Horizon 2020
European Union funding
for Research & Innovation

ITS4LAND innovations for land tenure

Deliverable 3.6

Technical Report

30 April 2019

Version 1.0

Abstract:

Concept of extended LADM ontology

Project Number: 687828

Work Package: 3

Lead: WWU

Type: R

Dissemination: Public

Delivery Date: 30 April 2019

Contributors: Malumbo Chipofya, Mina Karamesouti, Angela Schwering, Jan Sahib, Placide Nkerabigwi, Claudia Stöcker, Mila Koeva

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

This is the sixth deliverable report (D.3.6) of the 'its4land' project Work Package WP3, which presents how local domain models (LDMs) designed for its4land's SmartSkeMa system extend the ISO 19152 Land Administration Domain Model (LADM). The extension is achieved by injecting the local perspective on human-land relations, expressed in various modes (hand-drawn maps, narration etc.), into the LADM. Previous reports (D.3.1 and D.3.4) demonstrated: (i) the formalization of the indigenous concepts, directly or indirectly related to land administration; and (ii) a conceptual framework and the structural approach of the mechanisms (Adaptor Models) which enable the integration of the indigenous concepts into the LADM.

Land tenure systems implementing the LADM international standard cannot directly handle non-standard land tenure information such as rights, restrictions or responsibilities which are dynamic, rely on additional conditions, or whose temporal aspect is not fixed. Standard land administration systems use parcels which are quantitatively defined with their boundaries as spatial reference, while data collected with sketch maps relies on qualitative descriptions. Finally, standard land tenure systems cannot deal with land usage rights referring to areas whose spatial extent is determined by the function, thus spatial boundaries cannot easily be determined (e.g. *ronjo*, where nomadic grazers have the right to cross land and herd their animals until they reach their distant grazing reserves). In this deliverable we outline how its4land's SmartSkeMa system addresses the mismatch between non-standard land tenure systems and the LADM by supporting the extension of LADM through SmartSkeMa's LDM-LADM adaptor model. Three types of information are translated into concepts of LADM through the complex LDM-LADM Adaptor mechanism:

i. conceptual non-spatial information to model non-standard rights, restrictions, and responsibilities,
ii. qualitative spatial information as spatial references, and
iii. spatial artefacts, areas with underdetermined spatial boundaries.

With this deliverable we present an extensive revision of the LDM-LADM Adaptor which matures the Adaptor model to its second major development version. The new version of the Adaptor introduces dynamic assertion of conditional RRRs, decoupling of LDM and LADM assertion class hierarchies, and a mechanism for propagating the inference of LADM classes from LDM classes that starts only if a condition on a RRR is specified.

Classes for the new Adaptor Model are accessible at:
https://share4land.itc.utwente.nl:5566/fsdownload/blllSLX5n/Domain_Modelling

A demonstration of the use of the Adaptor Model in SmartSkeMa can be seen here:
http://smartskema.eu

Contents

Abbreviations

EDM	Ethiopian Domain Model
LADM	Land Administration Domain Model
LDM	Local Domain Model
MSKDM	Maasai of Southern Kenya Domain Model
RRR	Right, Restriction, Responsibility

PREAMBLE ITS4LAND

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 Eastern 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 Eastern 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 Eastern African countries: the necessary complementary skills and expertise is delivered. Responses to the range of barriers are prepared: strong networks across Eastern 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. Introduction to this deliverable

Customary, indigenous, or informal (from here on we refer to these as **non-standard**) land tenure systems often involve complex sets of human-land relations and cultural norms. This complexity makes it challenging to model and document non-standard land tenure information within standard, generic land administration systems. In particular, systems implementing the ISO 19152 Land Administration Domain Model (LADM) international standard [1] cannot directly handle non-standard land tenure information. For example, the conditional RRR reported in D3.4 [2] cannot, generally, be captured by the existing RRR model in LADM – consider rights, restrictions, or responsibilities that vary with climatic conditions. As such LADM-based systems are incapable of registering non-standard land tenure information. On the other hand, the LADM as an ISO standard, as well as systems based on it, have a well-established record, a strong foundation, and a broad community of technical and domain experts. This is why we consider the ability to capture and incorporate non-standard land tenure concepts into the LADM as a significant advance towards the goal of providing secure land tenure for all in the East African region.

In this deliverable we outline how its4land's SmartSkeMa system addresses the mismatch between non-standard land tenure systems and the LADM by supporting the extension of LADM through SmartSkeMa's LDM-LADM adaptor model. Non-standard information is documented using Local Domain Models (LDM). An LDM is a formal representation of concepts, relations and rules relating to land tenure within a cultural domain. Two LDMs developed within the its4land project, the MSKDM and the EDM, we reported in D3.1 [3] and D3.4. D3.4 also introduced a high-level generic LDM unifying common classes between the MSKDM and EDM.

The connection from the LDMs to the LADM model through the adaptor model enabled us to adapt the LADM model to the East African case locations in the its4land project. The extension of LADM is achieved by providing the ability to translate three main types of information from an LDM context to an LADM context (Figure 1):

- *Conceptual non-spatial information* such as dynamic or conditional RRRs (ref. D3.4) cannot be captured by LADM. This covers both the base RRR case and more complex cases as illustrated in Section 2.1.
- *Qualitative spatial information*: when at least one RRR is specified on a feature, then that feature is interpreted as a BAUnit in LADM. However, LADM can only process the spatial representations if they are given by a geometry using geo-referenced coordinates. Qualitative descriptions such as in non-standard land tenure systems cannot automatically be processed by LADM.
- *Spatial artefacts* are semantic spatial objects that do not have a material extension or whose extent is ambiguous. Indigenous land tenure information often refers to such spatial artefacts, that cannot be dealt with in LADM.

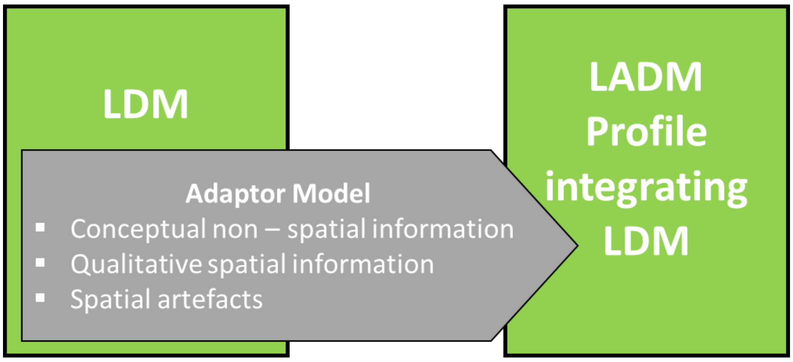


Figure 1. Graphic representation of the LADM extension through the LDMs.

The next section describes how LADM compliant data are obtained from LDM based data collected using SmartSkeMa and illustrates our methods using examples from its4land's case study locations. As per SmartSkeMa design these data are acquired through hand-drawn maps or from textual data (including narratives). The report is concluded in Section 3 with a short discussion and an outlook for the future.

2. How LDMs extend LADM

The Adaptor Model connects LDMs to LADM in a dynamic way: all facts are added to the local domain model using the language of the local domain; only those situations that meet predefined conditions are interpreted as LADM classes. This means that nothing is a right, restriction or responsibility beforehand. Rather, a land relation such as grazing is interpreted as a right if a positive condition is associated with it, as a restriction if a negative condition is associated with it, or as a responsibility if a burden-imposing condition is associated with it.

To view information added to an LDM in an LADM context, the user queries the Adaptor Model which performs the interpretation of the LDM data into LADM online (i.e. dynamically upon request). The translated information can then be combined with existing LADM information from official sources.

The SmartSkeMa Adaptor Model achieves the dynamic connection described above by (i) using dynamic assertion of conditional RRRs, (ii) decoupling of LDM and LADM assertion class hierarchies, and (iii) providing a mechanism for propagating the inference of LADM classes from LDM classes that starts only if a condition on a RRR is specified.

