THE MAASAI OF SOUTHERN KENYA DOMAIN MODEL OF LAND USE

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Commission VI, WG VI/2

KEY WORDS: Indigenous knowledge representation, Land administration, Land management, Answer Set Programming, Sketchmaps

ABSTRACT:

We present a domain model that formalises the human-land relations in the Maasai nomadic pastoralist society in Kenya, referred to as MSKDM, and its integration with the prominent Land Administration Domain Model (LADM). Our long-term aim is to facilitate a land administration system that can accurately capture and express salient Maasai concepts of land use, ownership, communal tenure, and to assist in transparency during land transactions. We use an extensive corpus of existing research literature, and input from our own on-site workshops, as source material for our domain model. We use real sketch maps drawn by Maasai community members that we collected during our field studies for validation, and to demonstrate how our model can be operationalised.

1. INTRODUCTION

1.1 Indigenous knowledge (IK) representation

Local communities often develop special codes of communication, capabilities and knowledge, and adopt certain ways of life, that are deeply integrated into, and coordinate with, highly specialised environmental conditions. Inevitably, conflicts appear when communities with significant differences in the established intra-human or human–environment relations begin to co-exist, particularly when this change is abrupt. Since 1998, the World Bank has openly recognised the power of local knowledge in community problem solving, as exemplified in 99 published IK Notes. For instance, the IK Note "Indigenous Knowledge and Science and Technology: Conflict, Contradiction or Concurrence?" reports on the sustainable use of land based on traditional observational practices (World Bank, 2004). Indigenous knowledge representation, through case-specific domain models, compatible with formal ontological schemas, could facilitate intra-community communication and possibly provide solutions for conflict alleviation.

1.2 Kenya

Kenya has been experiencing a relatively high number of conflicts related to land management and the definition of boundaries. These conflicts are triggered by the increasing number of family members claiming land, a trend of increasing urbanisation, the need for the co-existence of pastoralism, commercial agriculture and wildlife (Lamprey and Reid, 2004), and the conventions among the local society Maasai members (Seno and Shaw, 2002) that are not formally recognised nor accounted for by official administrations. Despite numerous efforts to develop a land tenure framework (Bekure, 1991; Davis, 1970; Grandin, 1987; Mwangi, 2005) that would address the societal needs and safeguard Maasai land rights, a sufficient land registration system has not yet been developed (Nyariki et al., 2009; Seno and Shaw, 2002). Key factors that make this an extremely challenging task include: the land registration system being highly complex; corruption and mistrust between the Maasai community and the government; the inadequacy of land administration systems to incorporate nomadic pastoralism practices that have taken place for many generations in Kenya (Bekure, 1991; Nyariki et al., 2009; Seno and Shaw, 2002).

In this context, land administrative information and geo-information may be in the form of (1) UAV-based imagery that is annotated by local community members (e.g. images are marked to identify land use regions, socially recognised boundaries, etc.) and (2) sketches in a semi-structured language. Relevant information must first be extracted from annotations and sketches, and then used to populate a land administration database. Unfortunately, in our particular focus area of Maasai of Southern Kenya, **existing domain models cannot be directly employed** for capturing and expressing real concepts of land use, social agreements, and land. For example, central concepts such as *boma* (a place where people live) do not map onto any concepts in prominent domain models such as CityGML, and the central notion that rights and restrictions may be *conditional* depending on environmental circumstances can not be directly expressed using the Land Administration Domain Model (LADM).

1.3 Maasai of Southern Kenya Domain Model

To address these issues we have developed an indigenous knowledge representation model, with a scope to provide "..a dominant label that may be used consistently … to denote the knowledge of traditional and indigenous communities…"

(Ngulube and Onyancha, 2011). The Maasai of Southern Kenya domain model (MSKDM) collects and structures Maasai concepts that are pertinent to land use. Our key contributions are: (1) a comprehensive **review** of Maasai research **literature**, and the collection and analysis of interviews from two on-site field studies (Section 3) to develop the MSKDM (Section 4.2); (2) an **adaptor** that forms the MSK-LADM so that Maasai land use scenarios can be expressed using the prominent Land Administration Domain Model (LADM) (Section 4.3); (3) an innovation to the LADM of ***conditional RRR***, that is of central importance in capturing many Maasai land use relationships (Section 4.4).

The content of our integrated MSK-LADM is a collection of: (1) concepts that are required to interpret annotated UAC imagery and sketches of land use made by Maasai of Southern Kenyan (e.g. objects that are likely to appear in sketches such as boma, trees, paths, etc.); (2) concepts that are required to express land use information (e.g. social structures, types of relationships between different social communities); (3) concepts and relations between them, related to land administration, as defined by the ISO 19152 international standard (known as LADM).

