yet included in the base map, i.e. there exists no corresponding feature. This is information about new features that were gathered via the sketching exercise. This is typically the case for features with local relevance such as a boma, an olopololi, a school building, boreholes, or ranch boundary. In this case, we aim to identify the location of the new features in the base map by describing their qualitative relations with respect to other, already aligned features.

3.1 Visualizing Corresponding Features

The visualization of corresponding features (case 1) is based on the successful alignment of features. The implementation of this alignment algorithm was explained in D3.5 [10]. After the qualitative relations between sketched features in the sketch maps (spatial qualifier algorithm described in D3.3 [11]) are compared with qualitative relations between features in the base map, SmartSkeMa produces a list of aligned features. Apart from the qualitative relations, SmartSkeMa also uses the feature type and the (unique) feature label for the alignment. We particularly refer to Figure 8 and Figure 9 of D3.5.

The user can inspect the alignment visually by hovering over the corresponding features in the SmartSkeMa web-interface. Figure 6 shows how the corresponding feature is highlighted in the geo-referenced base map while the user hovers over the marshland, the mountain, and the river. The system provides this functionality "Toggle Interaction" under the Align-to-Geometry menu to visualize the aligned objects by click events.

Figure 6: The corresponding features are highlighted in the base map while the user hovers over the feature in the sketch map: the mountain (top screenshot), the mountain (bottom left screenshot) and the river (bottom right screenshot).

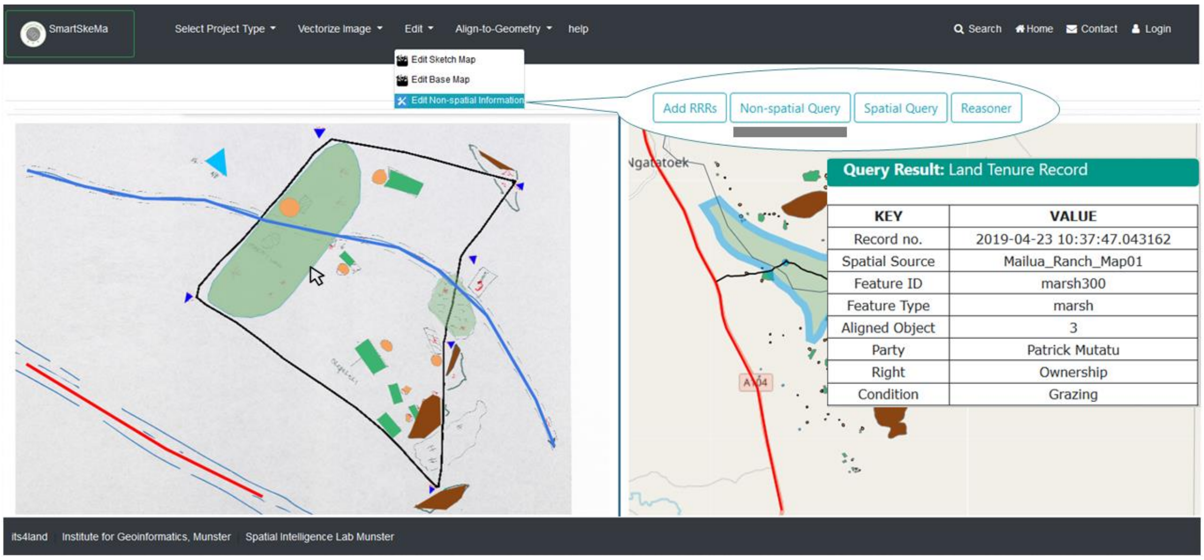

Figure 7: The non-spatial properties of an aligned feature are shown via a pop-up menu. Clicking on one of the two corresponding objects - here via clicking on the marshland in the sketch map - SmartSkeMa will highlight the corresponding feature in the base map and open a pop-up menu with the non-spatial properties.

Figure 7 shows how the non-spatial properties of corresponding objects are visualized in SmartSkeMa. When the user queries non-spatial information, clicking on an aligned feature will open a pop-up menu next to the highlighted corresponding feature in the base map showing the land tenure record of this feature. In the figure you can see that the drawn marsh grass land (ID: marsh300) is aligned with marsh grass land (ID: 3) in the georeferenced map. The marsh grass has the common ownership by Patric Mutatu Family and family as grazing right.

3.2 Visualizing Features without Correspondences

The visualization of the location of features without corresponding features in the base map (case 2) is done via indicating possible locations by highlighting the qualitatively described regions. SmartSkeMa has the functionality to extract the qualitative spatial relations between drawn features in the map. Figure 8 illustrates how SmartSkeMa lists the qualitative spatial relations between the selected feature (here: a beacon of the ranch boundary) and other sketched features such as the river, the marsh grass land and the road with a pop-up menu after having selected “spatial query” and clicked on the beacon. The selected beacon is to the “Right_of” Ngatatak river, “Near_by” marsh grass land and to the “Left_of” Namanga Road.