The dynamic connection implemented by the Adaptor Model in turn facilitates the extension of LADM from LDMs through the inclusion of

i. Conceptual non-spatial information (Sections 2.1),
ii. Qualitative spatial information (Sections 2.2), and
iii. Spatial artefacts (Section 2.3).

In the following subsection we describe how each of these three information types are handled using the adaptor model.

2.1. Conceptual non-spatial information

LADM captures RRRs which are permanent or fixed term relations between spatial units and parties. But it cannot capture those RRRs in non-standard land tenure systems which are dynamic, rely on additional conditions, or whose temporal aspect is not fixed. For example, in the Mailua group ranch in Kenya there are areas where different families have grazing rights which are dynamic based on the prevailing climatic conditions (e.g. during the rainy season). 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. SmartSkeMa provides an intuitive user interface through which end users interact with the data (Figure 2). Conceptual non-spatial information is added as attributes of parties (called social units in the LDM context) and spatial features. Such attributes cover all sorts of concepts including environmental characteristics, social characteristics, human activities, and, in general, all such concepts that do not describe the spatial component of the geographic features of interest.

2.1.1 Technical Implementation

The LDMs register non-spatial information under the high-level classes *SocialUnit*, *SocialCharacteristic*, *Activity*, *Status*, *EnvironmentalCharacteristic*, *Material*, *Livestock* and *TimeInterval*.

To interpret a related set of facts in an LDM into LADM, the Adaptor Model must first be given a triple of classes of the form (*SocialUnit*, <condition>, *Activity* or *Status*) connected by three object properties. The first of these three object properties, *participatesIn*, connects a *SocialUnit* to an *Activity* or a *Status*. *participatesIn* is a general relation in the generic LDM model which can be interpreted (read) as indicating that a particular social actor takes part in the stated activity or occupies the stated status. The other two object properties can be any one of the following pairs

i. *hasParticipationRestrictedBy* and *restrictsParticipationIn*
ii. *hasParticipationPermitedBy* and *permitsParticipationIn*
iii. *hasParticipationImposedBy* and *imposesParticipationIn*

Each of these pairs connects the *SocialUnit* to an *Activity* or a *Status* via an arbitrary object called <condition>. The <condition> "invokes" the rule that sets on the transformations as follows:

i. *(hasParticipationPermitedBy* **o** *permitsParticipationIn)* ⟹ *LADM∷Right* (domain: *SociaUnit*; range: *Activity* OR *Status*)
ii. *(hasParticipationRestrictedBy* **o** *restrictsParticipationIn)* ⟹ *LADM∷Restriction* (domain: *SociaUnit*; range: *Activity* OR *Status*)
iii. *(hasParticipationImposedBy* **o** *imposesParticipationIn)* ⟹ *LADM∷Responsibility* (domain: *SociaUnit*; range: *Activity* OR *Status*)

Where '**o**' is the OWL2 composition operator and '⟹' indicates implication. Once RRRs have been inferred additional object properties will extend the inference to other types of objects in the model as appropriate. Below we show how different kinds of inferences are achieved using examples based on real data.

2.1.2 Examples

Example 1: inferring *Party*, *BAUnit*, and instances of related concepts or relations

The sketch map shown on the right side of Figure 8 is a map of a boma. A person named Mama Kesho has the right to live in one of the houses, labelled with *House1*. This relation can be modelled as an ownership relation in LADM. Due to the indigenous rights, also her sister has the right to live in this house. However, this is a conditional right – Mama Kesho's sister has only the right to live in *House1* as long as Mama Kesho is living there – and this conditional right cannot be modelled directly in LADM.

To illustrate how to interpret these object property pairs consider the relationships between Mama Kesho and her sister both of whom live in *House1*. In the LDM (MSKDM in this case) these relationships would be represented by the following set of relations

SocialUnit∷Mama_Kesho – participatesIn → Activity∷OccupationBy_Mama_Kesho

– occursAt → HumanDwelling∷House1

SocialUnit∷Mama_Kesho_Sister – participatesIn → Activity∷OccupationBy_Mama_Kesho_Sister

– occursAt → HumanDwelling∷House1

This simply states a pair of facts in the LDM. Translating these data into LADM facts entails asserting that both *Mama_Kesho* and her sister have the right to occupy *House1*. But of course their rights of occupation are not the same. Mama Kesho has permanent right of occupation because it her home. Mama Kesho's sister has the right of occupation by virtue of her relationship to Mama Kesho.

To make the translation of the input data into LADM facts the Adaptor Model looks for the triangle of (*SocialUnit*, <condition>, *Activity* or *Status*) instances which the user specifies by asserting the following:

SocialUnit∷Mama_Kesho – hasParticipationPermitedBy → TimeAlways∷ timeAlways

– permitsParticipationIn →Activity∷OccupationBy_Mama_Kesho

SocialUnit∷Mama_Kesho_Sister – hasParticipationPermitedBy →

Activity∷OccupationBy_Mama_Kesho – permitsParticipationIn →

Activity∷OccupationBy_Mama_Kesho_Sister

The class *TimeAlways* in the LDM represents time intervals that extend for the duration of any instance in the model (in this case *Mama_Kesho*). The assertions above say that *timeAlways* qualifies the *participatesIn* relation between *SocialUnit∷Mama_Kesho* and *Activity∷OccupationBy_Mama_Kesho* as a relation between an LADM *Party* and an LADM *Right*. The corresponding interpretation for *Activity∷OccupationBy_Mama_Kesho_Sister* is qualified by Mama Kesho's occupation of *House1*, namely, the *Activity* instance *OccupationBy_Mama_Kesho*. Internally, the adaptor uses the following rule to make this interpretation:

hasParticipationPermitedBy **o** *permitsParticipationIn* ⊆ *hasRight* and *participatesIn*

This says that the object property chain *hasParticipationPermitedBy* **o** *permitsParticipationIn* is a kind of *hasRight* object property. As explained in D3.4, the reasoner can infer from this that in LADM *Mama_Kesho* has type *Party* and *OccupationBy_Mama_Kesho* has type *Right*.

From this point on, the adaptor uses a series of object properties and classes axioms to propagate the inferences from LDM classes and object properties to LADM classes and object properties. In particular, to infer that *HumanDwelling∷House1* in our example is a *BAUnit*, the following set of axioms are used:

1) *ConditionalRight* ⊆ **inverse**(*permitsParticipationIn*) **some** (**inverse** (*hasParticipationPermitedBy*) **some** *owl∷Thing*)

2) *ConditionalRight* ≡ *isConditionalRight* **some Self**
3) *isConditionalRight* **o** *occursAt* ⊆ *hasRightOnBAUnit*

As above, the reasoner infers from the domain and range specification of *hasRightOnBAUnit* that *House1* has LADM type *BAUnit*. This example illustrates how the Adaptor Model infers that there exists a *Party* that has some right on some *BAUnit*. Similar logic applies to LADM restrictions and responsibilities.

An important thing to note in the example above is that if the condition had not been connected to *SocialUnit* and *Activity* in the object property chain then none of the inferences would have been made. For example, if there was no traditional stipulation that Mama Kesho's sister has the right to reside in Mama Kesho's home, then her (the sister's) occupation of *House1* would not be interpreted as a *Right*. The condition, therefore, on the one hand allows the model to distinguish between RRRs that have an official interpretation and those that do not. On the other hand, the condition attaches additional information about a specific RRR which varies the situations under which the RRR holds.

Example 2: RRRs depending on membership to a tribe

The integration of the formalized non-spatial indigenous information into the LADM is performed using the Adaptor Model following the certain general mappings as a basis (e.g. listed in Table 6 of the D3.4 in the case of MSKDM and EDM). In this table no equivalence for all the LDM non-spatial concepts can be observed (i.e. for the Material, TimeInterval, Livestock etc.). Such concepts provide additional meaningful information, which could not so far be registered in the general LADM.

An example of a non-spatial LDM concept which extends the LADM is the "social characteristic", expressed by the LDM class *SocialCharacteristic*. Through the class *SocialCharacteristic,* additional semantic information is attributed to the LDM class *SocialUnit*, which is still available even when a *SocialUnit* instance is viewed as an LADM *Party* (see D.3.4).

