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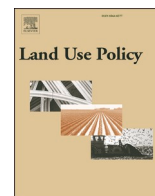
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Methodology for the development of LADM country profiles

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ABSTRACT

The growing recognition and influence of the ISO 19152:2012 Land Administration Domain Model (LADM), is revealed by the multiple country profiles that have been developed based on the standard in various jurisdictions across the world. The ongoing revision of the LADM Edition I, initiates discussions related to the development of country profiles, as well as considerations regarding their maintenance.

Till today, various approaches for creating LADM-based country profiles have been followed. This resulted in the creation of an interesting mosaic of country profiles' developing methods, with parts to be exploited and an outline of the basic steps of the development provided. Based on this knowledge, the aim of this paper is to design a methodology for the development of LADM country profiles, expected to become part of future version of the ISO 19152 LADM, the Edition II.

Collective experience from good practices in the development of profiles based on LADM Edition I reported in the literature have been reviewed and used as basis for a qualitative comparative analysis. For this purpose, a set of six characteristics/criteria was developed based on key publications selected through experts' consultation. The characteristics are generic and can be applied to all the country profiles, as well as they refer to the lifecycle of the development and implementation of a country profile, taking into account legal, institutional and technical issues. Characteristics regarding the scope of country profiles are also considered.

Given this context, the design of the methodology to develop LADM-based country profiles is presented, structured in three phases: scope definition, profile creation and profile testing.

1. Introduction

The research concerns the design of a methodology for the development of LADM country profiles, based on good practices. This methodology is expected to be included in the ISO 19152 Land Administration Domain Model (LADM) Edition II.

The LADM captures the semantics of the Land Administration (LA)

knowledge domain and provides a shared ontology that defines a common terminology for LA (Lemmen et al., 2019). ISO (2004) defines a profile as 'a set of one or more base standards or subsets of base standards, and, where applicable, the identification of chosen clauses, classes, options and parameters of those base standards, that are necessary for accomplishing a particular function.' A profile valid for a whole country is a 'country profile' (ISO, 2012). Such profiles require thinking about the future of

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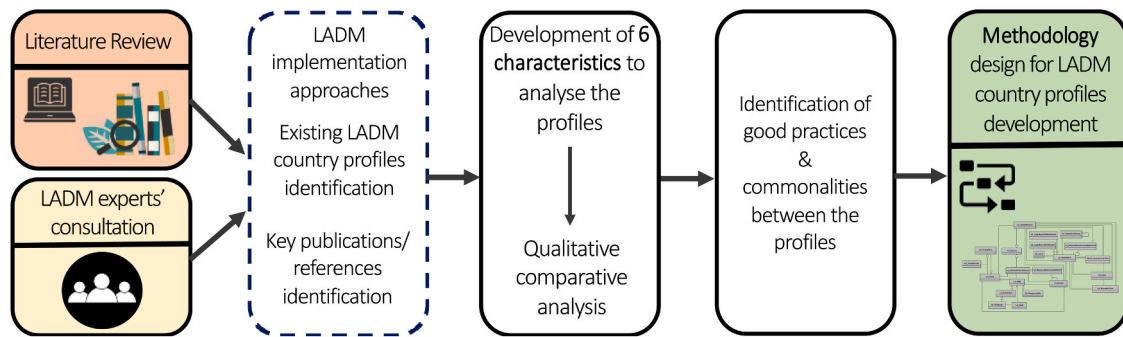


Fig. 1. Research-methodology followed in this paper.

LA, about its purpose, its new and innovative products and services, its integration with other domains and its benefits to society. International organisation, such as UN-Habitat, FAO, World Bank, etc. support and promote the use and implementation of LADM Edition I to worldwide LAS projects.

LADM country profiles integrate the legal and institutional context governing Rights, Restrictions and Responsibilities (RRRs) with the desired Land Administration Systems' (LASSs), advancements. A significant number of countries has developed LADM-based country profiles. Experiences from these developments are in the direction of integrated LA with vision for the future and can serve as good practices for the countries. As good practices a collection of methods, techniques or experiences that have produced results that can be recommended as a 'model' and deserved to be shared, so that it can be adopted, are considered (FAO, 2020b). Knowledge sharing and capitalization of good practices shall play a key role in the wider development and adoption of LADM. In this regard, nowadays, the ground seems mature to propose a standardized methodology for developing a generic country profile. It is noted that the specialisation of SDTM is out of the scope of this paper and its adoption and implementation around the world are not discussed in this publication.

The methodology of this research is presented in Section 2. Section 3 presents the findings of the literature review, an overview of LADM-based country profiles and the outcome of experts' consultation. Section 4 introduces the characteristics that will be used as key-criteria for the profiles' analysis and presents the quantitative comparative analysis. Section 5 provides an overview of good practices and identifies commonalities between profiles and lessons learnt based on the analysis from previous Section. The design of the methodology to develop LADM-based country profiles is presented in Section 6, while Section 7 is devoted to discussion and future work directions.

2. Research-methodology

The research methodology followed in this paper is schematically explained and visualised in Fig. 1. The first step includes research of relevant literature for the documentation on LADM country profiles, as well as the respective technical implementation approaches. The research records and evaluates the country profiles developed between 2012 (when Edition I was first published) and 2020, with the ongoing revision of LADM Edition II. The findings are comparatively presented in Section 3, Table 1. The analysis was complemented by consultation of experts and interviews organised with the Editors of Edition I and parties involved in country profiles development, reporting their knowledge and identifying key references. Key references combined with the documentation from the literature review, and results pointed by experts' consultation are then used for the development of the set of characteristics, which aims to identify good practices within the existing profiles.