The work presented in this paper is one of the core components of a large 4-year international EU research project, *its4land*. Thus, our MSKDM integrates directly with two other project components on: (1) UAV-based image recognition and (2) semi-structured sketch recognition, all targeting Maasai of Southern Kenya. The MSK-LADM is formal (i.e. unambiguous; can be automatically interpreted and processed in software) and thus provides a uniform language for querying across a large number of sketches. Our aim is to make this current version readily accessible to users and other researchers with the intention that they adapt, extend, improve, and refine as needed.[1]

2. RESEARCH CONTEXT AND RELATED WORK

In the domain of land administration, we identify several efforts for standardizing cadastral information, along with case-specific applications: the Swiss DM.01 (Steudler, 2006), the FIG Core Cadastral Domain model (Lemmen and Van Oosterom, 2006), with applications in Portugal (Hespanha et al., 2006), the Hungarian digital base map standard, DAT (Iván et al., 2004), the Social Tenure Domain Model (STDM) (Lemmen et al., 2007), with applications in Ethiopia (Lemmen and Zevenbergen, 2010), and the Zambia land delivery ontology (Abanda et al., 2011). In Southern Kenya, various approaches have been used to document the particular human-land relations formed in residence areas of the Maasai Mara (Wayumba, 2017), but to the best of our knowledge, this is the first attempt towards the development of LADM within the southern Kenyan Maasai framework.

2.1 Sketchmaps

Sketchmaps are human-made sketches that capture and communicate information about the environment, e.g. to describe a wayfinding route or the structural (spatial) arrangement of geographic features in the local environment. Workshops, with governmental and non-governmental stakeholders in Kenya, Rwanda and Ethiopia, revealed sketchmaps to be amongst the most preferable technologies that could meet the local needs for cadastral and non-cadastral purposes, due to the low cost, and the encouragement of local community participation, which is expected to enhance transparency and highlight actual community issues (Ho et al., 2017).

Our domain model has a core role in sketch interpretation: what makes smart sketchmaps "smart" is that explicitly drawn spatial objects are identified and assigned a semantic (i.e. conceptually meaningful) category. When a person is communicating an object or land use boundary in the form of a sketch they may represent ("draw") the object as a point, line, or contour. Importantly, the object being communicated is not a geometric object; it is a much richer *concept* that has complex relationships with other meaningful concepts. For this purpose, our domain model alignment with the sketchmaps (Lemmen and Zevenbergen, 2010), was a core aspect for sketchmap objects' identification and interpretation.

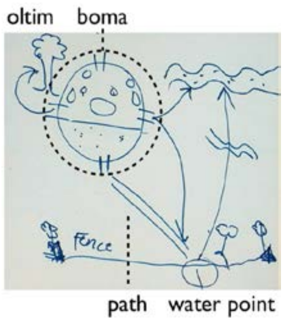

Figure 1. Maasai sketch communicating land use

The real sketch in Figure 1, drawn during a field exercise, depicts a large complex residential structure (*boma).* The *oltim* (a chopped tree) is a culturally highly significant gate. When the oltim is not positioned in front of the entrance to the boma (e.g. in the evening the tree is moved inside the boma) this indicates that the boma is closed and should not be entered. The sketcher is communicating several key objects in their locale of regular activities (e.g. a path that leads to a water point), and the qualitative position of these objects relative to each other. We make the following claim about sketches communicating land use: *Information that is being communicated in the sketch is about objects (e.g. bomas, lakes, paths) and particular qualitative spatial relationships between those objects (e.g. eastward, left of, near, between). In contrast, the information being communicated is not about points, lines, polygons, and exact numerical distances, dimensions, and angles.*

Thus, to capture the information that is being communicated by the human sketcher, we require a domain model that anticipates the objects and relationships that will be communicated. We also need to be able to query the corpus of sketches in an intelligent manner, for example: (1) *Find all sketches in which a human dwelling is relatively far from any body of water; (2) Find all sketches in which grazing land is shared between different tribes.* As a further example, consider a scenario in which the government is considering building a large road to transport materials between different cities: *Does*

[1] Please download the **MSKDM** and complete cross-referenced literature review at:
https://share4land.itc.utwente.nl:5566/sharing/blllSLX5n

this region intersect with any activities of local Maasai communities? To address such queries, and to correctly interpret the semantics of a sketch, a domain model needs information such as: (1) a *boma* is a type of community residence, which is a *human-made* structure; (2) a *lake* is a type of *water body etc.*

3. METHODOLOGY FOR DEVELOPING MSKDM

By *domain model* we mean a collection of concepts and relationships between concepts. Concepts include cultural, spatial, environmental, societal notions that have either a direct or indirect impact on land use patterns of Maasai communities. In this section we present our methodology for developing this domain model, following the IDEF5 methodology for knowledge engineering and ontology development (Benjamin et al., 1994). Following IDEF5, we have undertaken five development stages as we describe below, and we are currently undertaking an additional refinement and validation stage with a third return visit to Kenya in 2018.

3.1 Organization and scoping

The area of application for the MSKDM is the Southern Kenyan County of Kajiado. Functional requirement for the development of the domain model was to be able to include concepts capturing information communicated in a variety of modalities such as sketches, interviews, other forms of oral communication, or through a user - system interaction. Two groups of researchers performed distinct tasks, namely literature review and field data collection, that involved communication with six key stakeholders: (1) land administration specific public-sector entities (national, county); (2) adjacent policy domains or public organisations public sector entities; (3) non-statutory entities; (4) private sector entities (5) NGOs not-for-profit/donors and development partners; (6) research and development stakeholders. Communication with locals of different social status, age and gender was attempted in order to register the actual issues related to land administration and reveal the most suitable and useful tools that would address society's needs.