From the Ethiopian case study, we extract the information that the ethnicity (which is registered in LDM as a social characteristic) plays an important role in the human – land relations. An instance of the class *SocialUnit* with a specific ethnicity may be able to have rights on land (i.e. right to own or right to lease land) in a specific area, but the same *SocialUnit* might be barred from any right on land in another area, exclusively because of his ethnic identity. The formalization of this example within the LADM framework is presented in D3.4 (Scenario 1B). In the LDM this can be achieved by

1. Explicitly stating the membership relation between each person and each tribe using the object properties *memberOf* and *notMemberOf* both with domain *SocialUnit* and range *Tribe*:

   <tribeName>*LandRelationNonParticipant* ≡ *notMemberOf* **some** {tribeName}

2. Explicitly stating the tribe that has recognized claim over each region of land registered in the LDM. This is achieved using the object property *hasJurisdictionOn (*domain*: Tribe,* range*: LandCharacteristic)*. Use this object property to implicitly define the class of individuals that may participate in land relations in the tribe's jurisdiction:

<tribeName>*LandRelationParticipant* ≡ *participatesIn* **some** (*occursAt* **some** (**inverse**(*hasJurisdictionOn*) **some** {tribeName}))

3. Add the axiom that states that non-members of a tribe cannot participate in a particular set of land relations.

   <tribeName>*LandRelationParticipant* **disjoint from**
   <tribeName>*LandRelationNonParticipant*

Example 3: variations on RRRs depending on membership to a tribe

A particular strength of our model is that it allows considerable complexity in the definition of RRRs. For example, a condition may be a simple, information free statement such as "True" for RRRs which always hold and do not rely on a specific condition. But it may also be a complex statement that is based upon other conditions.

The example of the tribe could have been modeled as a condition on the particular conditions involved. To illustrate, suppose non-tribe members can obtain long term land use rights of up to 10 years. This can be modeled as a higher-level condition that connects to conditions justifying the specific lease type.

This example has illustrated of a complex specification for interpreting local land relations within the LADM context. In general, these structures within the domain model are created only once during deployment at the beginning – updates are applied as with any other software.

2.1.3 Implementation in SmartSkeMa

To add a non-spatial attribute in SmartSkeMa, the user must first activate the attribute editing mode by clicking on the **Add RRR** button as shown in Figure 2. Then the attribute is added by performing the following steps:

i. Select the object in the sketch map to which the non-spatial information refers. In the pull-down menu that opens upon selecting a feature, add the non-spatial information in the appropriate fields (i.e. the social unit involved, the relationship to the spatial feature, and any conditions specified on that relationship).
ii. Click **Add Record** to save the new data. The system will give the user a message that the information was successfully registered.

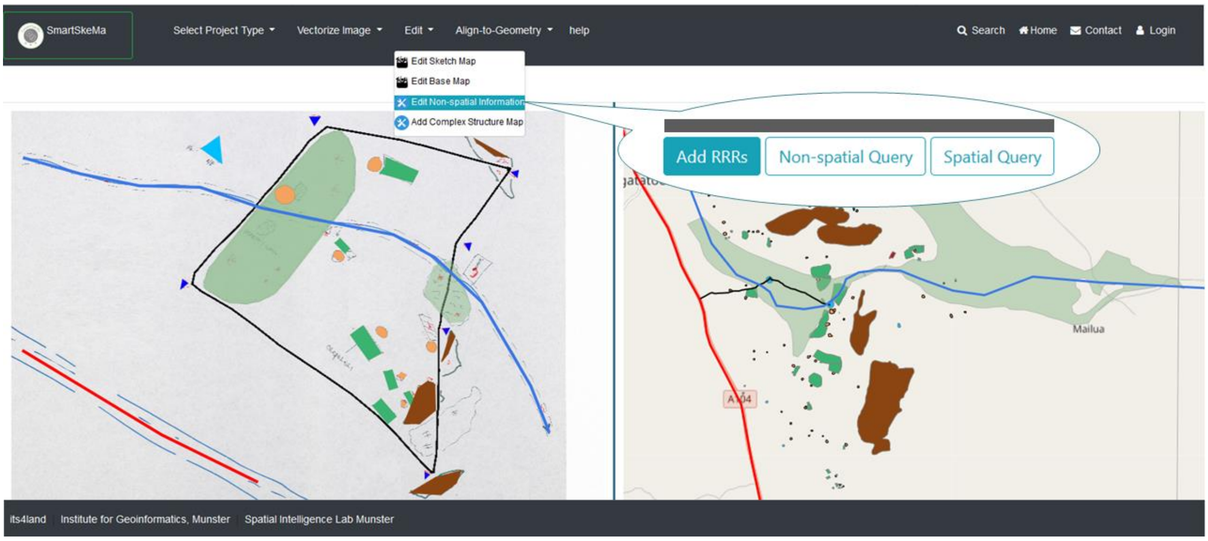
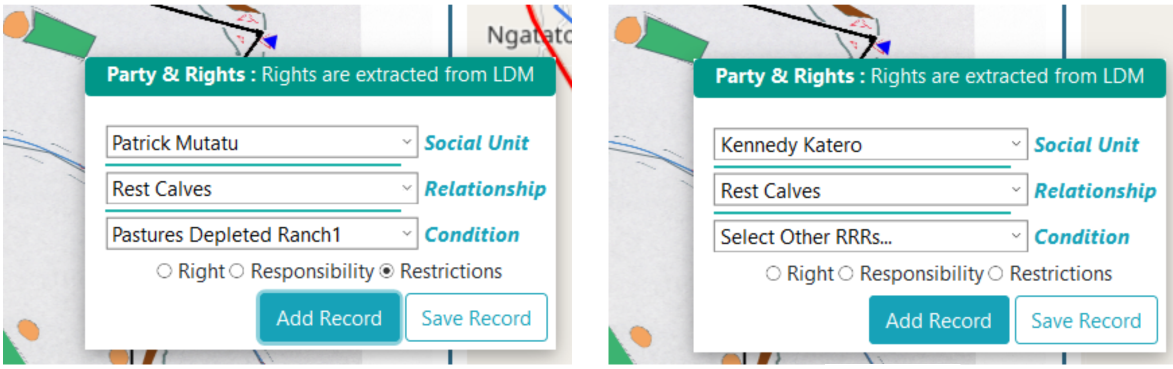


Figure 2. Adding non-spatial attributes in SmartSkeMa (click **Add RRRs**).



(a) (b)

Figure 3. Adding non-spatial attributes in SmartSkeMa: (a) with a condition specified the attribute becomes a conditional RRR, and (b) without the condition the attribute remains an LDM relation.

In this example, the individual Patrick Mutatu is registered as a Social Unit with the right to rest their calves in the olopololi labeled Olopololi301 only when all other previously suitable pastures within the ranch are depleted (Figure 3a). Kennedy Katero on the other hand (Figure 3b), is registered as a participant in the activity 'rest calves' at Olopololi301 without giving a condition. The omission of the condition means that SmartSkeMa's adaptor will not interpret this participation in the activity as an RRR. This can be seen in the results returned by the Non-spatial Query on Olopololi301 shown in Figure 4.