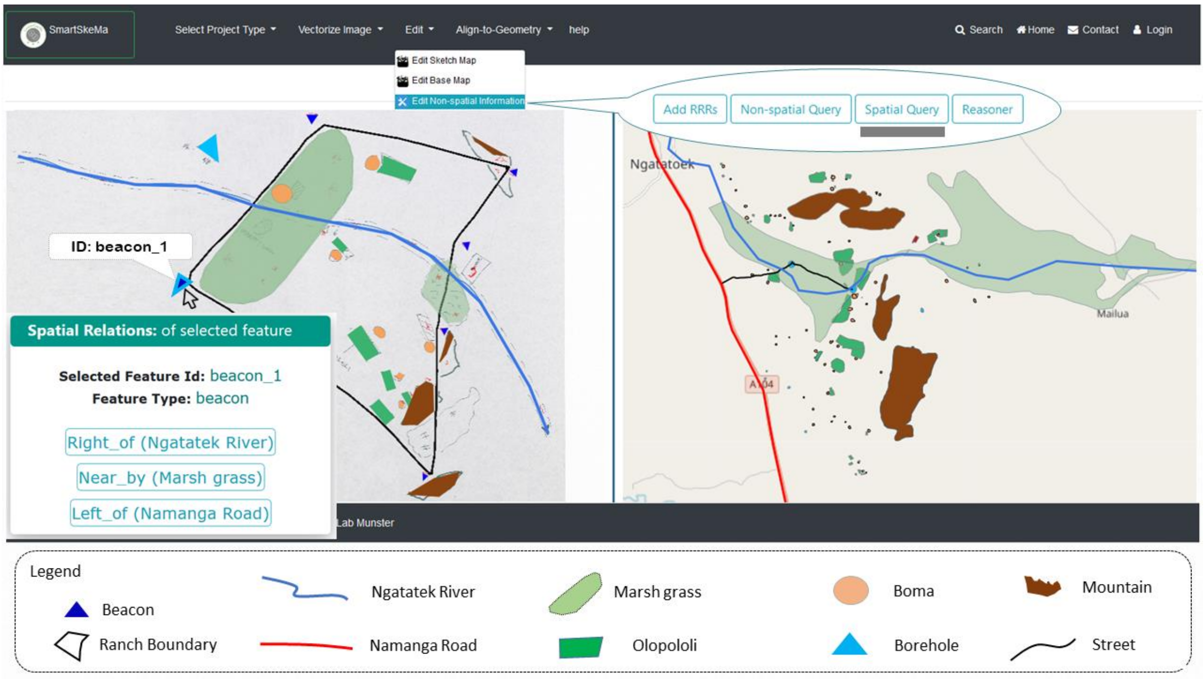

Figure 8: SmartSkeMa shows the qualitative spatial relations between the selected feature beacon (ID: beacon_1) and other drawn features such as *river*, *road* and *marsh grass in* a pop-up menu after having selected "spatial Query" and having clicked on the beacon. The bottom legend explains the different features in the sketch and base map.

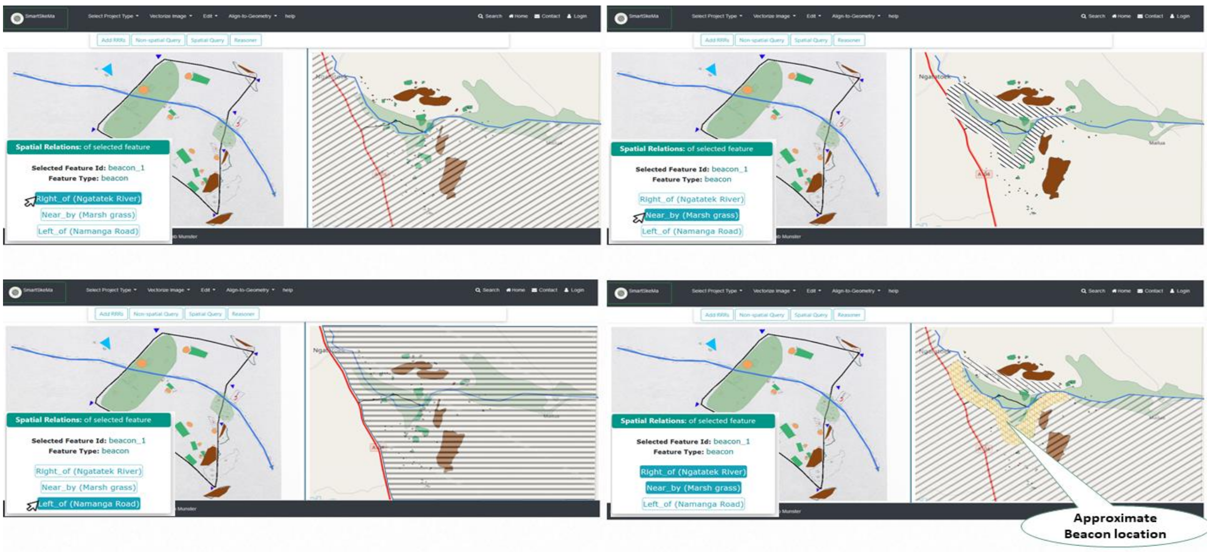

Figure 9: SmartSkeMa lists qualitative relations of sketched features without correspondences to other features via a pop-up menu. The user may select one or more qualitative relations to look at the spatial extent of this region in the base map. Top left figure illustrates the qualitative relation "Right_of" Ngatatak river, top right illustrates "Near_by" marsh grass land, bottom left illustrates "Left_of" Namanga Road and bottom right shows how two relations can be visualized at the same time.