We opted for expressing our domain model, and the subsequent integration with LADM, using the Ontology Web Language (OWL) (Antoniou and Van Harmelen, 2004) within Protégé (Knublauch et al., 2004) to ensure that the model is *formal* (unambiguous) and logically consistent. Our *adaptor model* is an independent tool that has the exclusive role of integrating MSKDM with the LADM. The MSK-LADM aims to cover the information needs of local stakeholders in Kenya (i.e. government, communities and NGOs), who originally highlighted the problem of poor cadastral information and the ensuing social concerns. From an ontological standpoint, knowledge inference using our MSK-LADM is based on an open-world assumption - a land administration system used for answering queries based on our MSKDM cannot assume that all information about a concrete situation has been entered into the system. In practice this means that "do not know" is a permissible query response, and that inference is not only deductive, but also abductive. This **marks a rather significant departure from standard LADM usage**, and thus we additionally extend the LADM with the innovative concept of a *conditional* RRR.

3.2 Data collection: accessing source material and expert knowledge

We obtained source material for the domain model through: (1) a comprehensive review of academic literature relating to Maasai culture (approximately 40 academic documents including research journal articles and Maasai language dictionaries); (2) on-site field study visits to Kenya (workshop exercises and interviews on two separate trips to Kenya in 2016, 2017, attended by governmental and non-governmental stakeholders; participants discussed and reported on challenges and potential technological solutions concerning Maasai land use and land administration systems).

3.3 Data analysis

For the MSKDM the collected and integrated concepts derived from the broader cultural and societal context, rather than a strictly land use perspective. Our aim was to identify any implicit human - land relations, which could not be directly identified by forming i.e. a human - land use model. Hence, we formed approximately 15 broad concept categories i.e. society, activities, spatial organization, soil-land characteristics and land formations, vegetation, landmarks, climate, etc. For each of these categories, were collected a plethora of concepts, accompanied by case-specific information, e.g. the term "olameyou" is interpreted as the dry season (Knowles, 1993), and we determine from literature and field studies that "climatic variability significantly affects human life and land use in our study area" (Lengoiboni, 2011).
Importantly, regarding model reuse and the semantic web, *we did not find any adequate existing domain models that could be linked to for capturing aspects of the domain in a suitable manner*, e.g., other models that we reviewed with the aim of covering environmental and infrastructural concepts included OpenCyc, CityGML, and Industry Foundation Classes. We instead opted to organise and integrate the body of concepts directly from literature and our interviews as the MSKDM, and leverage model *reuse* by connecting it directly with LADM, forming the MSK-LADM.

3.4 Initial domain model development

Our initial domain model was built iteratively from all prominent concepts that appear in the collected sketches, and by iteratively integrating concepts from a significant number of literature sources. As semantic distinctions emerged, we introduced more general concept classes. We cross-checked concepts gathered from academic literature with concepts collected from our on-site workshops for redundancy, or to conclude whether they played a more prominent role in sketch interpretation than we had initially realised.

3.5 Refinement and validation

The IDEF5 methodology, at this stage examines the qualitative characteristics of the domain model. However, based on (Bernard, 2017), the validation process has three main aspects: the instrument, the data and the findings validation. The validation aspect which directly aligns with the scope of this research is *instrument* validation.

The initial domain model validation stage consisted of an unstructured expert review by partners from the Technical University of Kenya. As a second validation stage we followed the process described by (Gómez-Pérez et al., 1995) of reviewing the domain model performance in case-specific scenarios and through competency questions. This consists of (1) creating instances inside the domain model classes and checking if the model adequately captures the injected scenario information, and (2) running queries to check response validity. Our last validation process was conducted through the use of concepts depicted in 30 sketch maps we collected during our field trips in Kenya (2016, 2017) during field interviews with participants from peri-urban, rural, and pastoralist Maasai communities (1st field trip: 15 male, 8 female; 2nd field trip: 13 male and 13 female); we present the validation results in Table 1. Additional domain model refinement and validation, with more sketchmaps from the Kenyan study site has already been planned.

4. SOUTHERN KENYAN MAASAI LAND USE

4.1 Data analysis results and key findings

In this section we summarise key findings from our data analysis that impact land administration processes, or motivated our defining of corresponding concepts and concept relationships in our domain model.

4.1.1 Environmental characteristics: Vegetation and climatic characteristics refer to concepts such as olari (wet season), olameyu (dry season), oit ekitum (acacia forest) and oltim. Many activities are intrinsically connected to climate and vegetation. Vegetation also plays a significant role in defining landmarks used to communicate spatial information about land use and tenure. The inherently dynamic, changing character of climate directly impacts the notion of rights, restrictions and responsibilities. This led to our defining of the notion of conditional RRR, presented in Section 4.4.

4.1.2 Land use: Two main concepts related to the Kenyan Maasai land ecosystem are the domestic ecosystem and the wild ecosystem. In terms of conservation policy, these areas can be classified as protected or non-protected. For the Kajiado District, the main land use patterns are the pastures, the agricultural land, the urban areas and the wildlife reserves. During the last 30 years land use has changed from a sparsely settled pattern, with predominance of grazing and forested lands, to a heavily settled pattern, where agricultural cultivations and urban system expand, in detriment to former land use status, and overlooking the basic land use and land management principles of the traditional Maasai societies, leading to a serious social division (Butt, 2015; Galvin et al., 2008; Knowles, 1993; Mwangi, 2005). Despite international efforts to re-establishing socio-ecological equilibrium, turbulences persist (Abbink et al., 2014), mainly due to the steady transformation of the commonly used land, into individual parcels of land and fenced areas (Butt, 2015; Mwangi, 2005; Nyariki et al., 2009). Among the Maasai communities, the concept of sharing natural resources is not just symbolic. Rather, it works as a safety net for difficult periods, such as extended droughts (Butt, 2011). Consequently, the main land use types (i.e. agricultural areas, grazing land, artificial land, ranches, boundaries) as well as the ownership status (i.e. private, public etc), were considered as core components for the current domain model (Jandreau and Berkes, 2016).