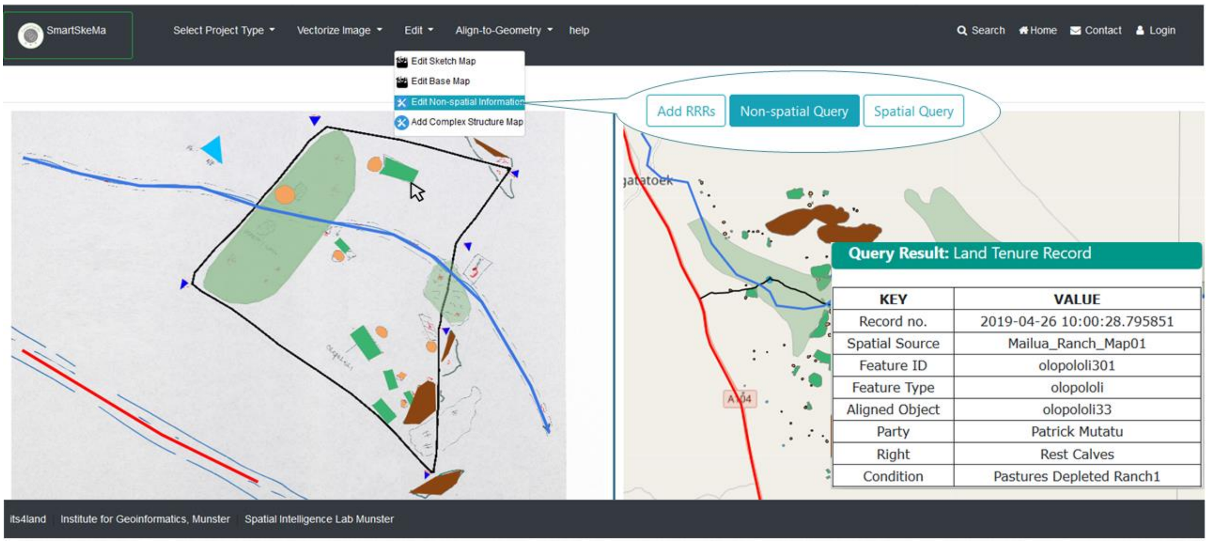


Figure 4. Displaying non-standard land tenure relations as LADM concepts in SmartSkeMa.

2.2. Qualitative Spatial Information

The main way in which LADM captures parcels is through points, lines, and polygons. LADM also allows for parcels to be described using text and sketches. However, in its raw form, this information cannot be automatically interpreted by a land administration system: This profile does not allow spatial operations on the spatial unit. Deliverable D6.3 [4] section 2.2 gives a detailed overview on this aspect. For example, if you describe a spatial unit based on the text based spatial profile, its boundary, its location and its shape are described entirely in a textual way. None of the existing spatial profiles in LADM can handle qualitative descriptions of spatial objects in such a way that they allow spatial operations on them. The text based spatial profile would allow a qualitative description, but not spatial operations.

In SmartSkeMa we transform the pictorial information in sketches into qualitative spatial information. This allows the spatial extent of a parcel to be described by formalized, qualitative spatial relations and therefore automatically interpreted by the system.

Qualitative spatial information is a primitive information type in the SmartSkeMa model. It allows SmartSkeMa to connect imprecise knowledge given in sketch maps to standard information types used in Cadastral databases. This is achieved by introducing a spatial type called *AbstractShape*. An abstract shape can be described by a concrete geometry when available or in purely qualitative terms if only relative spatial information is available. The subclass *Shape* of the *AbstractShape* class has a geometry attribute which refers to the concrete geometry that describes the shape.

2.2.1 Technical Implementation

Spatial Unit and Abstract Shape

Our extension of the spatial part of the LADM builds on the *SpatialUnit* class in LADM. In LADM the *SpatialUnit* class represents a generic container for the spatial component of a particular Basic Administrative Unit (*BAUnit*). *SpatialUnit* derives its semantics from the particular LADM profile under which it is implemented. For example, in the Kenyan land administration system, using the Registry Index Maps as a reference, each polygon in the map for which there exists a reference to a record in the land register (maintained by the Land Registrar) represents an instance of *SpatialUnit* [5]. *SpatialUnit* itself is not necessarily a geometry or other spatial representation but it is associated with a spatial representation such as a polygon which can have other properties – such as a topological description specifying for each boundary section the left and right side regions that it borders.

In the LDM-LADM adaptor model a *SpatialUnit* is associated with an *AbstractShape*. In the generic LDM model every feature of interest is spatially defined by a *SpatialEntity* object which in turn may be described by an instance of the *AbstractShape* class. The interpretation of the class *AbstractShape* is that it is an object in Cartesian space (a point, a curve, a region, or a collection thereof). Under this interpretation a point given by its coordinates is as much a point as is one merely asserted – e.g. by the statement "the **north corner** of the boundary is at the foot of Mount Kilimanjaro".

The Shape class represents a concrete geometry given by a set of coordinates in the Cartesian plane. Thus every Shape instance is an AbstractShape instance but not all *AbstractShape* instances are Shape instances. Figure 5 illustrates the relationship between the geometry classes defined in LADM and the classes under *Shape*.

The adaptor model introduces a new profile of spatial unit represented by the class *QR_SpatialUnit*, a subclass of *LA_SpatialUnit*. A *QR_SpatialUnit* is a qualitatively described spatial unit defined to have an association to one or more *AbstractShape* instances. This relationship is established through the object property *hasShape*:

LA_SpatialUnit - hasShape - AbstractShape

The separation of the *SpatialUnit* as a land administration object from the general spatial representation model is important. A mountain may be a feature of interest when describing a land administration object such as a ranch. But it may itself not be an object of interest in the land administration system. Therefore, the *AbstractShape* representing the mountain would not be associated with any *SpatialUnit* instances whereas the one for the ranch would.

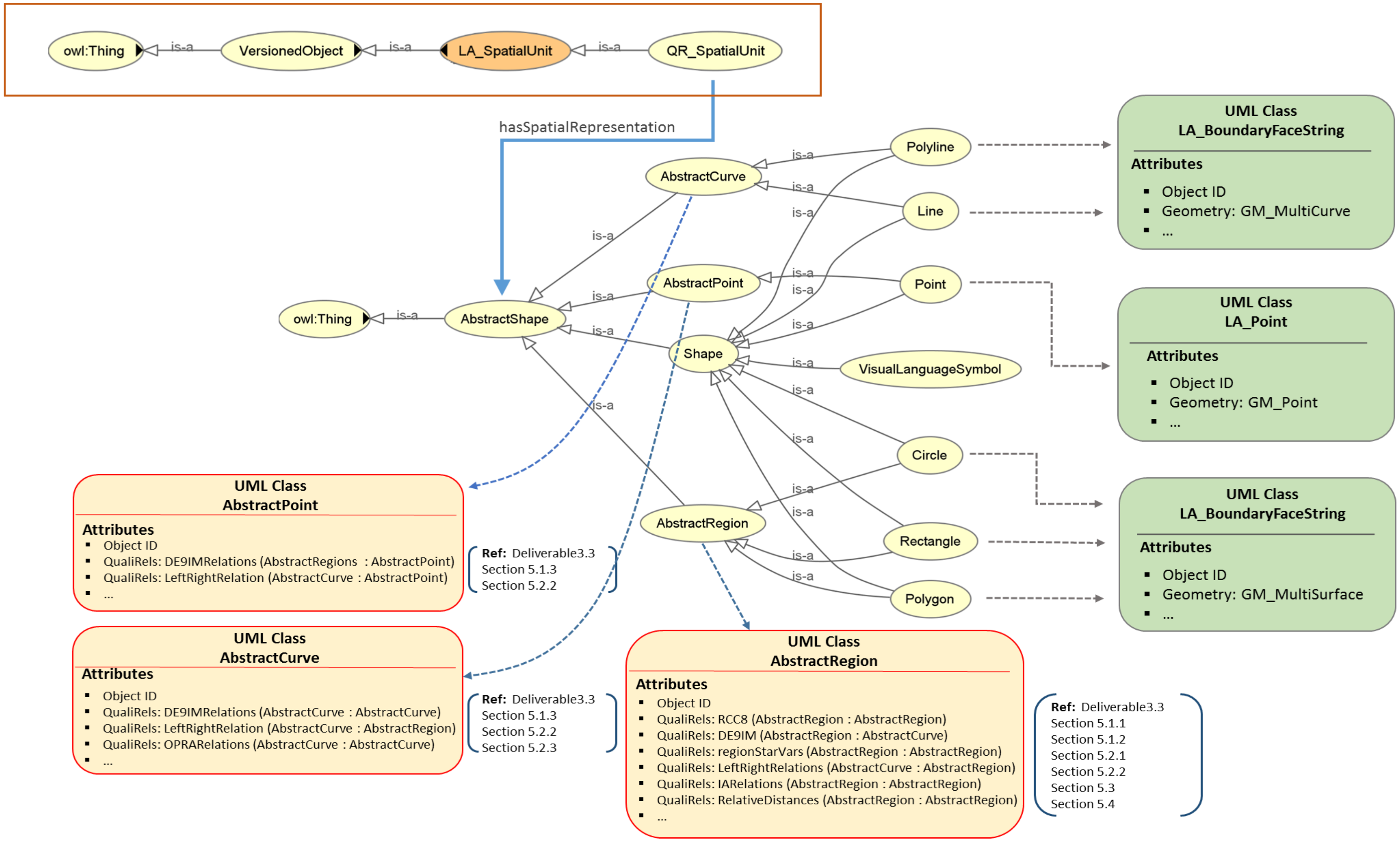


Figure 5. Class hierarchy of the AbstractShape class and its subclasses and their relationships to the LA_SpatialUnit and QR_SpatialUnit class. The Shape class and its subclasses (green colored) are LADM classes to represent concrete geometries given by a set of coordinates, while other subclasses of the AbstractShape such as AbstractCurve, AbstractPoint, and AbstractRegion (orange colored) represent geometries through qualitative descriptions.