Then those characteristics are used to perform a quantitative comparative analysis of the profiles. Analysing such qualitative data

entails scanning of the profiles, looking for similarities or substantial discrepancies in their development approach. The characteristics used to evaluate a representative subset of the country profiles and the outcomes of its analysis, are presented in Section 4, Table 2. The result is a set of good practices, which is further elaborated and presented in Section 5. Based on this the design of the methodology for LADM-based country profiles development follows.

3. Methodological background and research design

In the LADM Edition I, eight (8) country profiles are included: Portugal, Queensland (Australia), Indonesia, Japan, Hungary, The Netherlands, the Russian Federation and the Republic of Korea. Since then, the number of developed country profiles has increased (Kalogianni et al., 2019) and the LADM has become a significantly considered international standard.

Its flexibility and its potential to meet needs in LA, are indicated from the multiple country profiles (40) that have been reported, see Table 1. The capacity of LADM is further documented in many documents, such as the Fit-For-Purpose Guiding Principles (UN Habitat/GLTN/Kadaster, 2016), the OGC White Paper on Land Administration (OGC, 2019), etc.

INSPIRE Cadastral Parcels (INSPIRE, 2009) is LADM based but not included in this overview. Some of the profiles have been developed only at a conceptual level, while for others, implementation solutions have been proposed and realised. 2D and 3D modelling representations are included ranging from simple 2D land parcels to 3D air parcels. The profiles refer to formal and informal land tenure and land use rights.

Experts' consultation has facilitated the identification of several key references and publications in support to the design of a set of characteristics that are used in the profiles' analysis. Interviews were held with the Editors of LADM Edition I and with parties involved in the development of country profiles from Croatia, Montenegro, Greece, Czech Republic, Poland, Serbia, Saudi Arabia, Indonesia, and Scotland.

Publications presenting the actual country profiles' development and implementation are considered as key publications. This concerns the lessons learnt from the development of four country profiles (Janecka et al., 2018); the proposed steps followed for the development of three country profiles (Govedarica et al., 2018); the proposal of guidelines for the development of country profiles based on existing experience (Kalogianni et al., 2019); the proposed roadmap to adopt LADM in current Cadastral Information Systems – CISs (Kalantari et al., 2015); the approach proposed by Bydłosz (2015) to adopt LADM to reduce data redundancy and facilitate LA-related data exchange between countries; the methodology and tools for LADM implementation presented by Jenni et al. (2017) emphasizing stakeholders engagement and the development of the profile in Victoria, Australia, focusing on the spatial aspects (Kalantari and Kalogianni, 2018). Another key reference concerns the results from the 3rd Fig. 3D Cadastres Questionnaire with on the LADM adoption for 3D LA (Shnaidman et al., 2019).

Table 1
Overview of the LADM-based country profiles.

#	Country/ Jurisdiction	References	#	Country/ Jurisdiction	References
1	Bénin	Mekking et al. (2020)	21	Morocco	Adad et al. (2020)
2	Brazil	(Paixao et al. 2015; Dos Santos et al., 2013; Purificação et al., 2019)	22	Mozambique	Balas et al. (2017)
3	Cape Verde	Andrade et al. (2013)	23	Nigeria	(Abidoye et al., 2017; Babalolaa et al., 2015)
4	China	(Guo et al., 2011; Zhuo et al., 2015; Xu et al., 2019)	24	Nicaragua	FAO (2020a)
5	Colombia	(Jenni et al., 2017; Morales et al., 2019; FAO, 2020a)	25	Poland	(Gózdź et al., 2014; Bydłosz, 2015; Gózdź and Van Oosterom, 2016)
6	Croatia	(Vučić et al., 2017, 2013; Mader et al., 2018)	26	Portugal	ISO (2012)
7	Cyprus	Elia et al. (2013)	27	Queensland, Australia	(ISO, 2012; Karki, 2013)
8	Czech Republic	Janečka and Souček (2017, 2016)	28	Republic of Srpska	Govedarica et al. (2018)
9	Ethiopia	Kebede et al. (2018)	29	Russian Federation	(Elizarova et al., 2012; ISO, 2012)
10	Greece	(Psomadaki et al., 2016; Kalogianni et al., 2017)	30	Saudi Arabia	Alattas et al. (2020)
11	Honduras	Koers et al. (2013)	31	Scotland	Reid (2019)
12	Hungary	ISO (2012)	32	Serbia	(Radulović et al., 2019, 2017; Govedarica et al., 2018)
13	Indonesia	(ISO, 2012; Budisusanto et al., 2013; Indrajit et al., 2020)	33	Singapore	(Soon et al., 2016; Yan et al., 2019)
14	Israel	(Felus et al., 2014; Adi et al., 2018)	34	South Africa	(Tjia and Coetzee., 2013; Tjia, 2014)
15	Japan	ISO (2012)	35	South Korea	(Lee et al., 2015; Kim, Heo, 2017)
16	Kenya	(Kuria et al., 2016; Karamesouti et al., 2018)	36	The Netherlands	(ISO, 2012; Kara et al., 2019)
17	Korea	(ISO, 2012; Jeong et al., 2012; Kim et al., 2013; Lee et al., 2015)	37	Trinidad & Tobago	Griffith-Charles and Edwards (2014)
18	Malaysia	(Zulkifli et al., 2019, 2014; Rajabifard et al., 2018; Hanafi and Hassan, 2019)	38	Turkey	(Alkan and Polat, 2017; Kara et al., 2018a)
19	Mongolia	Buuveibaatar et al. (2018)	39	Victoria, Australia	(Aien et al., 2012; Kalantari and Kalogianni, 2018)
20	Montenegro	(Radulović et al., 2015; Govedarica et al., 2018)	40	Vietnam	(Le et al., 2012)