4.1.3 Artificial (human-developed) areas: Spatial organization of the Maasai communities (traditional nomadic Nilo-Saharan groups), with the multi-household organizations and the commonly used territories (primarily for grazing) is one of the critical components in a domain model, aiming at formalizing the Maasai community system. Different types of permanent or temporary homesteads, constructed by different materials reveal the distinguishing role they serve in the community and the social roles of people that reside in them. Characteristics of the human and animal homesteads, animal enclosures, as well as their main components, provide important spatial information and were thus incorporated into the ontological model. As an example of how material is relevant to land use: homesteads constructed with mud tend to be more temporary housing, and thus indicate nomadic communities. In contrast, thatched or tin-roofed houses are permanent homesteads, and thus indicate sedentarized pastoralism or farmers.

4.1.4 Activities: Agropastoral activities are the main source of income for Maasai communities, while supplementary income might derive from land leasing for cultivation, conservation (wild life) or touristic use. The fragmentation of the communally used grazing lands appears to be a serious cause of conflict due to competing activities. Thus, the concept of activities was incorporated in the model. The way that pastoralism is performed, and consequently the areas that are used, usually depends on the size of the herd, household wealth, social constrains as well as the climatic conditions.

4.2 The Maasai of Southern Kennya Domain Model

In this section we present an overview of the structure of our MSKDM. The MSKDM currently consists of 280 classes. Table 1 presents the basic class statistics to give an indication of the scope and depth of each high-level subclass.

High-level class	Subclass levels	Number of subclasses	MSKDM Concepts in Workshops	MSKDM Concepts in Sketch maps
EnvironmentalCharacteristic	7	202	67%	51%
SocialUnit	3	26		
Activity	2	23		
HometeadComponent	1	12		
Livestock	2	6		
Shape	1	7		
Material	1	4		
MSKDMSource	0	0		

Table 1. Number of subclasses and inheritance depth for each high-level concept, and percentage of MSKDM concepts addressed during workshops and sketch-mapping.

Additionally, we present the percentage of MSKDM concepts that were addressed during the on-site workshops, as well those validated through sketch-mapping, during the first-level validation process. The validation stage determined that 67% (resp. 51%) of MSKDM concepts raised or addressed independently during the workshops (resp. in sketch maps). Conversely, **all** key concepts relevant to land administration that were addressed during the workshop and in sketches are also present in the MSKDM.

https://doi.org/10.5194/isprs-annals-IV-4-105-2018

The MSKDM defines eight high-level classes, immediate subclasses of **Thing**. (1) **EnvironmentalCharacteristic**: characteristics relating to vegetation, land, and climate; (2) **SocialUnit**: social structures and roles (e.g. resident, shepherd, rancher); (3) **Activity**: primarily geographical-scale activities (e.g. agriculture, land leasing, tourism) and ceremonial activities (e.g. emanyatta (warriors camp)); (4) **HomesteadComponent**: objects that make up parts of a homestead (e.g. engishomi (gates, doors), olengati (yard)), and interior furnishing; (5) **Material**: substances used in built structures or that impact tasks such as emunui (sediment) or engare (water); (6) **Shape**: geometric figures such as points, lines, polygons, circles; (7) **Livestock**: domesticated animals used for farming e.g. cattle, sheep, zebu; (8) **MSKDMSource**: registers metadata about the source of information (e.g. the date and the name of creator of a sketch map).

4.3 Integrating MSKDM with LADM

Figure 2 presents the conceptual integration of the MSKDM, which formalizes the information acquired from the Maasai community, with the ISO 19152 international standard for land administration, the well-known LADM (Lemmen et al., 2009), forming the MSK-LADM. Using MSK-LADM, users familiar with LADM can express Maasai land use scenarios using the LADM framework. We implement this integration as an adaptor that bridges MSKDM concepts into relevant LADM concepts.

Figure 2. Conceptual integration of MSKDM with LADM

The LADM consists of four main packages: (1) spatial sources (surveying), and spatial representations; (2) spatial units; (3) parties; (4) basic administrative units and rights, responsibilities, and restrictions. The Adaptor model (currently consists of 39 classes) bridges the MSKDM concepts with the relevant LADM concepts, by establishing relations such as: DomesticEcosystem (class of MSKDM) is a BAUnit (class of LADM), Boundary (class of MSKDM) is a BoundaryFaceString (class of LADM), Activity (class of MSKDM) is a RRR (class of LADM) etc.

4.4 Conditional RRR

Not all MSKDM concepts were satisfactorily interpreted into the LADM. In the Kenyan Maasai community, *dynamic* (i.e. changing) climatic and vegetation characteristics play a central role in understanding human-land relations. Thus, we propose to extend LADM with the innovative notion of *conditional* rights, restrictions and responsibilities (RRR). For example, the mutually agreed right to a particular activity (such as grazing) on a particular region of land may only apply IF dry weather during the dry season makes grazing difficult or impossible in other regions. Thus, the right to an activity is conditional on specific, periodically changing climatic circumstances. In order to accurately capture and describe real-world Maasai land use patterns we require such conditional RRR.