The sketch map does not tell you the exact geometry, but only the relations to other features (compare D3.3 on the qualitative nature of sketch maps). To get further information on the possible location of the selected feature, the user can go through each qualitative relation and let SmartSkeMa highlight the possible area in the base map. Figure 9 visualizes this for our example: Clicking on the top qualitative relation, SmartSkeMa highlights the area on the right side of Ngatatak river in the geo-referenced base map. On the one side, the boundary is given by the river, on the other side it is determined by the size of the spatial area of interest (defined in the project in "Publish and Share", cf. section 5). The next qualitative relation, "Near_by" marsh grass land, is visualized via a buffer around the marsh grass land in the base map. By selecting two or more relations at the same time, the user can highlight two or more qualitative relations at the same time and further restrict the possible location of a "feature without correspondences". This functionality is intended to give the land administration officer visual assistance to determine where the spatial feature is possibly located.

We decided to implement a one-by-one visualization of each qualitative relation, as automatically calculating the intersection of possible polygons has proven not suitable in all cases, because intersections can be disconnected and can result in regions with holes and open ends. It is impossible to automatically select a particular region. The chosen approach relies on the dialogue with the land administration officer providing her/him with the required information to make an informed decision (as described in the following subsection).

3.3 Geometric Information Editable by the Land Administration Officer

SmartSkeMa can automatically create records for spatial features that were drawn in the sketch map and indicate their approximate location with qualitative relations to features with well-known geometries. However, it is technically impossible to automatically determine the exact geometries for such sketched features. In case the land administration officer can determine the location of the sketched features (e.g. because of her knowledge of the area, additional information that she has that lets her estimate a location with reasonable precision), she can use the "edit base map" functionality to assign a geometry to the sketched feature.

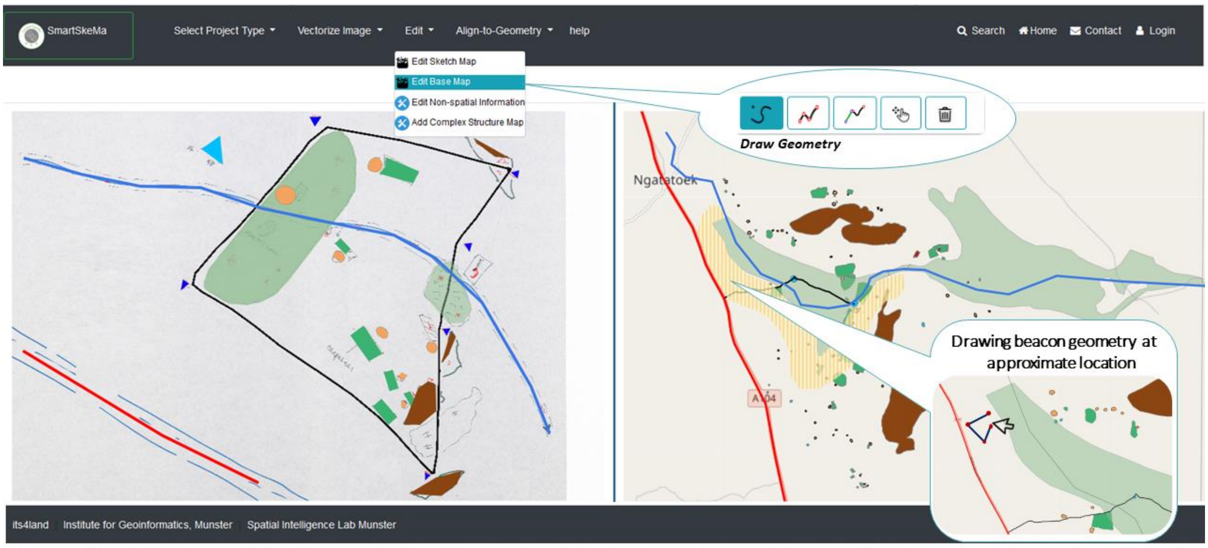

Figure 10: SmartSkeMa provides the functionality to edit the base map and draw a geometry (line, polygon etc) on top of the base map that can be associated with a sketched feature. This way a land administration officer can assign a geometry to a sketched feature within the area that was determined as a possible location via the qualitative relations.

Figure 10 shows a screenshot of SmartSkeMa, where the land administration officer can edit the base map to assign a geometry to a sketched feature (without a correspondence). By selecting “edit base map”, the user can edit, draw and delete geometries in the base map. The visualization of the qualitative relations helps the land administration officer to decide on a reasonable location. Figure 11 shows the beacons that were drawn in the sketch map and their corresponding geometries drawn by the user in the base map. The drawing functionality is implemented as an SVG editor. The system automatically converts the coordinates of the drawn geometries to the coordinate system of the base map. The drawn geometries are saved in a geojson file.