4. Comparative analysis of the LADM-based country profiles

Having collected and analysed the background information in the previous section, six generic characteristics of country profile development were identified:

- **Characteristic 1** – Profile scope (Section 4.1)
- **Characteristic 2** – Stakeholders involvement (4.2)
- **Characteristic 3** – Status existing LAS (4.3)
- **Characteristic 4** – Profile development stage (4.4)
- **Characteristic 5** – 3D LA (4.5)
- **Characteristic 6** – Future LADM scope (4.6)

These characteristics have been designed according to the findings from country studies (literature review), key references study and discussion of expert interviews and aim to indicate commonalities, differences, and thus distil good practices so far. The comparative (qualitative) analysis performed is based one of the six characteristics in each of the next six subsections. The lessons learnt provide the good practices of LADM development so far and go beyond them: aspects as validation of the developed profiles, training, and dissemination are covered. In Subsection 4.7 a table is presented with a representative sample of LADM-based country profiles analysed with respect to the six characteristics.

4.1. Profile scope

A country profile may describe the existing situation in the LA domain and adjust the current LAS into the LADM concepts or it may describe the vision/need for a future situation. From the performed analysis it is observed that country profiles describing current situation are developed on existing cadastral data models: Croatia (Vučić et al., 2013), Czech Republic (Janečka and Souček, 2017), Poland (Bydłosz, 2015), (Gózdź and van Oosterom, 2016), Serbia (Radulović et al., 2017), Montenegro (Radulović et al., 2015) and the Republic of Srpska (Govedarica et al., 2018).

When the profile describes a future state, it includes new functionality related to data not currently registered or currently registered by other authorities as tax offices, mapping agencies, municipalities, etc. Such a case is the profile developed for Greece (Kalogianni, 2016), which refers to a multipurpose LAS recording land and marine parcels, mines, archaeological sites, utility networks, etc.

The developed profiles can be categorised into two groups: those applying a holistic approach in modelling land information, e.g. The Netherlands and Poland and those where a specific application of land information is mapped, e.g. natural resources in China or the utility cadastre in Serbia.

4.2. Stakeholders involvement

The main involved stakeholders are academic institutions, government or LA/geodetic authorities and industry. Country profiles prepared by academia are mainly based on the conceptual schema of the LADM influenced by the good practices of profiles developed in jurisdictions with similar characteristics and relevant adjustments to their national needs. In Croatia, Czech Republic, Poland and Serbia the initial development of the country profile did not come from the national mapping agency, but from academia (Kalogianni et al., 2019).

Till today, a small number of country profiles has been developed by collaboration between the government and/or responsible organisations and academia, as in the case of Colombia (FAO, 2020a), the Czech Republic (Janečka and Souček, 2016), Korea (Lee et al., 2015) and Malaysia (Rajabifard et al., 2018). A profile completely led by a government authority is that of Scotland (Reid, 2019; Alastar, 2019). It is noted that detailed documentation of the data model is often not publicly available and therefore it is necessary that professionals within

depth knowledge of the LA domain are in the team of profile developers.

4.3. Status of existing LAS

Depending on the level of maturity of the existing LAS a different approach to adopt the LADM is followed. Kalantari et al. (2015) designed a roadmap consisting of six stages to adopt the LADM, see Fig. 2. LADM country profiles for countries with a well-developed LAS are mainly related to Stage 4 'Data Organisation', i.e., how the different data entities are linked to each other.

In the cases of Serbia, Montenegro and the Republic of Srpska in Bosnia and Herzegovina the main goal is to modernize the LAS and to overcome issues such as: existence of different institutions with overlapping responsibilities for land data; data storage in multiple places and in analogue form; use of a non-relational data model; discrepancy in records with the situation on the ground; separation of alphanumeric and geometric data; complex structures of the records as a result of inheriting data from different sources; poor performance of data search and updating and use of the concept of immovable property in software solutions as defined by the outdated law (Radulović et al. 2017).

It is important to note that all these issues impeded the operation of the LAS and the quality of data stored and therefore, such systems although they are considered established and operational, need to be entirely redesigned to overcome the deficiency problems inherited.

4.4. Profile development stage

The profile development stage relates to the modelling process being at only conceptual or already also at implementation level. The country profiles studied have several differences, not only in development stage, but also in the steps that have been followed towards their development.

For the countries with a well-established LAS, the physical data model of the existing cadastral database is usually the starting point for the development of the country profile. The conceptual cadastral data model is obtained by reverse engineering (Janečka and Souček, 2017) and based on it, the conceptual model of the profile is developed. For the vast majority of country profiles examined in Kalogianni et al. (2019) conceptual models in UML diagrams were created, where the three core packages were used with adaptation to local needs, while the 'Surveying and Representation' subpackage was used as presented in the ISO. Apart from the modelling of the core conceptual model, also other parts are modelled as extensions of some profiles, indicatively referring to additional land use components (Pržulj et al., 2017) and utilities (Radulović et al., 2019), as well as modelling dynamic processes in Serbia (Sladić et al., 2020) additionally to the static structure of the data model.