In the Adaptor model we introduce one new class ConditionalRRR, with subclasses ConditionalRight, ConditionalRestriction. These two classes are related to the Right class of the LADM model through the ObjectProperties ConditionalRightFavorsRight and ConditionalRestriction-HindersRight respectively. The ConditionalRight class is also related to LADM class Party through the ObjectProperty Party-FacesCondRRR. The (logic-based) interpretation of a conditional RRR is that, if the condition C is TRUE in situation s, denoted $C(s)$ then the corresponding RRR, R, applies to situation s denoted $R(s)$,

$$C(s) \rightarrow R(s) \quad (1)$$

Importantly, given such a conditional RRR, if condition C does not hold, i.e. $\neg C(s)$, then it is not the case that the RRR necessarily does not hold, $\neg R(s)$. Intuitively, a right or restriction (such as grazing) may apply under various different conditions. If any of those conditions hold then the RRR applies, and if none of the conditions hold then the model expresses the case that it is unknown whether the RRR applies. Making useful inferences in the context of such a lack of information is addressed by the research fields of abduction and default reasoning (Hanks and McDermott, 1986; Poole, 1988; Reiter, 1980).

5. CASE-SPECIFIC SCENARIOS

In this section we present case-specific scenarios used for domain model validation following the process described by (Gómez-Pérez et al., 1995). These examples incorporate components of all the core concepts of the studied system (i.e. environmental characteristics, land use, artificial areas, activities), into the enhanced (including the conditional system state) LADM concepts of Rights, Restrictions and Responsibilities. Thus, the case-specific scenarios also serve to demonstrate the applicability of our domain model and overall MSK-LADM approach towards GIS-based land administration systems that can record and query Maasai land use concepts.

Each case scenario is artificial and hand-crafted, combining a variety of interacting concepts to more rigorously exercise the domain model. Scenarios are constructed by applying a range of real situations and concepts to real sketch maps. The following scenarios rely on the following background knowledge: "*Bomas, are the homesteadsof circular shape where the Maasai live. Residents of the boma are also considered to be the owners while they reside there. A fenced area called olopololi is located next to each boma. Olopololi are used by the residents of neighboring bomas, or relatives after unofficial permission, for animal grazing purposes. The ranch is a broader societal organisation that includes bomas and olopololis. Families and clan members reside in each ranch. The right of residence passes on from generation to generation. The free space within the ranch (excluding the olopololis and the bomas), is considered by the Maasai community as communal land (can be freely used by any ranch member, under the condition that the activity of one member does not prohibit the activity of another ranch member). Various types of case-specific unofficial regulations are readily identifiable, e.g. land use based on climatic conditions or defined by natural boundaries*".

The background knowledge is applied to the sketch map in Figure 3, which is a real sketch drawn by members of the

Maasai society, during one of our field studies in Kenya (2016, 2017). Overlaid annotations highlight various features of the case study. The lines representing the boundaries of the specific ranch are not necessarily indicated by some physical fence or barrier. Nine homesteads (bomas) are represented by circular shapes. The rectangular formations, representing olopololi (fenced areas used for grazing), are located next to each boma. Other significant spatial characteristics represented are marshlands, mountains, paths, water points, a river with an estimated buffer zone, and a public building (school).

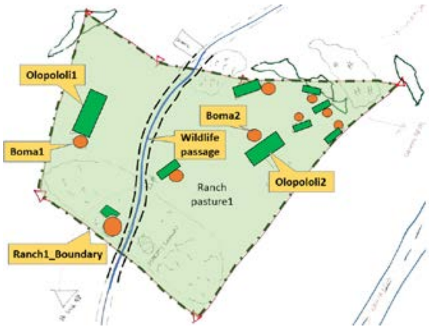

Figure 3. Sketchmap created by members of the Maasai community during field study in Kenya (with annotations)

Scenario A1: Impact of climate. From field studies we learn that the entire ranch area can be used by any ranch member, the only exception being fenced rectangular areas (olopololis), located next to circular features, the households (bomas). Olopololis can be accessed only by their owners, the residents of the adjacent boma. In this scenario, we capture the impact of climate to the potential of land use as conditional RRR (Figure 4). Using this scenario we check the adequacy of the MSKDM classes MSKDMSource, EnclosureForAnimal (subclass of EnvironmentalCharacteristic), and the SocialUnit class (including subclass Rancher). Moreover, we check the functional correctness of the Adaptor model, i.e. the proper interpretation of instances (RanchGroupMember1 and RanchGroupMember2) of the MSKDM class SocialUnit into LADM LA_Party class. This scenario highlights the inadequacy of the standard LADM to express dynamic conditions impacting RRR on land use status. The LA_Party (i.e. RanchGroupMember1) has the right to graze (Grazing-RanchPasture1_byRGM1) in the area RanchPasture1 (an instance of LA_BAUnit) only under the condition that it is olari (seasonal wet period). However, if it is olameyou (seasonal dry period), there is a restriction on this activity.