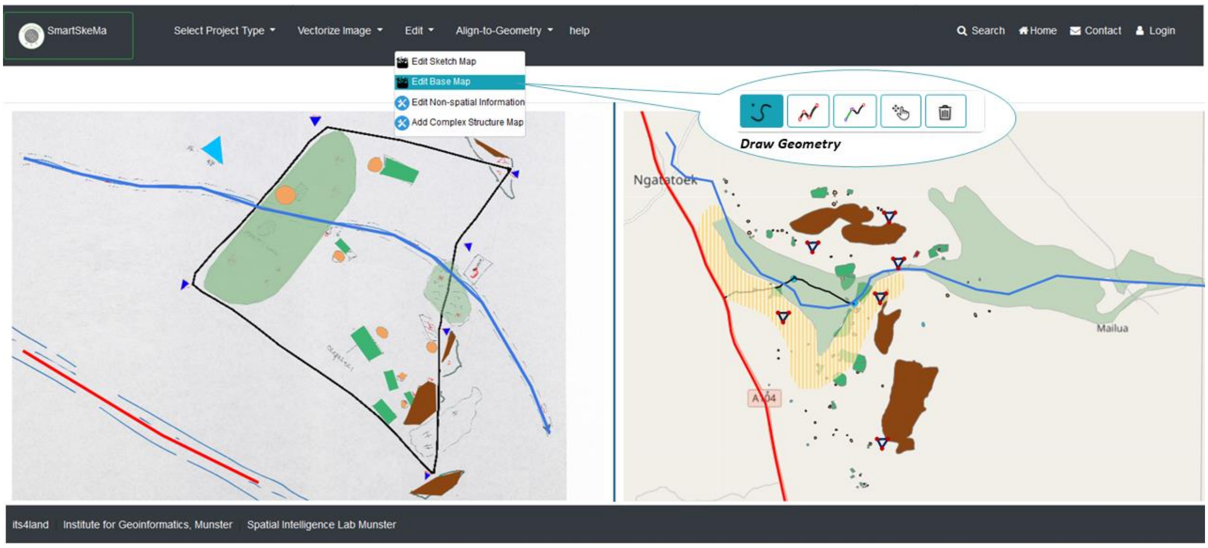

Figure 11: Shows all the assigned geometries of beacons in the base map.

The geometric representation of beacons in the base map allows the land administration officer to approximate the ranch boundary. This can be done by connecting the beacons using the drawing functionality, in which the administrator can simply connect the beacons' geometries through a polyline (Figure 12). This forms the polygonal region representing the ranch boundary (Figure 13).

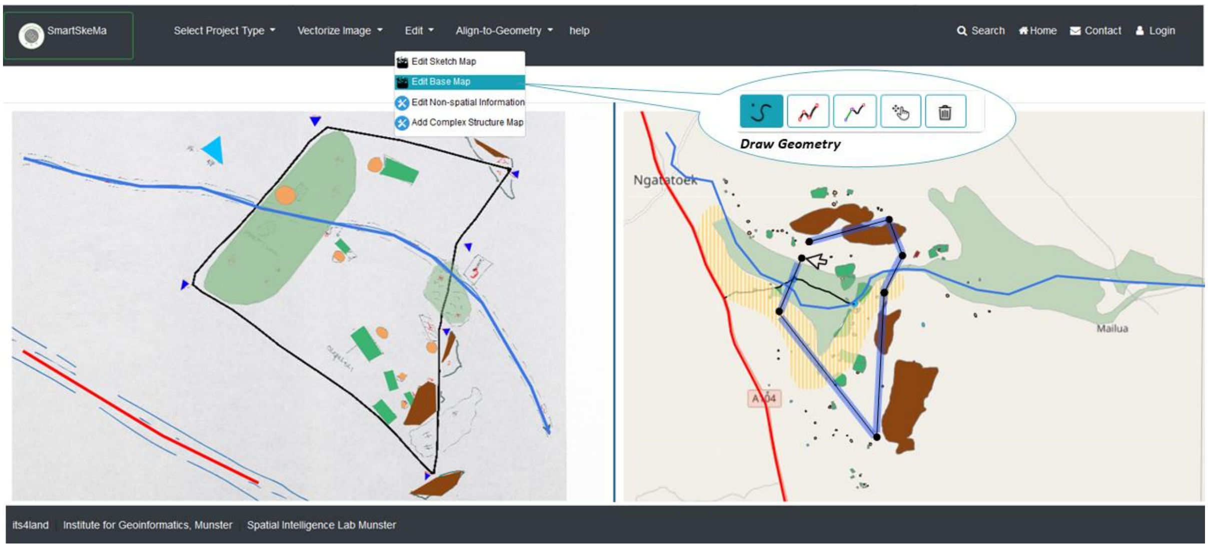

Figure 12: Shows the approximate location of ranch boundary by connecting the beacons' geometries using the drawing functionality in the SVG editor.

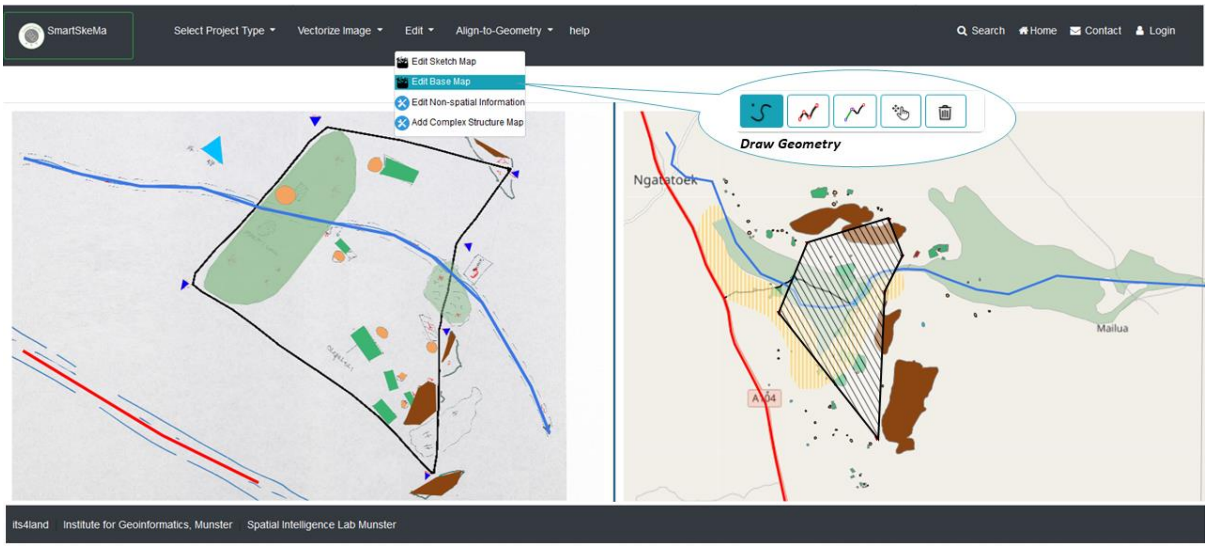

Figure 13: Shows the approximate location and polygonal representation of the ranch boundary.