Following the development of the UML model of the country profile, its conformity with ISO 19152:2012 Edition I is tested, according to the conformance test in Annex A of ISO 19152:2012 (Kalogianni et al., 2019). The technical implementation of the model varies from prototypes and pilots, to full-scale production systems. The development approach followed for most of the profiles starts with the translation of the conceptual model into a technical, the data conversion and loading

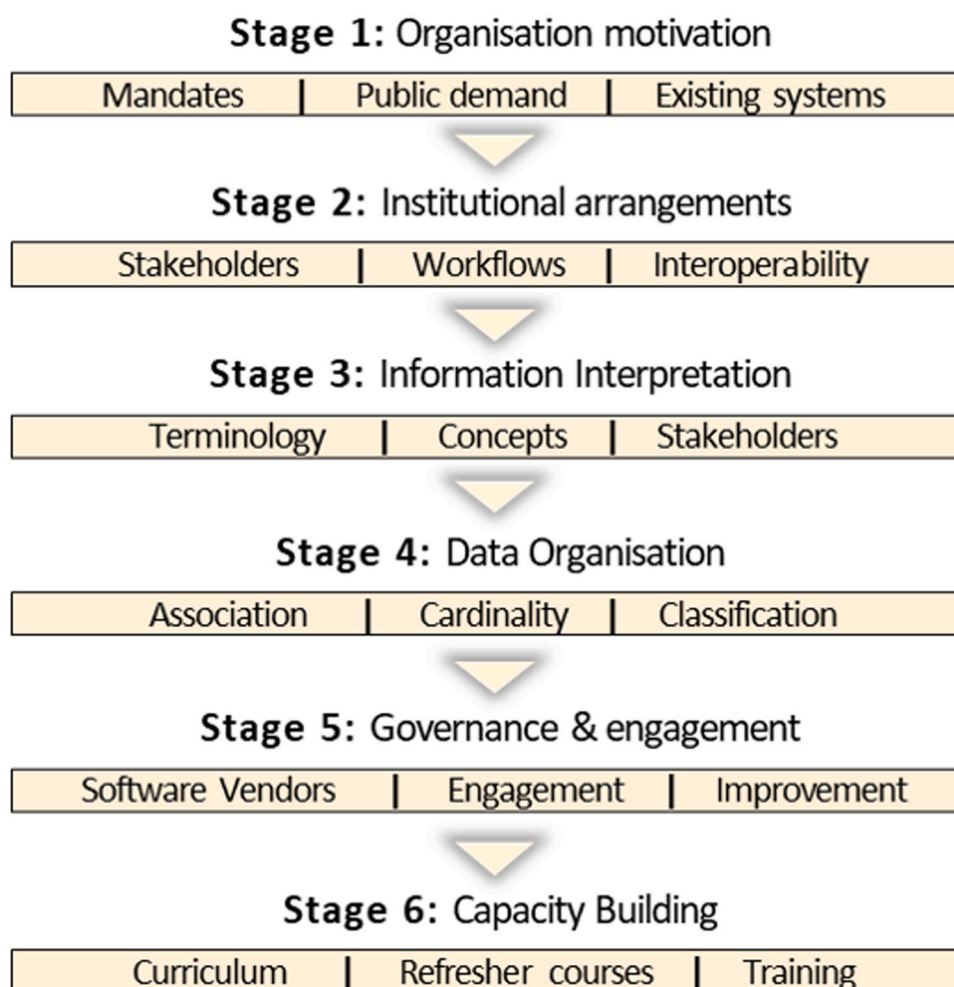


Fig. 2. A roadmap to adopt LADM in a LA organisation (Kalantari et al., 2015).

in a database is done, followed by application development, with the creation of a LADM-compliant database schema. During each stage of the implementation, new insights can be used to further improve the country profile. In addition, due to the growing awareness and involvement of stakeholders, the improvement of the conceptual model continues until a sufficient description of the represented reality is achieved, e.g. through an iterative work in inter-institutional modelling workshops (Jenni et al., 2017).

4.5. 3D land administration

This characteristic makes a distinction between 2D and 3D representations. It also configures the profile in relation to physical counterparts. LADM Edition I supports the registration of 3D spatial units and several LADM country profiles are in 3D: the Russian Federation (Elizárova et al., 2012), Poland (Gózdź et al., 2014), Malaysia (Zulkifli et al., 2014), Israel (Felus et al., 2014), Greece (Kalogianni, 2016), Trinidad and Tobago (Griffith-Charles and Edwards, 2014) and Turkey (Alkan and Polat, 2017). From the profiles studied, it is noticed that several countries consider 3D LA and often both 2D and 3D spatial representation options are used. Annex E of the current standard describes a 3D spatial profile with full 3D topology. The second edition of the LADM will support multiple 3D representations through various 3D spatial profiles and will provide implementation options supporting 3D.

4.6. Future LADM scope

The first step in developing a country profile is setting the scope, which also indicates which stakeholders are to be involved. However, it is important to realize the future scope may be different than the current LA scope. Different types of spatial units may be included, e.g. land parcels, apartments, utility networks, etc. For example, the country profile for Serbia is extended with classes covering the detailed structure of the utility network cadastre prescribed by the national law (Radulović et al., 2019). The utility network cadastre in Serbia is an integral part of the real estate cadastre and registration of rights and restrictions on utilities is the similar as on real properties.