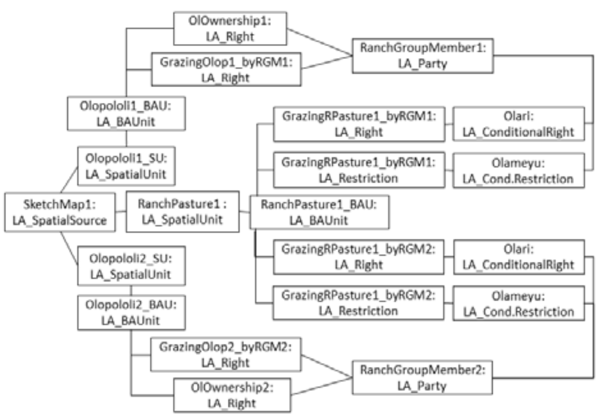

Figure 4. Human-land relation LADM diagram with conditional RRR based on climate (Scenario A1).

Scenario A2: Impact of wildlife. From field studies we learn that a wildlife corridor exists along the river. Thus, the area is extremely dangerous for the locals themselves, as well as for their herds. Several cases of conflict were reported during our field studies, while other studies have reported that wildlife-herd conflict as a major issue for Maasai societies (Hazzah et al., 2013). Current scenario captures the restriction, applied to RanchGroupMember1, of access to the area around the river, characterized as a wildlife passage. This can be characterized as a case-specific unofficial regulation (i.e. not recognised by public administrations) applied by the ranch group members. Similarly to the scenario A1, RanchGroupMember1 faces the conditional Restriction of grazing in the area RanchPasture1, under the condition olameyou. The process of validation was successful for this case scenario as well.

Reasoning using ASP. As a demonstration of reasoning and querying with the MSKDM we have implemented these scenarios in Answer Set Programming (ASP). ASP is a logic programming language that has its foundations in first-order logic (Gebser et al. 2016). Similar to Prolog, ASP has a knowledge base of facts and rules of the form "Head :- Body" meaning that, if the Body holds, then the Head must hold; unlike Prolog, ASP supports classic negation and abductive reasoning needed for conditional RRR. We are using the Clingo ASP solver (ibid.) in these examples.

MSKDM concept hierarchies are encoded as ASP facts, e.g. a *boma* is a *human dwelling*, which is an *artificial area*, etc.:

```
is_a(type(boma), type(human_dwelling)).
is_a(type(human_dwelling), type(artificial_area)).
is_a(type(artificial_area), type(land_use_type)).
```

We can encode particular scenarios as ASP facts, e.g. entity "boma_1" is a "boma" type:

```
mskDm(id(boma_1), type(boma)).
```

We express the general rule that an entity of a given type *T1* is the implied type *T2* according to the is_a hierarchy:

```
mskDm(Id, type(T2)) :-
  mskDm(Id, type(T1)), is_a(type(T1), type(T2)).
```

We can then ask ASP to find all entities that are human dwellings:

```
#show is_human_dwelling(D) :
   mskDm(D, type(human_dwelling)).
```

We get the result that "boma_1" is indeed a human dwelling:

```
is_human_dwelling(boma_1)
```

Expressing LADM relations in ASP. We continue by adding facts that describe the particular LADM relations, e.g. that *ranch_group_member_1* is a *la_party*, etc.:

```
la_entity(id(ranch_group_member_1), type(la_party)).
la_entity(id(olopololi_1), type(la_baunit)).
...
```

We consider two types of RRR, *ownership* and *grazing*:

```
la_rrr_type(ownership). la_rrr_type(grazing).
```

Entity *ranch_group_member_1* owns *boma_1* (etc.):

```
la_rrr(entity(ranch_group_member_1),
       entity(boma_1),right(ownership)).
...
```

We express domain knowledge as ASP rules e.g. one cannot "graze" a boma (in ASP, rules with no Head are constraints equivalent to "False :- Body", i.e. if the Body holds then there is no consistent interpretation):

```
:- la_rrr(entity(Id1),entity(Id2),
          (right(grazing) ; restriction(grazing))),
   mskDm(id(Id2), type(boma)).
```

If one owns *pasture* or *olopololi* then they have a right to graze:

```
la_rrr(entity(Id1), entity(Id2), right(grazing)) :-
```

```
mskDm(id(Id2), type(pasture ; olopololi)),
la_rrr(entity(Id1), entity(Id2), right(ownership)).
```

Conditional RRR in ASP. We introduce conditional RRR facts that ranch group members 1 and 2 may graze *ranch_pasture_1* during the *olari* (rainy) season:

```
la_conditional_rrr(
  entity(ranch_group_member_1 ; ranch_group_member_2),
  entity(ranch_pasture_1),
  right(grazing),condition(season(olari))).
```

We add a rule that, if there is a conditional RRR, and the condition holds, then indeed the RRR also holds:

```
la_rrr(Id1, Id2, RRR) :-
  la_conditional_rrr(Id1, Id2, RRR, condition(Value)),
  holds(Value).
```

We add an ASP choice rule of the form "{Head}:-Body" that expresses that, in general, any right and restriction could apply between any party and BAUnit:

```
{la_rrr(entity(Id1),entity(Id2)
       (right(R);restriction(R)))} :-
  la_entity(id(Id1), type(la_party)),
  la_entity(id(Id2), type(la_baunit)),
  la_rrr_type(R).
```

We can now use ASP to infer all possible consistent interpretations, i.e. all combinations of rights and restrictions that might apply in a way that is consistent with all rules. ASP finds 21,609 interpretations, e.g. in some interpretations *ranch_group_member_1* is restricted from grazing *ranch_pasture_1*:

```
la_rrr(entity(ranch_group_member_1),
       entity(ranch_pasture_1),restriction(grazing))
```

Given an interpretation, if a right and the corresponding restriction are *not* in the interpretation, then we say that we *do not know* whether that right or restriction holds. Suppose we add the fact that it is *olari* season:

```
holds(season(olari)).
```

ASP now finds 3,969 consistent alternative interpretations, and in all of those interpretations both ranch group members have the right to graze in *ranch_pasture_1*.