Qualitative spatial relations

The modeling of *QR_SpatialUnit* and *AbstractShape* make it possible to:

i. integrate spatial information extracted from hand-drawn sketch maps with more precise information from other sources at a compatible level of abstraction, and

ii. incorporate new concepts that enrich the semantics of the identified spatial features, beyond LADM capabilities.

Within the LDMs these qualitative spatial relations specify the relative positions and locations of *AbstractShape* instances and are implemented as object properties with domains *AbstractShape* and range *AbstractShape*).

For sketch maps the spatial relations are computed by the SmartSkeMa qualifier (D3.3 [6]). For each sketched feature and each spatial aspect, a qualitative spatial relation is computed against every other applicable feature. For example, an *AbstractCurve* representing the feature River in Figure 7 will have *LeftRight* relations with all other *AbstractShapes* in a sketch. If the *AbstractRegion* representing Boma1 in the sketch is on the left side of the river, the LDM will contain an assertions of the form:

AbstractCurve∷River - *hasToTheLeft* - *AbstractRegion∷Boma1*

AbstractRegion∷Boma1 - *leftOf* - *AbstractCurve∷River*

For the full set of qualitative spatial relations used in SmartSkeMa (which are encoded in the generic LDM) we refer the reader to the report on D3.3. When features are extracted from the sketch map by SmartSkeMa, the following steps are performed.

1. An instance of one of the LDM *AbstractShape* subclasses *Shape*, *Point*, *Line*, *Polyline*, *Polygon*, *Circle*, or *Rectangle*, is created based on the geometry of the extracted features. If the feature has mixed dimensions, it is simply classified as a shape.
2. Object properties representing the spatial relations computed by the qualifier are inserted into LDM for each pair of *Shape* instances.
3. An instance of one of the subclasses of the LDM class *EnvironmentalCharacteristic* is created together with an instance of the *SpatialEntity* class and connected to the corresponding *AbsractShape* subclass via the *hasSpatialAspect* and *hasShape* object properties.

After applying these three steps for all features extracted from the sketch map, the LDM will contain all the spatial and feature type information relating to each feature. This spatial information is also used to infer further LADM relations as described in section 2.3 below.

2.2.2 Implementation in SmartSkeMa

In SmartSkeMa, qualitative spatial relations between all spatial features in the input maps are computed as part of the basic data processing workflow (see D3.3 [6] and D3.5 [7]). In the LDM qualitative spatial relations become attributes of abstract shapes. The user can directly preview a list relations computed for different pairs of objects in the SmartSkeMa user interface (Figure 6). The qualitative relations visualizer which is part of the work reported in D6.3 also provides a way for users to generate concrete geometric approximations for the features in the sketch map.

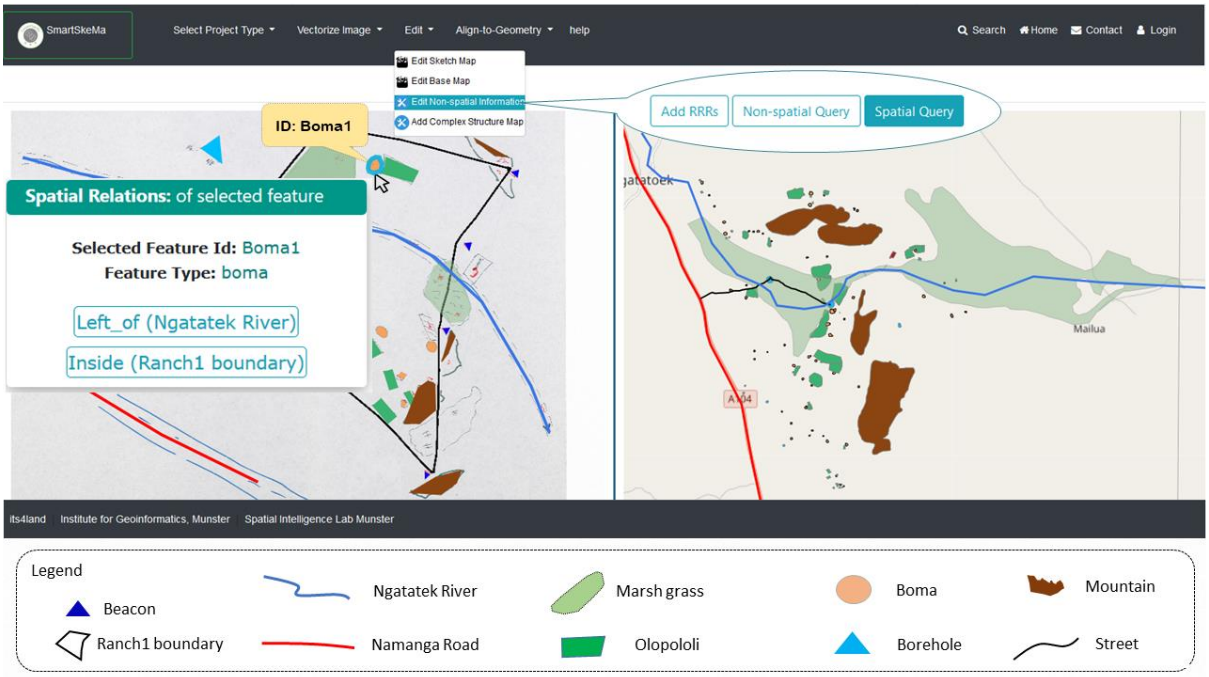


Figure 6. An example of spatial relations between a boma (ID: boma1) and the Ngatatek river, Ranch1 boundary in a geographic scene as displayed in SmartSkeMa.

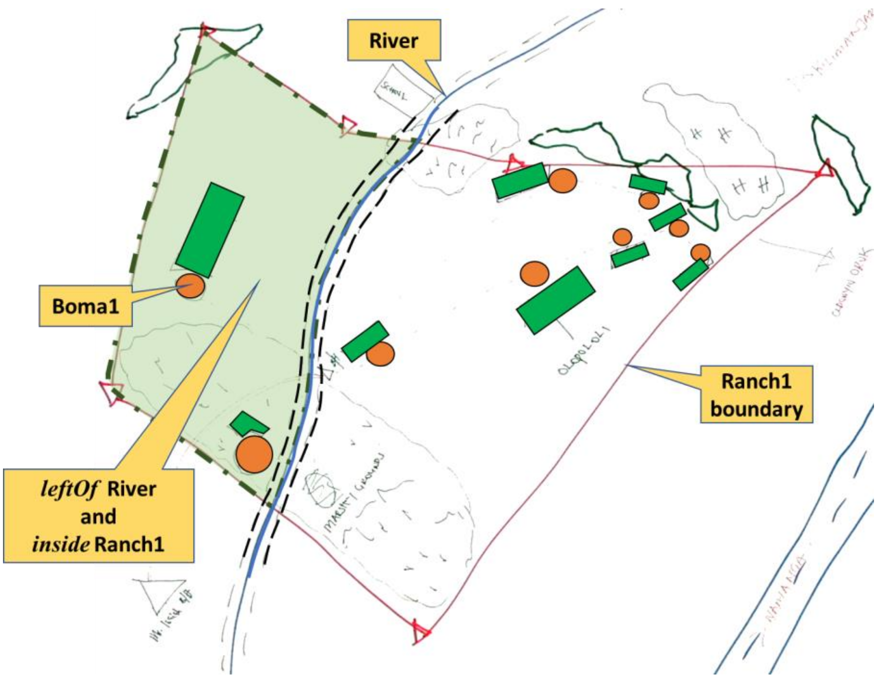


Figure 7. The light green polygon labeled "*leftOf* Ngatatek River and *inside* Ranch1 boundary" represents the region satisfying the LeftRight (leftOf Ngatatek River) and the topological relation (inside Ranch1 boundary) where Boma1 is located.