For LADM Edition II an extended scope will be developed in order to include valuation information, spatial plan information and the representation of the marine space, see Lemmen et al. (2019). In some countries these registrations are traditionally close to the organisations involved in registration of land tenure. In other countries, more stakeholders need to be involved if these new domains are integrated in the country profile. For example, in Croatia, Flego (2018) extends the profile with a marine cadastre.

4.7. Comparative analysis

A subset of the country profiles, as presented in Table 2, is selected for further analysis with respect to the applicability of the six characteristics. Those country profiles have been chosen as some of the most complete and well-documented developments. They represent a variety of LAs and their developments involve various stakeholders. Table 2 reflects the flexibility and adaptability of LADM Edition I through its implementation in jurisdictions with a variety of land tenure norms, in different development stages and with different scopes. The characteristics are very well applicable.

Table 2

Comparative Analysis of the characteristics on a representative subset of country profiles.

LADM Country Profile	1: Scope Profile	2: Stakeholders	3: Status	4: Dev Stage	5: 3D LA	6: Scope LADM
Colombia	PCS	Ac & Gov	Est & Mod	UML & TI	2D	N/A
Croatia	CS & FS	Ac	Est	UML	2D & 3D	MC
Czech Republic	CS	Ac & Gov	Est	UML	2D	N/A
Malaysia	CS	Ac & Gov	Est	UML & TI	2D & 3D	N/A
Montenegro	CS	Ac & GA	Est	UML & TI	2D	N/A
Poland	CS & FS	Ac	Est	UML	2D & 3D	N/A
Republic of Srpska	CS	Ac & GA	Est	UML & TI	2D	Future UNC
Scotland	CS	GI	Est	UML & TI	2D & 3D	N/A
Serbia	CS	Ac & GA	Est	UML	2D	UNC

CS: Current Situation, FS: Future Situation, PCS: Post Conflict Situation, Ac: Academia, Gov: Government, GA: Geodetic Authority, Est: Established, Mod: Modernised, TI: Technical implementation, UML: UML model, MC: Marine Cadastre, UNC: Utility Network Cadastre, N/A: Not applicable

5. Good practices in country profile development

According to the literature review, the experts' consultation and the comparative analysis, the lessons learnt from the good practices in country profile development are related to:

1. Stakeholders' involvement
2. Conceptual modelling approach
3. Country profile validation
4. Country profile implementation
5. Training and dissemination of the profile

Each one of those aspects is elaborated in the subsections below.

5.1. Involving the stakeholders

Involving stakeholders in the process of the country profile design (starting with a future proof scope), development and implementation is crucial for the acceptance of the result. Academia can demonstrate the usefulness of the LADM in partnership with governmental organisations (Janečka et al., 2018). Lacking or insignificant participation of the LA authorities limits the practical use of the profiles. With regards to the countries with well-established LAs, the data model of the database is not always available to public and academia. Therefore, the experience of experts involved in LA is necessary. The stakeholders from various sectors (academia, government, responsible organizations) could work well together (Janečka et al., 2018), as for the country profiles of Croatia and the Czech Republic. Also, for profiles for specific domain, e.g. archaeology, natural resources, marine, public spaces etc, the participation of the domain experts is crucial.

As mentioned by Jenni et al. (2017), the implementation of the LADM in Colombia is particularly challenged by a complex institutional setting. Although it is broadly recognized that adopting the LADM in Colombia will enhance interoperability speeding up LA processes, the implementation will imply changes in the institutional setting creating resistance. By including the LA stakeholders in the modelling process and in developing a roadmap for implementation, this resistance can be reduced.

For the Croatia case, academia led the development of the profile, with researchers from the State Geodetic Authority (national cadastre) being involved. The country profiles for Serbia, Montenegro and the Republic of Srpska in Bosnia and Herzegovina were developed by academia supported by domain experts of authorities (Govedarica et al., 2018). Academia is engaged in the research and development of country profiles, in conformance testing and in the development of the technical implementation. The developed country profile of Montenegro is adopted officially by the Geodetic Authority and serves basis for implementation. In the Republic of Srpska, the LADM profile was delivered to the Geodetic Authority as part of the documentation for the development of a CIS.

In Poland the Technical Committee 297 on Geographic Information of the Committee for Standardisation has taken an interest in the future ISO 19152 development and implementation. Perspectives of such a participation are very encouraging.

5.2. Conceptual modelling

From this research it is concluded that there are three main approaches (with combinations) in the development of LADM country profiles. Those are:

1. using LADM classes, attributes, code lists and associations from the UML model of ISO 19152,
2. modelling an inherited structure between the LADM and the existing data model, see examples from the Czech Republic (Janečka and Souček, 2017) and Poland (Gózdź et al., 2014), (Gózdź and van Oosterom, 2016), and
3. mapping of elements between the LADM and the existing LA model, see the examples from Belize (Kalantari et al., 2015) and Poland (Bydłosz, 2015).