The standard LADM captures parcels through points, lines, and polygons. It also allows for parcels to be described using text and sketches. However, this information cannot be automatically interpreted by the system. SmartSkeMa transfers the spatial information in freehand sketches into qualitative spatial information. This allows the spatial extent of a parcel to be described by a qualitative description and therefore automatically interpreted by the system. The qualitative spatial information allows SmartSkeMa to connect imprecise knowledge given in sketch maps to standard information types used in Cadastral databases. In order to achieve this in SmartSkeMa, we have extended classes in LADM, i.e. *Shape* class through adopter model into *AbstractShape* class. An abstract shape can be described by a concrete geometry when available or purely in terms of qualitative description if only qualitative spatial information is available (D3.6). On the Publish and Share platform, we handle this information by an additional spatial profile for LADM (see chapter 4). This allows spatial units to be represented through qualitative descriptions and stores any computed approximate geometries in SmartSkeMa as a boundary face string.

Similarly, the standard LADM captures RRRs (right, restriction and responsibility), which are permanent or fixed term relations between spatial units and parties. However, it cannot capture those RRRs in non-standard land tenure systems (customary, indigenous, or informal) which are dynamic, rely on additional conditions, or their temporal aspect is not fixed. As such, LADM-based systems are incapable of registering non-standard land tenure information. In SmartSkeMa we extended the RRR concept through the adaptor model. The adaptor model allows SmartSkeMa to accept non-standard conceptual information and interpret it in terms of LADM concepts (D3.6).

By deploying SmartSkeMa on the Publish and Share platform, the qualitative spatial unit and its associated properties are made available to other tools via a standardized interface. The approximate geometries created by a SmartSkeMa user using the svg-editor tool can be saved to disk and opened using a GIS locally. Storing this using Publish and Share APIs makes these geometries available on demand – together with the corresponding RRR attributes and associated qualitative spatial relations. An example of this integration with other tools is the case that SmartSkeMa is used in conjunction with the *Automate It* tool developed in work package 5. In that case, invisible boundaries that have not been surveyed can still be approximated using SmartSkeMa and a representative parcel instance would be used to carry the RRRs – for example the rights of use on the ranch region implied by rights of use on an olopololi within the ranch.

When no geometry has been created for a qualitative spatial unit, corresponding qualitative spatial relations can still be used to answer queries on the cadastral database. Queries that can be addressed using qualitative spatial relations take the form of tests, checking if there is some spatial interaction between any pair of objects given the set of spatial relations between them. A typical example of interaction is overlap: "*does the protected area overlap with grazing rights*" is a typical land administration question in both Kenyan and Ethiopian pastoral regions that cannot always be addressed using information made available by existing land administration systems.

4 Extending LADM for qualitative data

We suggest extending LADM by an additional spatial profile to handle qualitative data. The spatial profile is named "qualitative base". The spatial profile should satisfy the following requirements:

- Store the qualitative description of a spatial unit in a computational way, so that it can be used for spatial queries
- An additional quantitative representation as 2D polygon for the manually created approximation in the SmartSkeMa should be available

4.1 Specification of the 'qualitative base' spatial profile

The "qualitative base" spatial unit is used when its definition is the outcome of a qualitative mapping process in SmartSkeMa. A spatial unit itself represents one spatial feature in the sketch map. The 'qualitative base' spatial profile supports 2D.
The boundary face string for "qualitative base" spatial unit is inherited from the original LADM class LA_BoundaryFaceString and is called "I4L_QualitativeBoundaryFaceString".

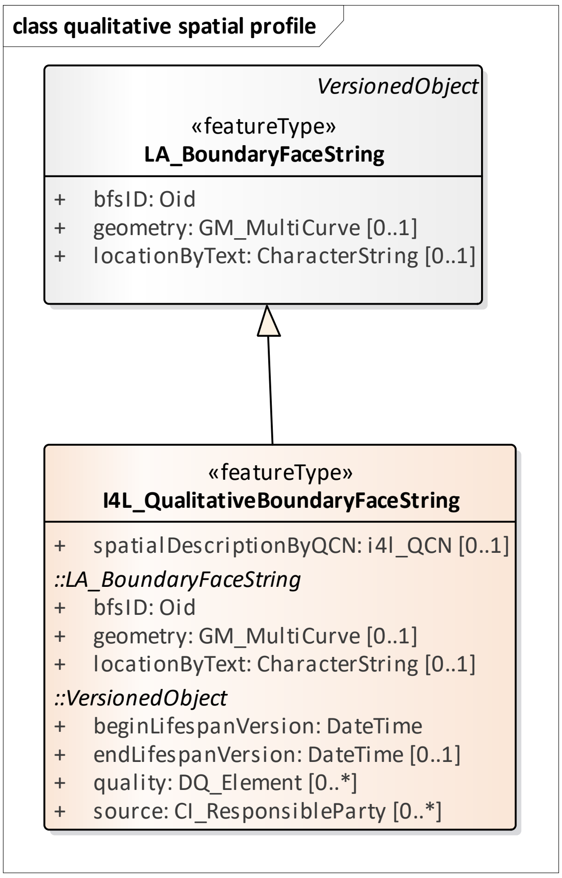

Figure 11: Extension of LA_BoundaryFaceString

An instance of class I4L_QualitativeBoundaryFaceString is a qualitative boundary face string. The class I4L_QualitativeBoundaryFaceString is a sub class of LA_BoundaryFaceString.