The sketch map in Figure 7 shows, in light green, the region of the map corresponding to the relations "*Boma1 inside Ranch1boundary*" and "*Boma1 leftOf NgatatekRiver*". This knowledge can be used to restrict possible locations of Boma1 in the geo-referenced base map, but it can be also used to test whether certain RRRs (e.g. grazing restriction to left of the river) are implied even for spatial features for which SmartSkeMa does not have precise location information.

When used together with the conditional RRRs described in Section 2.1 above, qualitative spatial relations can be used to infer additional RRRs. An example of this is the following scenario. Since Patrick Mutatu is registered with a right to use Olopololi301 SmartSkeMa infers that he must also have the right to use the ranch Ranch1 which contains Olopololi301. The model can handle more complex scenarios as illustrated below. Note that all these steps of inference do not require the use of actual geometries.

2.3. Spatial artefact

LADM allows the assignment of RRRs on spatial units with well-defined boundaries. However, in our study areas we found that there are RRRs specified on regions with under-determined spatial boundaries. For example, during the activity of *ronjo* which is performed during periods of drought, nomadic grazers herd their animals to distant grazing reserves. The paths taken during ronjo cover wide corridors with under-determined boundaries because they depend on the nature of the drought and other conditions at the time. SmartSkeMa introduces the concept of spatial artefact to deal with these situations.

In SmartSkeMa we consider two main types of spatial artefacts. Those referring to complex structures which can be illustrated by the sketcher at variable levels of abstraction and those features with varying or underdetermined spatial or temporal extents, which are specified based on the sketcher's experiences and knowledge.

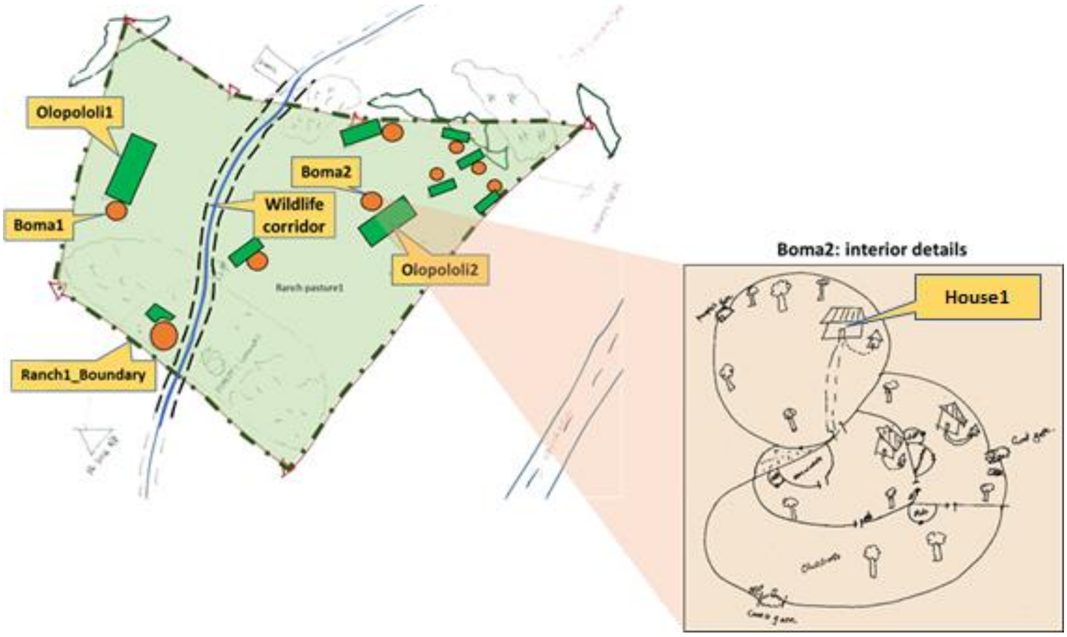


Figure 8. Details of the interior of a boma are connected to the original record of the boma by associating the original boma record with its interior components via various qualitative spatial relations.

Complex spatial structures are captured at a higher level of detail than can be given in a small scale, overview map. Using the adaptor model SmartSkeMa connects RRRs on features in the detailed map to features in the small scale map. Figure 7 illustrates a scenario where information from two sketch maps is connected via a *contains* topological relation. The implication of this connection is that new RRRs are inferred based on the RRRs separately specified on the input sketch maps. For example, the right of occupation on one of the houses in the boma implies a right of occupation on the ranch. A detailed example is given below. The sources for the information at different levels of detail can be of different types. In our example, both sources are sketch maps but one may have well been a geographic map (with precise georeference). The crucial information here are the spatial and conceptual relations between the two inputs maps.

2.3.1 Technical Implementation and Examples

Complex spatial structures

The nature of spatial representations in a sketch map is abstract. For example, a homestead in traditional Maasai communities (boma, in the Maasai language) is drawn as a single circle in a sketch map but in reality it is a complex of structures usually arranged in a circular pattern. From our study site in Ethiopia, we also obtained single object representations for households. These, however, represented both single structures and multiple structures within a single compound. Such spatial artefacts, being abstracted away at different levels, can be captured as such in each LDM, since the interpretation of concepts is driven by the semantics specified in the LDM as opposed to, for example, the details of their structural form (we detect a boma not a group of houses and animal sheds). More detail can then be added to the data by adding records of the necessary type (e.g. add an actual house – Enkaji – as a component of a boma).

To elaborate we refer to the sketch map on the left of Figure 8. In this sketch map, the sketcher has drawn circular objects representing bomas neighboring rectangular objects representing Olopololis. The implied information of this representation, is that the Olopololi, which is a fenced area used for grazing mainly during the dry period, is exclusively used by the resident of the neighboring boma (or by other authorized persons). Administratively, this complex structure (the boma and the olopololi) can be handled as a single basic administrative unit (both spatial units are subject to the same RRRs) or as separate administrative units.

In the sketch map on the right hand side of Figure 8 describes the interior structure of the boma labeled Boma 2 in the overview sketch map on the left. This sketch is itself a representation of the concept **Boma** and the interior components are representations of concepts **Enkaji**, **House**, **Olosingo**, **Emuatata**, **Olale**. In MSKDM these will be added as instances of the corresponding classes, allowing for the registration of more detailed land relations within the boma.

In SmartSkeMa, the user, upon loading and processing the overview small-scale (large area) sketch map on the left in Figure 8, can click on any feature (super-feature) and select another sketch map as a more detailed sketch of that particular feature. SmartSkeMa then goes through its processes detecting the individual components of the super-feature as drawn in the detailed sketch map. The extracted (sub-)features are added to SmartSkeMa just like any other features with the additional spatial relation that states that each of the sub-features are spatially contained in the region covered by the super-feature.

In the adaptor model, the above stated containment relation induces a *subSpatialUnitOf* relation (realized by the *subSpatialUnitOf* object property). From this point-on the relations between the other LADM objects and the new sub-features can be handled in different ways depending on the LADM profile that is being extended.

1. The *BAUnit* associated with the super-feature is associated with the *SpatialUnit*s of the sub-features. This is the case where the RRRs on the super-feature's *BAUnit* might need to be transferred to the sub-features.
2. The *BAUnit* associated with the super-feature is associated with the *BAUnit*s of the sub-features. This is the case where the RRRs on the sub-features' *BAUnit*s might need to be transferred to the super-feature.
3. A SmartSkeMa deployment can specify another sequence of actions that fit to the deployment environment.