Preferred interpretations. We would like to prefer those interpretations that make a minimal number of assumptions – a right (and restriction) should not be asserted unless we know that it holds. We encode this in ASP by applying a "cost" to every RRR fact in an interpretation. Firstly, there is no cost if an RRR is absent from an interpretation (i.e. "`not la_rrr(…)`"):

```
cost(0, la_rrr(Id1, Id2, RRR)) :-
  la_entity(Id1, _), la_entity(Id2, _),
  la_rrr_type(R), RRR=(right(R) ; restriction(R)),
  not la_rrr(Id1, Id2, RRR).
```

There is cost 1 for every RRR that holds in an interpretation:

```
cost(1,la_rrr(Id1, Id2, RRR)) :- la_rrr(Id1, Id2, RRR).
```

ASP should minimise this cost:

```
#minimize{C, X : cost(C,X)}.
```

By asking ASP to minimise this cost, we are preferring those interpretations where ASP only infers RRR that can be deduced. ASP finds an optimal interpretation (within 0.01 seconds) that confirms the ranch group members' right to *graze* in *ranch_pasture_1*:

```
la_rrr(entity(ranch_group_member_1),
       entity(ranch_pasture_1),right(grazing))
la_rrr(entity(ranch_group_member_2),
       entity(ranch_pasture_1),right(grazing))
```

Suppose we retract the fact that it is *olari* season. The optimal interpretation now does not include the two above facts about grazing – importantly, it also *does not include* any facts about restrictions, and thus we *do not know* whether those rights or restrictions hold, without further information.

6. CONCLUSIONS AND DISCUSSION

We have presented an overview of our Maasai Southern Kenyan domain model (MSKDM), an integral component of a larger land tenure recording project, designed to capture concepts related to land use. For the model, an incremental, iterative development process, based on IDEF5, was employed. At the most general abstraction level, the model divides concepts into eight categories: activity, social unit, homestead component, source, material, shape, livestock, and environmental characteristic. The MSKDM was integrated with the prominent LADM through an adaptor, so that Maasai land use scenarios can be expressed within the LADM framework. In particular, the novel notion of *conditional RRR was introduced* into the LADM to capture the relationship that rights, restrictions and responsibilities are often conditional on changing climatic and vegetation characteristics. Sketchmaps, created by members of the Maasai community during two field studies in Kenya (2016, 2017), were used for a first-level model validation. Sketchmaps were selected as a low-cost tool, with high level of acceptance among the Maasai, in terms of use and usefulness, enhancing local community participation to land administration processes. We are currently planning a third visit to our study site in Kenya that will provide a further iteration of the domain model refinement and validation.

ACKNOWLEDGEMENTS

This research was partly funded by the EU Horizon 2020 programme, under the its4land project number 687828. We acknowledge the contribution of all project partners.

REFERENCES

Abanda, H., Ng'ombe, A., Tah, J.H., Keivani, R., 2011. An ontology-driven decision support system for land delivery in Zambia. Expert Systems with Applications, 38, pp. 10896-10905.

Abbink, G., Askew, K., Dori, D.F., Fratkin, E., Gabbert, E.C., Galaty, J., LaTosky, S., Lydall, J., Mahmoud, H.A., Markakis, J., 2014. Lands of the future: transforming pastoral lands and livelihoods in eastern Africa. Working paper 154, Max Planck Institute for Social Anthropology, Halle/Saale, Germany.

Antoniou, G., Van Harmelen, F., 2004. Web ontology language: Owl, Handbook on ontologies. Springer, pp. 67-92.

Bekure, S., 1991. Maasai herding: an analysis of the livestock production system of Maasai pastoralists in eastern Kajiado District, Kenya. International Livestock Centre for Africa, Addis Ababa, Ethiopia, pp. 3-154.

Benjamin, P.C., Menzel, C.P., Mayer, R.J., Fillion, F., Futrell, M.T., deWitte, P.S., Lingineni, M., 1994. Idef5 method report. Method Report, Knowledge Based Systems, Inc., University Drive East College Station, Texas, USA.

Bernard, H.R., 2017. Research methods in anthropology: Qualitative and quantitative approaches. Rowman & Littlefield, pp. 308-458.

Butt, B., 2011. Coping with uncertainty and variability: The influence of protected areas on pastoral herding strategies in East Africa. Human Ecology 39, pp. 289-307.

Butt, B., 2015. Herding by mobile phone: technology, social networks and the “transformation” of pastoral herding in East Africa. Human Ecology 43, pp. 1-14.

Davis, R.K., 1970. Some issues in the evolution, organization and operation of group ranches in Kenya. Discussion paper 93, Institute for Development Studies - University College, Nairobi, Kenya.

Galvin, K.A., Reid, R.S., Behnke, R., Hobbs, N.T., 2008. Fragmentation in semi-arid and arid landscapes. Consequences for Human and Natural Systems. Springer Netherlands, pp. 195-390.