A qualitative boundary face string represents the boundary of a spatial unit. The class I4L_QualitativeBoundaryFaceString has the same properties and can be used in the same situations as the class LA_BoundaryFaceString.

I4L_QualitativeBoundaryFaceString extends LA_BoundaryFaceString by one additional attribute:

- spatialDescriptionByQCN: the boundary represented by the qualitative constrained network (QCN) extracted from geometric representation of input maps in work package 3.

The qualitative representation using the QCN stores the spatial configuration as a set of qualitative relations between spatial features in sketch map. These are determined in the sketch map qualification process in SmartSkeMa.

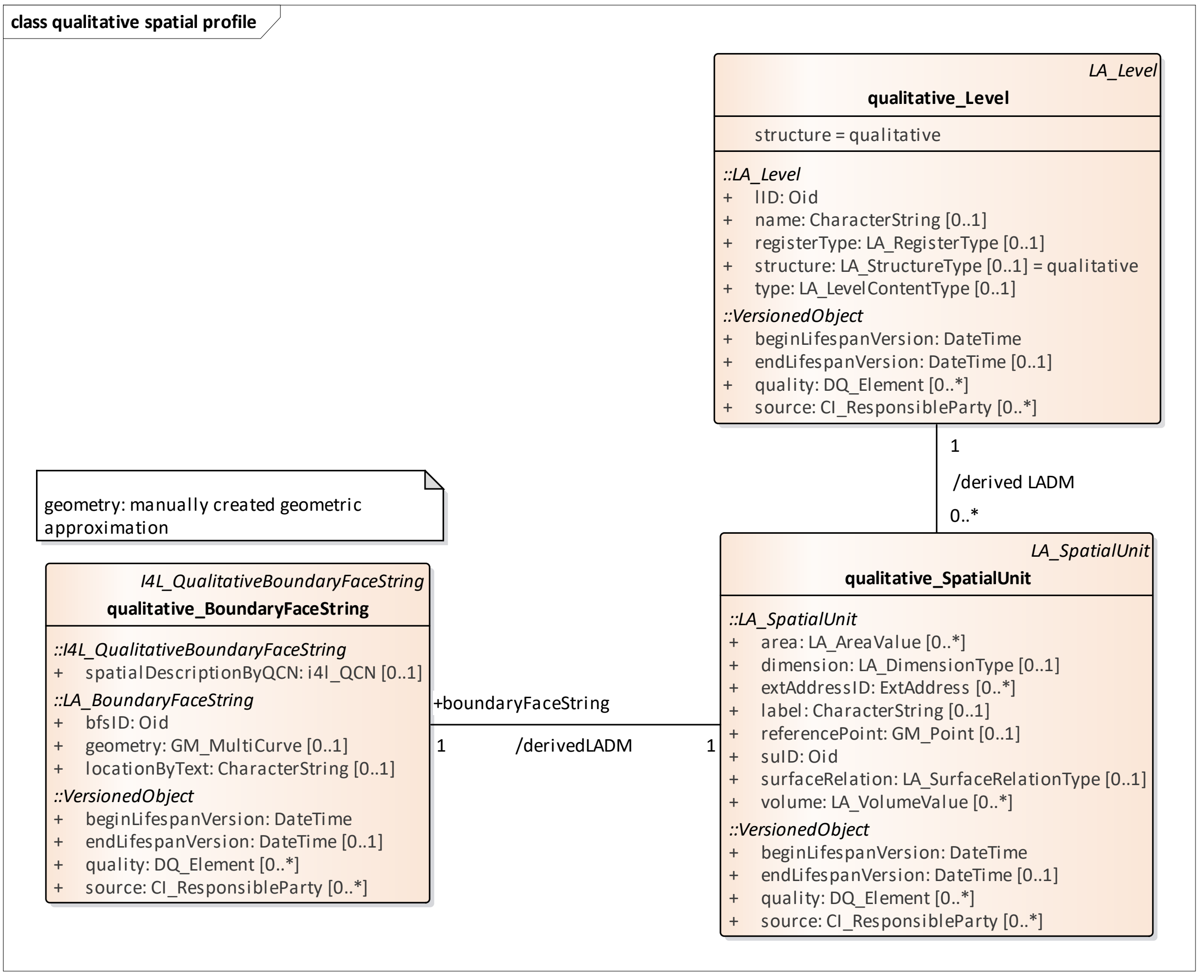

Figure 12: qualitative base spatial profile

As a specialisation of LA_BoundaryFaceString, I4L_QualitativeBoundaryFaceString, also supports the geometry attribute for a quantitative representation of the boundary face string as a closed polygon in parallel to qualitative representation. The geometry attribute is used to store the manually approximated geometry of the spatial unit. This approximated geometry is created in SmartSkeMa.

A 'qualitative base' spatial unit allows up to one qualitative and up to one quantitative spatial representation of the boundary.