Spatially and temporally underdetermined features

While complex structures are dealt with using multiple classes and relations, most of the spatial artefacts documentable with a SmartSkeMa LDM will fall under the high-level class *EnvironmentalCharacteristic*. These spatial artefacts may occur as features with underdetermined temporal duration or periodicity, or as features whose spatial extent is not well defined, or both.

An example of spatially and temporally underdetermined features handled by SmartSkeMa are wildlife movement corridors. The interaction between grazing rights and wildlife movements introduces grazing restrictions around a wildlife corridor (whose precise boundaries are not well defined). Wildlife corridors are therefore land tenure features whose spatial and temporal extents are underdetermined.

The wildlife corridor in the sketch map of Figure 8 is an example of a feature that is both **temporally** and **spatially** underdetermined. There is no fixed boundary for the region considered to be the wildlife corridor, but the region covering the corridor is generally along the river. The event "elephant migration" can be considered as an event that occurs in the region wildlife corridor. This event (which cannot be currently described within the LADM framework) has an impact on other activities (i.e. grazing), which are directly related to land administration.

Spatial features

The wildlife corridor is determined by the sketcher as an abstract region (an area not precisely defined in space i.e. dimensions, orientation etc.). Despite the ambiguity of this spatial feature, specific RRRs apply on it (i.e. within this wildlife corridor grazing is must be done carefully, since pastoralists run the risk to be confronted with wild animals). For the demarcation of such spatial features, the SmartSkeMa adopts the approach of "Empty spaces" [8], originating from the field of architecture. Based on this approach, areas are not defined based on metric rules and fixed boundaries, but rather based on their functionalities. In our case scenario, land functionality will determine the boundaries of the wildlife corridor, on which certain rights and restrictions apply.

The qualitative spatial representations attached to *AbstractShape* instances in the LDMs enables us to formalize and represent semantically rich regions of empty space as distinct objects which we then employ in specifying conditional RRRs, land use queries, etc. The concept of abstract shape is also compatible to the spatial representation through sketch maps, since the sketcher might draw spatial features whose edges cannot be precisely determined in the real world.

When the SmartSkeMa extracts a feature from a sketch map its representation in an LDM has the following form:

SpatialEntity – hasShape → AbstractShape

(*EnvironmentalCharacteristic* or *HomesteadComponent*) – *hasSpatialAspect → SpatialEntity*

The location of the feature relative to others is given by qualitative spatial relations. The *AbstractShape* model used in the LDMs therefore renders itself naturally for representing features whose spatial extent is not well defined.

Temporal features

The elephant migration is a phenomenon that is assumed to be temporally defined during the dry period of the year. During the dry season, grazing must be done with care within the wildlife corridor (people risk being confronted with wild animals), but when it is the wet period conflicts with wild animals are significantly fewer, meaning that people can exercise their full right to graze over the wildlife corridor.

This temporal feature imposes a restriction or establishes a right, under certain preconditions. It can be captured by the SmartSkeMa LDM as a *ClimaticCharacteristic*, and can be interpreted into *ConditionalRRR*. In our example, the two conditions dry and wet season, could be instantiated as

OlariSketchMap1 (EnvironmentalCharacteristic ∷ *ClimaticCharacteristic*∷ O*lari*)

OlameyuSketchMap1 (EnvironmentalCharacteristic ∷ *ClimaticCharacteristic*∷*Olameyu*)

where "Olameyu" is the word for drought or dry season and "Olari" is the word for wet period in the Maa language. In the revision of the Adaptor model, Conditional RRRs which were introduced in D3.4 are instances of either the *Activity* or *Status* class. In the grazing example and instance of *Grazing*, which is a subclass of the *Activity* class, would be conditioned one of the two climatic conditions above. Both conditions cannot be true at the same time and as such the grazing activity would either be a right or a restriction depending on which season it is.

Terra nullius

A classic case of the "empty space" concept is the so called terra nullius. Terra nullius refers to officially unoccupied or unused land. However, this designation is often false since such lands may form part of migration routes for pastoral communities or serve some other purpose for a community such as being the location for cultural or traditional rituals. Because of its status a terra nullius may be designated for other land uses without consideration of the function it plays in the livelihoods of the communities that use it. As Makki [9] notes, in many situations

"...communal holding rights may be subject to privatization at any time without the consent of the communities concerned, and that there are no clear legal provisions as to whether or not communally held land is to be compensated"

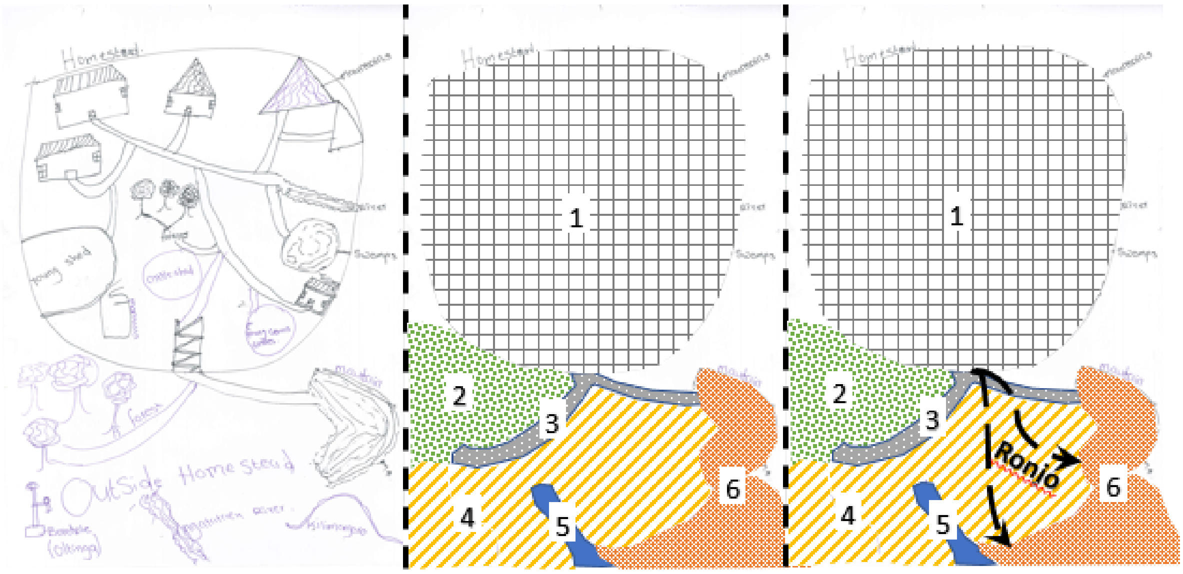


Figure 9. (left) Original sketch map from the Kenyan study site. (middle) Annotated sketch map showing the feature classification for different regions of the sketch with 1: Boma area, 2: Forest, 3: Paths/roads, 4: unclassified area outside the boma, 5: River, 6: Mountains. (right) Possible trajectories of the ronjo activity within area 4.

As such modelling the terra nullius and the unrecognized rights incumbent upon them can help protect communities from the unintended consequences of land registration. We illustrate this in the following example where the local government's planning office might want to appropriate a piece of land and designate it for another land use as part of the local development plan (e.g. to construct a hospital).