Gómez-Pérez, A., Juristo, N., Pazos, J., 1995. Evaluation and assessment of knowledge sharing technology. In: Towards very large knowledge bases, pp. 289-296.

Grandin, B.E., 1987. Pastoral culture and range management: Recent lessons from Maasailand. In: ILCA Bulletin 28, pp 7-13.

Hanks, S., McDermott, D.V., 1986. Default Reasoning, Nonmonotonic Logics, and the Frame Problem. In: AAAI, pp. 328-333.

Hazzah, L., Dolrenry, S., Kaplan, D., Frank, L., 2013. The influence of park access during drought on attitudes toward wildlife and lion killing behaviour in Maasailand, Kenya. Environmental conservation 40(3), pp. 266-276.

Hespanha, J.P., Van Oosterom, P., Zevenbergen, J., Dias, G.P., 2006. A modular standard for the cadastral domain: Application to the Portuguese Cadastre. Computers, environment and urban systems 30(5), pp. 562-584.

Ho, S., Crompvoets, J., Broucker, B., Pattyn, V., 2017. Its4land Deliverable 2.5 Report: Requirements Synthesis. The its4land consortium, Enschede, The Netherlands.

Iván, G., Mihály, S., Szabó, G., Weninger, Z., 2004. Standards and new IT developments in Hungarian Cadastre. In: Proceedings of Joint “FIG Commission 7” and COST Action G9 Workshop on Standardization in the Cadastral Domain, Bamberg, Germany.

Jandreau, C., Berkes, F., 2016. Continuity and change within the social-ecological and political landscape of the Maasai Mara, Kenya. Pastoralism 6(1), pp. 1.

Knowles, J.N., 1993. Power, influence and the political process among Iloitai Maasai. Doctoral dissertation, Department of Anthropology, Durham University, Durham.

Knublauch, H., Fergerson, R.W., Noy, N.F., Musen, M.A., 2004. The Protégé OWL plugin: An open development environment for semantic web applications. In: International Semantic Web Conference, pp. 229-243.

Lamprey, R.H., Reid, R.S., 2004. Expansion of human settlement in Kenya's Maasai Mara: what future for pastoralism and wildlife? Journal of Biogeography 31(6), pp. 997-1032.

Lemmen, C., Augustinus, C., van Oosterom, P., van der Molen, P., 2007. The social tenure domain model: design of a first draft model. FIG Working week, Hong Kong SAR, China.

Lemmen, C., Oosterom, P., Uitermark, H., Thompson, R., Hespanha, J., 2009. Transforming the Land Administration Domain Model into an ISO standard (LADM as ISO 19152). FIG Working Week, Eilat, Israel.

Lemmen, C., Van Oosterom, P., 2006. FIG core cadastral domain model, Version 1.0, FIG net http://www.fig.net/resources/proceedings/fig_proceedings/fig2006/papers/ts12/ts12_02_lemmen_vanoosterom_0605.pdf

Lemmen, C., Zevenbergen, J., 2010. First experiences with a high-resolution imagery-based adjudication approach. In: Innovations in land rights recognition, administration, and governance, Annual conference on land policy and administration, pp. 96-104.

Lengoiboni, M., 2011. Pastoralists seasonal land rights in land administration. A study of Northern Kenya. Doctoral dissertation C.T. de Wit Graduate School for Production Ecology and Resource Conservation, Wageningen University, Netherlands.

Mwangi, E., 2005. The transformation of property rights in Kenya's Maasailand: Triggers and motivations. CAPRi Working Paper 3, CGIAR Systemwide Program on Collective Action and Property Rights, International Food Policy Research Institute, Washington, DC, USA.

Ngulube, P., Onyancha, O.B., 2011. What's in a name? Using informetric techniques to conceptualize the knowledge of traditional and indigenous communities. Indilinga African Journal of Indigenous Knowledge Systems 10(2), pp. 129-152.

Nyariki, D.M., W. Mwang’ombe, A., Thompson, D., 2009. Land-use change and livestock production challenges in an integrated system: the Masai-Mara ecosystem, Kenya. Journal of Human Ecology 26(3), pp. 163-173.

Poole, D., 1988. A logical framework for default reasoning. Artificial intelligence 36, pp. 27-47.

Reiter, R., 1980. A logic for default reasoning. Artificial intelligence 13, pp. 81-132.

Seno, S.K., Shaw, W., 2002. Land tenure policies, Maasai traditions, and wildlife conservation in Kenya. Society & Natural Resources 15(1), pp. 79-88.

Steudler, D., 2006. Swiss cadastral core data model - experiences of the last 15 years. Computers, environment and urban systems 30(5), pp. 600-613.

Wayumba, G., 2017. The challenge of sustaining pastoralism land tenure system for ecological conservation of the Maasai Mara. International Journal of Scientific Research and Engineering Studies 2(7), pp. 98 - 103.

World Bank, 2004. Indigenous knowledge: local pathways to global development - marking five years of the World Bank indigenous knowledge for development program (English). Indigenous Knowledge (IK) Notes 1 - 60, Washington, DC: World Bank Group. http://documents.worldbank.org/curated/en/981551468340249344/Indigenous-knowledge-local-pathways-to-global-development-marking-five-years-of-the-World-Bank-indigenous-knowledge-for-development-program.