The last two approaches are probably used in countries with (at least partially) well-functioning LASs, as in Poland. Even if an inherited structure between the LADM and the existing data model can be demonstrated, there will be a need for inclusion of country specific classes, attributes, code lists or associations. Serbian followed the third approach, starting with the analysis of requirements from national legislation, followed by conceptual modelling in accordance with the current CIS and concluded with a compatibility test with LADM (Radulović et al., 2017). Similarly, the first version of the Croatian LADM profile was developed in 2012 by adding new classes, attributes, and types/ values in the code lists. New classes were introduced: 'HR_OldCadastralSurvey' and 'HR_LegalityOfTheBuilding' (Vučić et al. 2013). The first class is required for historical cadastral survey cases recorded in the cadastre, but not in the land book. The second is required because the cadastre is a key institution in checking the legality of buildings between 2007 and 2017.

As a next step, the LADM country profile can be extended with new classes which have no corresponding ones in the existing data model. For example, the legal spaces containing (planned) utilities that are not registered in the LADM class 'LA_LegalSpaceUtilityNetwork' can be considered for inclusion (Radulović et al., 2019). Or, in case legislation allows for registration of 3D spatial units, the inclusion of the class 'LA_BoundaryFace' can be considered (Janečka et al., 2018).

5.3. Country profile validation

Compliance testing and validation of the developed country profile is a crucial step towards its implementation. Most of the country profiles are tested with real-world use cases by creating UML-instance level diagrams for representative transactions, as presented in Annex C (ISO, 2012). In this way the conceptual model is tested in terms of suitability of classes, attributes, associations and multiplicities with respect to real-world needs.

Various country profiles went through the conformance test of Annex A of (ISO, 2012). Croatia, Czech Republic, Poland and Serbia meet the level 2 and even some classes in the Level (Janečka et al., 2018). In the case of Serbia, Montenegro and Republic of Srpska the conformance test was performed by academia. The Serbian country profile conforms level 2 and to four of the six classes there is level 3 conformance. Janečka and Souček (2017) argue that in order to meet conformance level 3, a country profile has to contain LADM classes like 'LA_BoundaryFace' modelling 3D spatial units: those concepts that do not exist in all the countries.

An important finding of this analysis is that it is not obvious which organisation is responsible for deciding on the certification of the compliance level. Validation means in some countries, official adoption as LADM country profile, sometimes translated into the native language, or LADM will be adopted as national standard. This is the case of the Czech Republic, where the LADM country profile (Janečka and Souček, 2017) is going to be published as the Czech technical standard by the Czech Office for Standards, Metrology and Testing (UNMZ). It means that the profile will be validated by the Technical Standardisation Committee for Geomatics/Geographic Information and certified by the URMZ. To get certified, the profile should also meet the requirements from the ISO 19106 (ISO, 2004).

Another example is Colombia, where the Ministry of ICT and the Colombian Spatial Data Infrastructure participated in the modelling processes in order to promote the defined country profile in their normative framework and national e-Government strategy (Jenni et al., 2017). The LADM has been described and translated to Spanish for the purpose of its application in the Colombian LADM profile (ICDE, 2018).

5.4. Country profile implementation

Usability and performance of the country profile is evaluated through its technical implementation. This can be summarised in two approaches:

1. **Database Implementation:** A database schema is derived from the conceptual model available in the Conceptual Schema Language. In this process, the conceptual model is checked and validated on completeness, correctness, duplicates, missing attributes. The conversion is based on transformation rules, resulting at a Data Definition Language (DDL) schema. This schema can be used to set up an SQL database (Hespanha et al., 2008). Most of the country profiles studied use UML to describe the conceptual model of the country profile (Alattas et al., 2018; Andrade et al., 2013; Budisusanto et al., 2013; Kalogianni, 2016; Kara et al., 2018; Kuria et al., 2016; Yan et al., 2019; Zulkifli et al., 2019, etc.). Other studies (Biljecki et al., 2018; Gózdź et al., 2014) use a Java-based tool, ShapeChange, which enables the conversion of the UML model to an XML or GML schema or to a XSD file in accordance with ISO 19109 (ISO, 2015b), ISO 19136 (ISO, 2007) and ISO 19118 (ISO, 2011). Those conversions require manual interference after the creation of the DDL/ XML schemas and during this stage various technical problems are reported, see Alattas et al. (2018) and Kara et al. (2018a).
2. **Data exchange format between systems:** this approach depends on the requirements of the application. Several tools are used for the conversion process from conceptual model to data exchange formats as XML, GML, GeoJSON, RDF, etc. Such tools are GDAL libraries,

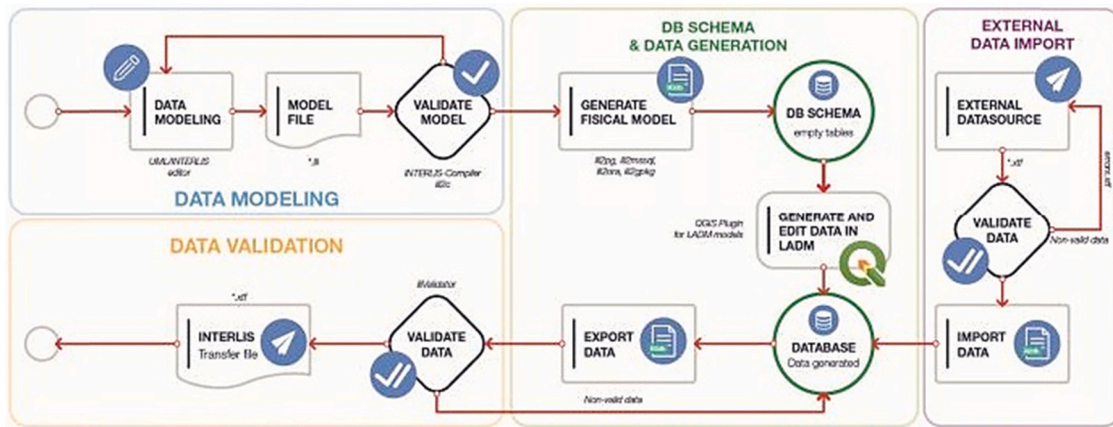


Fig. 3. Ecosystem of tools used in a typical workflow for implementing INTERLIS models (Baron et al., 2018).