Consider the scenario involving a terra nullius depicted in Figure 9. The original sketch map on the left, acquired during our field trip in Kenya, shows the location of a boma, a river, a borehole, and two mountains. The map in the middle shows the segmentation of the sketch into different classes. In addition, the sketchers mentioned that people from the boma sometimes trek to the mountains drawn for ronjo – shown as dashed arrows in the map on the right. The possible trajectories for the ronjo activity introduce a right of way for the herders over the region labelled as area 4. The area 4 represents part of the unclassified space outside of the boma and is an example of terra nullius. Given the description of the trajectories and the qualitative spatial relations among all the features in the map SmartSkeMa's LDMs contain sufficient information to determine a smaller region to which the ronjo activity is constrained. In this way we can attach the right of way for the ronjo activity to a region with an underdetermined extent and allow queries to be run against that region. In our example this *RonjoCorridor* region would be given by the relations:

i. *rightOf* pathToMountain
ii. *leftOf* pathToForest
iii. *rightOf* River
iv. *between* Mountains Boma

Now the planning office of the local government authority can check its plan against this information. Suppose that the planned to build a hospital in the region satisfying the constraints above. Then we would like the system to report back that there are rights that might be violated if the plan was executed as such. In SmartSkeMa this conclusion derives from the conditional RRR model. The facts registered in the LDM are:

SocialUnit::Herder1 –participatesIn→ Activity::Ronjo –OccursAt→ RonjoCorridor

Herder1 –hasParticipationPermitedBy→ OlameyuSketchMap1

OlameyuSketchMap1 –permitsParticipationIn→ Ronjo

This means that *Ronjo* becomes a conditional right whenever it is dry and is associated with the region *RonjoRegion*. After the sketch map is aligned with the base map, checking if the area proposed for any new land title issuances is in conflict any existing land rights, in this case the *Ronjo* right, involves checking the intersection of the proposed new area with existing features in the database, including the *RonjoRegion*, for which RRRs have been recorded.

2.3.2 Implementation in SmartSkeMa

The process of adding higher levels of detail to features in SmartSkeMa, is simple. The user selects '**Add detailed map to feature**' under the '**Edit**' menu. Then clicking on any feature in the sketch or metric map allows the user to upload a map representing the detailed spatial layout of the selected feature. This is illustrated in Figure 10.

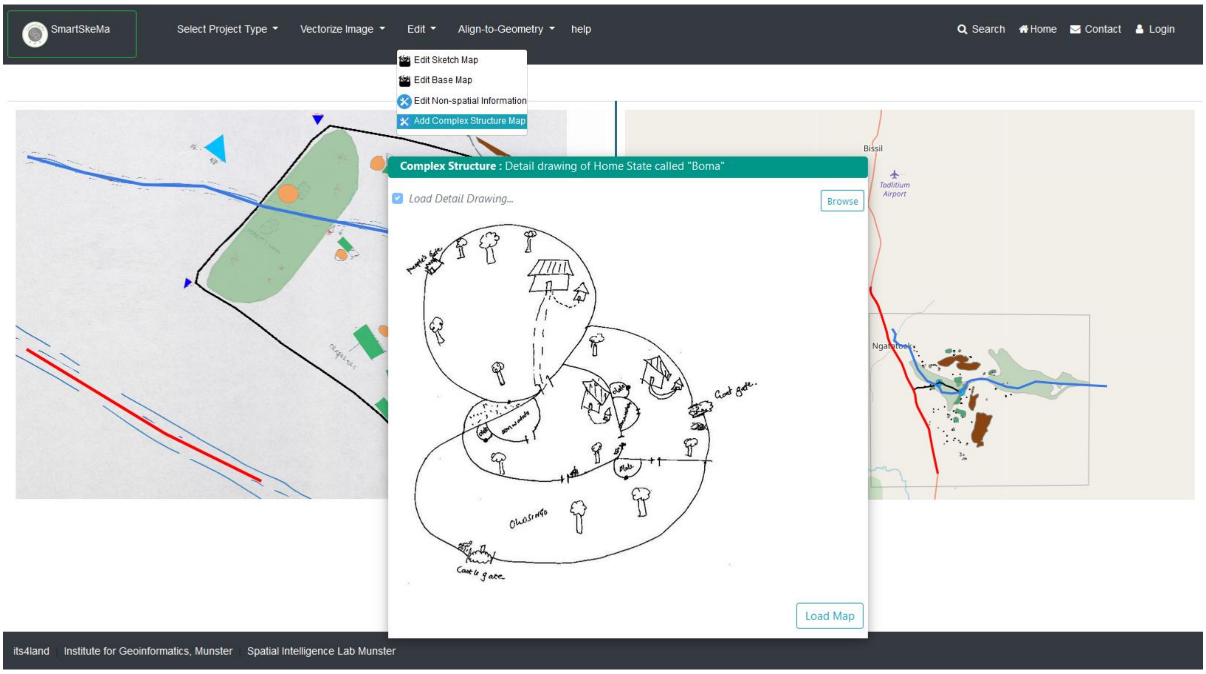


Figure 10. To add a more detailed description to a feature in SmartSkeMa, the user simply selects the feature and is given the option to upload a sketch map describing the feature at more refined level of detail. The screencast shows how the map is added in SmartSkeMa.

3. Conclusion

The concept of an extended LADM developed for the its4land toolbox introduces new dynamic structures for representing land information from non-standard land tenure systems in a way that makes such land information usable within a standard LADM based system. In this deliverable we have shown how the three planned extension are implemented using the SmartSkeMa adaptor: i) conceptual non-spatial information, ii) qualitative spatial information, iii) spatial artefacts.

The part of the extension covering conceptual non-spatial information allows the extended LADM to accept a wider variety of rights, restrictions, and responsibilities. The conditional RRR concept makes the translation of local land norms into rights possible by reducing complex social rules into conditions that apply on a specific activity or status relative to a land resource. This is a completely new contribution to the area of land information modeling.

Qualitative spatial information allows the domain models presented in D3.1, D3.4, to handle RRRs that apply on regions that are not necessarily parcels or those parcels for which precise geometric descriptions are not available because, for example, it was not possible to collect such precise data via survey or other means. We have demonstrated that qualitative spatial information can be used to administrate land even without the acquisition of precise geometric data. The power of qualitative spatial information can be observed in its ability to support inference of new land relations from the combination of a given set of land relations and a set of spatial relations.

Combining extensions for conceptual non-spatial information and qualitative spatial information in LADM produces the representational power required to capture more subtle but critical land relations: spatial artefacts. Spatial artefacts capture more subjective knowledge about land relations because their effects are indirect and only realized at the moment of interpretation. This has been captured in two different ways. Detailed information about a feature is grounded only by reference to other information, i.e. the location of the feature, which may, in turn, be grounded by reference to the metric base map. Features with poorly defined spatial extents are another class of artefact handled by SmartSkeMa. In both cases qualitative spatial relations form a crucial part of their representation allowing additional information not available at the onset to be inferred.

Looking ahead beyond the present state of play we observe that not all non-standard land tenure concepts can be represented in our model. There is need to extend the model to languages that do not rely on the open world assumption for their decidability properties. In Karamesouti et al [10] we already began to explore the use of Answer Set Programming for this purpose. This a future endeavor that may also open opportunities representing even more sophisticated land tenure relations.

Bibliography

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

[2] 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," Enschede, 2018.

[3] C. Schultz, M. Karamesouti, J. Sahib, M. Chipofya, C. E. M. Galeano, and Schwering, "Guide to the Southern Kenya Maasai Ontology. Its4land Deliverable 3.1," Enschede, 2017.

[4] C. Timm *et al.*, "Technical report about "Cadastre database with qualitative extended spatial reference". Its4land Deliverable 6.3," Enschede, 2019.

[5] Siriba, D. N. and J. N. Mwenda (2013). Towards Kenya's Profile of the Land Administration Domain Model LADM. 5th Land Administration Domain Model Workshop. Kuala Lumpur, Malaysia.

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

[7] M. Chipofya *et al.*, "Report on the implementation of a matching algorithm for the alignment of sketch maps with corresponding cartographic maps. Its4land Deliverable 3.5," Enschede, 2018.

[8] Bhatt, M., Schultz, C. and M. Huang (2012). The Shape of Empty Space: Human-Centred Cognitive Foundations in Computing for Spatial Design. VL/HCC 2012: IEEE Symposium on Visual Languages and Human-Centric Computing, (Innsbruck, Austria), pp. 33–40.

[9] Makki, F. (2014). Development by Dispossession: Terra Nullius and the Social-Ecology of New Enclosures in Ethiopia. Rural Sociology, 79 (1), 79-103.

[10] Karamesouti, M., Schultz, C., Chipofya, M., Jan, S., Murcia Galeano, C. E., Schwering, A., and C. Timm (2018). The Maasai of Southern Kenya Domain Model of Land Use. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., IV-4, 105-112, https://doi.org/10.5194/isprs-annals-IV-4-105-2018.