4.2 The 'qualitative base' spatial unit in Publish and Share

The implementation of the 'qualitative base' spatial unit can be fully adopted on the structure of the Publish and Share platform [12][13].

The QCNs representations are stored in JSON files. SmartSkeMa defines the internal structure of the file. This JSON structure is stored as a ContentItem via the corresponding endpoint (POST /ContentItem).

The Public API provides two endpoints to handle spatial units:

- /SpatialUnit - used for standard 2D 'polygon based' spatial unit. However, it also allows to access the quantitative representation of a 'qualitative base' spatial unit. When accessing a 'qualitative base' spatial unit via this endpoint it behaves like a 2D 'polygon base' spatial unit.
- /SpatialUnit/qualitative - provides full access to the 'qualitative base' spatial unit, which includes the qualitative representation. Depending on the size of the QCN JSON structure, it will be embedded into the response of the /SpatialUnit/Qualitative endpoint or retrieved separately via the /ContentItem endpoint.

For integration with standard GIS/LAS workflows, the quantitative representation of a boundary (of a 'qualitative base' spatial unit) can be disseminated via the data dissemination interface of Publish and Share [14].

5 Cadastre Database for qualitative spatial information in Publish and Share

In this chapter, we describe how the purported benefits of including qualitative spatial information in a LAS can be achieved with the use of the Publish and Share platform. Publish and Share implements a number of concepts from LADM with a possibility for different usage models (see D6.4 [14]). The Public API offered by Publish and Share offers users a means to implement these concepts in their usage scenarios.
The API provides several ‘endpoints’, which are accessed by a path (URL) on the web server hosting the platform implementation. A *request* to an endpoint consists of sending a data payload and requisite parameters to the correct path. Upon successful processing of a request, the server sends a *response* with a status code indicating success/failure along with an optional payload consisting of processed or requested data. The table below briefly describes the endpoints groups useful for storage of cadastral data including qualitative spatial information. An endpoint group consists of a set of related endpoints.

Table 2 Publish and Share Public API endpoint groups to implement Cadastral Database for Qualitative Spatial Information.

Endpoint Group	**Description**
Projects	Stores and retrieves the project context for Publish and Share. A project’s context information contains basic metadata, the spatial area of interest, input spatial sources, tags and any output spatial units.
ContentItems	Refers to raw content that is stored in the backend storage. The content is usually a file. The file and basic metadata about the file are stored without paying attention to the purpose of the file itself.
SpatialSources	A spatial source is an LADM concept, which documents the evidence for a spatial unit, such as sketch, map, orthoimages etc. This endpoint refers to a unique content item and provides meaning to raw data.
AdminSources	Similar to spatial sources, but deals with legal documents pertaining to evidence of interest in land.
SpatialUnits	Stores and retrieves information about the actual piece of land to register. Geometries of the land parcel are described as per a given LADM spatial profile.

The following subsections discuss how API endpoints are useful in implementing the cadastre database.

5.1 Storing Spatial Sources

As described previously, the GUI of SmartSkeMa consists of a sketch map panel and its corresponding base map. Sketch maps are stored in the SVG format and are not georeferenced, whereas base maps use features stored in GeoJSON format. Since both of these depict the same area of interest, in LADM terms, both are instances of spatial sources. Publish and Share uses the project context to structure related items, with each project having its own unique identifier. Within the context of a project, the spatial sources in Publish and Share are stored as follows:

1. Use the POST /*contentitems* endpoint to upload the sketch map and obtain a UUID. Let us call it *sketch_uid*.
2. Use the POST */projects/{project_uid}/SpatialSources* endpoint to register the content with *sketch_uid*, as a Spatial source.
3. Repeat steps 1 and 2, but this time with the base map to register the GeoJSON as a spatial source in the same project.

When stored in this manner, the actual content containing the spatial data is separated from the notion of a spatial source, which is a higher-level abstract concept. Given a spatial source, the API provides means to obtain its actual contents. A project can have multiple spatial sources; however, each spatial source is related to only one content item.

5.2 Storing Qualitative Representations

The qualitative data used to aid a user in the demarcation of land parcels captures spatial constraints between features in the project area. These are described as a qualitative constraint network (QCN). A QCN is serialized in a file and describes the relationship, according to a chosen calculus, between pairs of features. The file describing the QCN is stored via the *contentitems* endpoint.

The mechanism for storing a qualitative representation using the 'qualitative base' profile of LADM has been discussed in section 4.2.

5.3 Storing Non-spatial information

In addition to spatial data, LADM also has provisions to capture the legal rights of parties for a piece of land. Publish and Share stores this non-spatial information via *AdminSources*. An AdminSource documents the evidence for interest in land such as rights like ownership or restrictions such as the right-of-way. The document merely provides evidence for later registration in an LAS and does not constitute the registration itself.
For storing such non-spatial information, the *adminsource* endpoint of API requires a reference to a *contentitem* pointing to the actual document and optionally URLs to external sources along with standard metadata fields such as name and description. The AdminSource document can also be added to the context of a project. Additionally, the AdminSource document can point to one or more spatial units, which are the actual parcels of land being registered.

5.4 Support for interactive tools

Tools in Publish and Share can run either in *batch mode* or in *interactive mode*. Batch mode is ideal for computationally demanding tasks with long running times, which do not require user prompts to proceed. For a tool with a GUI such as SmartSkeMa, interactive mode is required. With interactive mode, tools can accept user input when running in order to perform a task.