HUMBOLDT Alignment Editor with open standards, INSPIRE data, Feature Manipulation Engine with validation (FME, 2020) and various databases. In this category, the Swiss standard INTERLIS (SN 612030) (INTERLIS, 2020), has been used in LADM implementation projects (Kalogianni et al., 2017; Kara et al., 2018b; Baron et al., 2018). It has some advantages over other modelling languages, such as the definition of the formal description of constraints using and comprehensive quality checks (Kalogianni et al., 2017; Germann et al., 2015).

In the case of Serbia, Montenegro and the Republic of Srpska, the development of the country profile was followed by the similar processes concerning the software solution for the CIS (Govedarica et al., 2018). The first implementation phase is the design of the cadastral database schema, its implementation and the data migration. The second phase is the development of desktop and web software solutions based on MDA principles and the implementation of web services based on the principles of Service Oriented Architecture to achieve interoperability.

In Colombia, the whole process from data collection to data registration and visualisation has been achieved in compliance with the LADM. The fully participatory data collection phase is organised by a ‘fit-for-purpose’ professional. For this purpose, a ‘Fit-for-purpose App’ has been developed, which together with a GPS antenna enables the storage of the coordinates and GPS accuracy for each vertex of the parcel. An ESRI’s data collector suite adapted to LADM is used. For the registration phase, an ecosystem of INTERLIS tools has been developed to support an information infrastructure, facilitating the implementation of any LADM country profile (Fig. 3).

Scotland is the first country in Western Europe with an known LADM implementation, which is currently operational (Reid, 2019), stimulating the development of corresponding software applications. The implementation solution uses DIA software for the creation of the UML model, which is exported to SpatialLite (for portability) and PostgreSQL and visualised using Python. For the ontology development Tawny-OWL

is used. Initial conceptual modelling is undertaken directly in Protégé software and Attempto Controlled English (ACE), while also python RDFLib is used.

5.5. Training and dissemination

A step towards LADM developments relates to education and awareness raising. This is an on-going activity occurring at various moments. Involved stakeholders should have literacy with respect to the modelling language and the context of the standard. A normative ISO standard document is not ‘the ideal textbook’, despite the attempts made in the annexes to further explain the normative part of the LADM.

When the UML diagrams were introduced in Polish cadastral regulations in 2013, it caused concerns amongst renowned experts in LA. For them, the technical and computer science-based descriptions of cadastral issues were very difficult to comprehend. Nowadays, even though more of the stakeholders are familiar with UML, there are still concerns.

In many countries, different training approaches are organized on the basics of the LADM before the development of the country profile commenced. Kalantari and Kalogianni (2018) argue that in the long term, it is needed to introduce the LADM in relevant tertiary education systems together with refresher courses for the stakeholders. In this regard, Jenni et al. (2017) proposed to develop courses on ISO 19152, directed to all professionals involved in the new Multipurpose Cadastre in Colombia. In the context of the Erasmus+ project, a Massive Open Online Course ‘Geonatura’ was developed including LA principles and trends, where the ISO 19152 holds a central role.

Janečka et al. (2018) explored how the developed LADM-based country profiles have been promoted to the wider public, i.e. via scientific journals and international conferences, as well as specialised national or regional events. An important aspect towards LADM adoption and dissemination is its translation to other languages. Besides the official ISO languages (English and French) the LADM is already translated into Spanish, Czech, Chinese, Korean, and Russian. Lastly, the LADM Wiki (<http://isoladm.org/>) contains complementary materials,

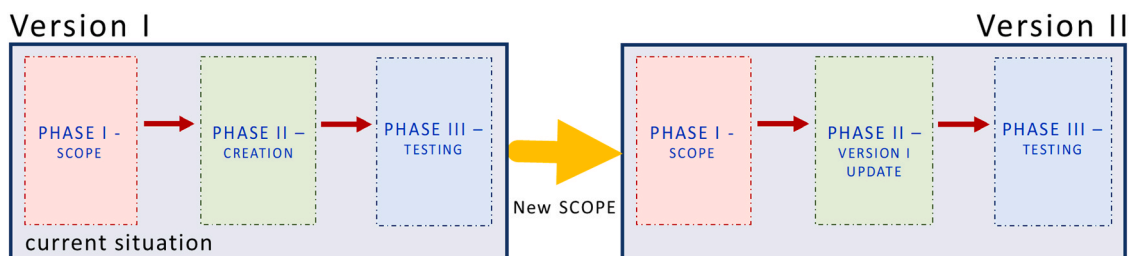


Fig. 4. Versioning of an LADM-based country profile.