While SmartSkeMa is capable of running as a standalone application, there are several advantages offered by integrating it with the Publish and Share platform. These benefits accrue depending on to what extent the tool is integrated. Integration consists of using the provided API and workflow guidelines. The integration can be basic or tightly coupled to Publish and Share.

Basic Integration – For a basic integration with Publish and Share, it is sufficient to use the API to use the *projects* endpoint to load and save the project context. A basic integration provides an organized structure for storing related information such as spatial sources and admin sources relevant to the task. Storage of required files however becomes the responsibility of the SmartSkeMa tool. Anytime the project is loaded, the required sketch map, non-spatial information and base map will be retrieved from the tool's storage area or uploaded by a client. This level of integration is sufficient to perform one-off tasks, where one does not expect to reuse stored data frequently.

Complete Integration – In a complete integration, in addition to the Projects endpoint, other endpoints such as SpatialSources, AdminsSources, ContentItems and others are used. The resources are saved in the backend cloud storage of Publish and Share and available for reuse anytime. Resources are available anytime and shared between different running instances of the tool. Another advantage is that dissemination is easy since the platform hosts all resources. Benefits at this level of integration however, come at the cost of greater level of design and development complexity for the tool writer.

6 Conclusion

In this report, we have documented the use of Publish and Share as a cadastral database for qualitative spatial data. In combination with SmartSkeMa, Publish and Share allows handling not only quantitative spatial data as is done traditionally, but also qualitative data.

The use of qualitative data in cadastral database provides several advantages, which open up new commercialisation possibilities for its4land:

- Development of land administration systems based on land management policies that do not follow the paradigm of crisply demarcated parcels. This is the case in societies with alternative concepts of rights or access to land and space like native tribal communities or pastoralists.

- Qualitative extended cadastral database can be used in existing land administration systems as an add-on for modelling restrictions. Restrictions are often demarcated vaguely by definition, like large scale landscape planning or animal migration corridors.

The ‘qualitative based’ spatial profile in combination with the implementation of SmartSkeMa on Publish and Share allows the seamless use of qualitative and quantitative spatial data in land administration workflows.

Storage of cadastral data that includes qualitative information requires specialized tools to visualize and query it. The SmartSkeMa interface developed as part of the work package 3 - *Draw and Make* offers several functionalities to this end. The tool is designed to aid users of land administration systems in visualizing and demarcating spatial features, which may or may not exist on topographic base maps, using qualitative data gathered from spatial sources such as sketch maps. In addition to spatial information, it also has the capacity to display non-spatial information such as RRR’s on land parcels.

Integrating SmartSkeMa with the Publish and Share platform makes use of the functionality provided by the latter’s Public API. The API implements concepts from LADM and provides means to integrate them into applications and existing systems through different usage models. The process of integration can happen at different levels, which determines how tightly the program being integrated is coupled to the platform. A looser integration just uses the API for data organization and modelling whereas a tighter integration uses it extensively and utilizes content storage and other facilities provided for data registration and dissemination. Within the context of its4land, Publish and Share provides a common data model for different tools being developed. In a typical land administration workflow, this means that output from tools that extract features from UAV imagery such as *Automate It*, can be edited and enriched by tools such as SmartSkeMa, in a straightforward manner.

7 Bibliography

[1] UNECE, “Land administration guidelines. With Special Reference to Countries in Transition,” New York, Geneva, 1996.

[2] UNECE, “Guidelines on Real Property Units and Identifiers,” 2004.

[3] ISO/TC 211, “No ISO 19107:2003, Geographic Information — Spatial schemaTitle,” 2003.

[4] ISO/TC 211, “ISO 19111:2007 Geographic Information — Spatial referencing by coordinates,” 2007.

[5] C. Schultz, M. Karamesouti, J. Sahib, M. Chipofya, C. E. M. Galeano, and Schwering, “Documentation on extended Land Administration Domain Modeling (LADM). Its4land Deliverable 3.4,” 2018.

[6] M. Chipofya, J. Sahib, and A. Schwering, “Concept of extended LADM ontology. Its4land Deliverable 3.6,” 2019.

[7] C. Lemmen and P. Van Oosterom, “The Land Administration Domain Model Standard,” in *5th Land Administration Domain Model Workshop*, 2013, no. September 2013, pp. 11–30.

[8] ISO/FDIS 19152, “Geographic information - Land Administration Domain Model (LADM),” vol. 2012, pp. 1–118, 2012.

[9] C. Lemmen, P. Van Oosterom, R. Thompson, J. Hespanha, and H. Uitermark, “The modelling of spatial units (parcels) in the Land Administration Domain Model (LADM),” in *FIG Congress 2010*, 2010, no. April.

[10] J. Sahib *et al.*, “Report on implemented qualitative representations for sketch and geo-reference maps. Its4land Deliverable 3.3,” 2018.

[11] J. Sahib *et al.*, “Semantic recognition of sketched objectse. Its4land Deliverable 3.2,” Enschede, 2017.

[12] C. Timm, M. I. Humayun, S. Walter, M. Chipofya, J. Sahib, and K. Kundert, “Technical report and software prototype of the mobile qualitative data processing system. Its4land Delivery 6.2,” Enschede, 2018.

[13] C. Timm, M. I. Humayun, S. Walter, R. Borchert, S. Crommelinck, and C. Stöcker, “Technical report and software prototype of the mobile image processing system. Its4land Deliverable 6.1,” Enschede, 2018.

[14] C. Timm, M. I. Humayun, S. Walter, and R. Borchert, "Technical report about 'Land tenure dissemination and integration tool'. Deliverable 6.4," 2019.