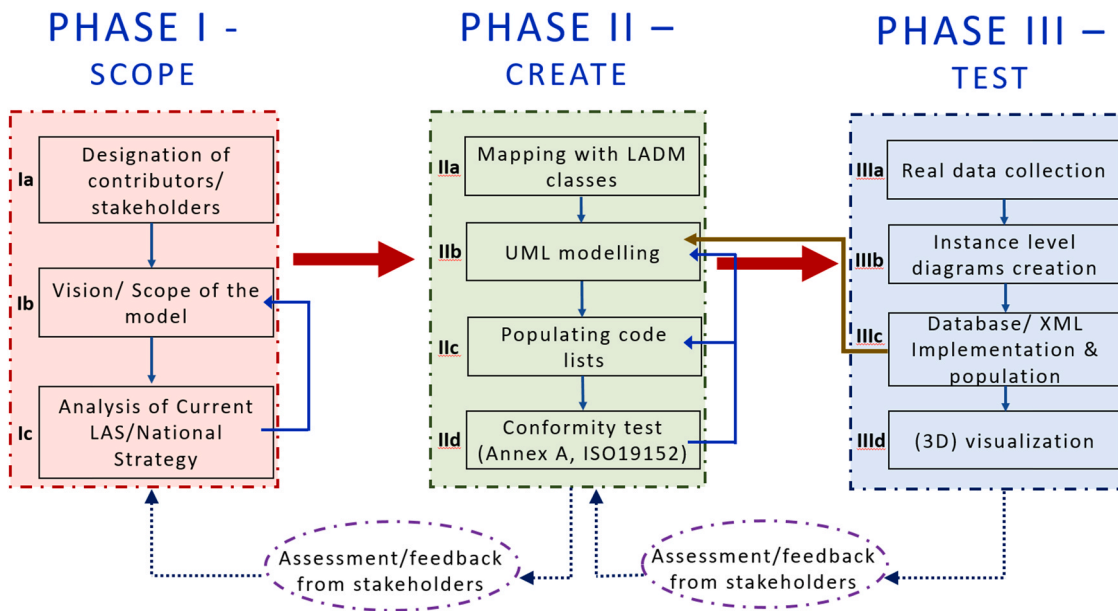


Fig. 5. Phases of the LADM-based country profile development.

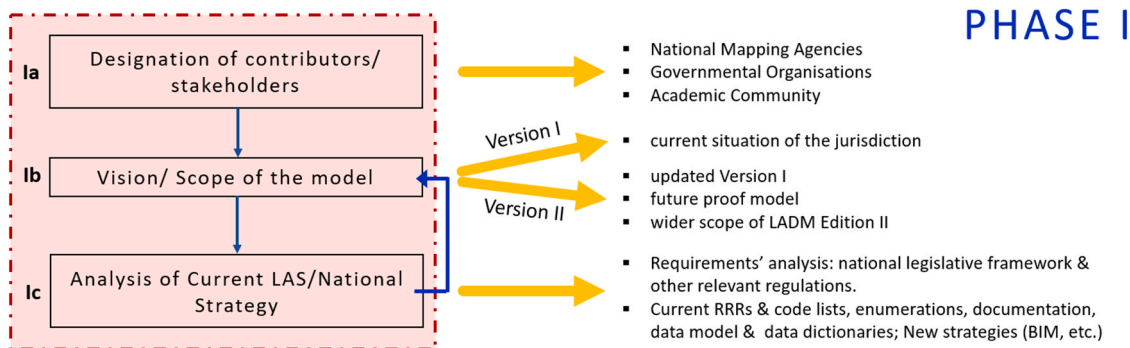


Fig. 6. Phase I - Scope definition from the proposed methodological framework.

such as UML models, country profiles examples, LADM publications, education materials, implementation materials and information on the maintenance of the standard.

6. Proposed methodology for LADM country profile development

The methodology for developing a LADM country profile is based on the above research and builds on the existing technical knowledge and experience with LADM implementation, considering both technical (principles of data modelling, UML notation, etc.) and non-technical aspects (good knowledge of the domain, the related processes, institutional and legal aspects, etc.). The proposed methodology distils the good practices from the design of existing profiles and experience so far, and is structured in three phases, as depicted in Fig. 4:

- Phase I – Scope definition
- Phase II – Profile creation (modelling)
- Phase III – Profile testing (implementation)

The three-phase process usually in iterations, as the implementation of the profile (Phase III) tests the profiles functionality and efficiency, and this may lead to further iterations through Phase I or Phase II. It should be noted that this methodology applies to both Edition’s I and II of the LADM.

At this point, it is important to mention the versioning aspect of the country profiles. Some country profiles have been developed at the early stages of LADM development (2012–2013), some were also included in Annex D of ISO 19152 and then, a new version was developed (e.g. Israel, Indonesia, etc.) improving and enriching the initial version. The versioning of the profiles will be in the methodology.

Fig. 4 visualises the methodology to be followed within the various versions of the models. Specifically, the initial LADM-based country profile – Version I – is expected to capture the LADM terminology and the operational LA system. This could be considered as reverse engineering to create starting point for, when needed, the model update to Version II. The second version will enrich the content of the first. It is expected that the initial model needs to be updated by adding and/or removing elements and concepts and maybe it will have a new, wider or more narrow scope resulting in a second version of the model. The process to be followed is the same (Fig. 4), however at Phase II the existing UML model will be used as basis.

Fig. 5 zooms in to the three phases of the methodology and the interrelation and iteration between them that need to be followed in the development of any version of the profile.

In the following three sections, the context and the steps to be followed in the phases is described.

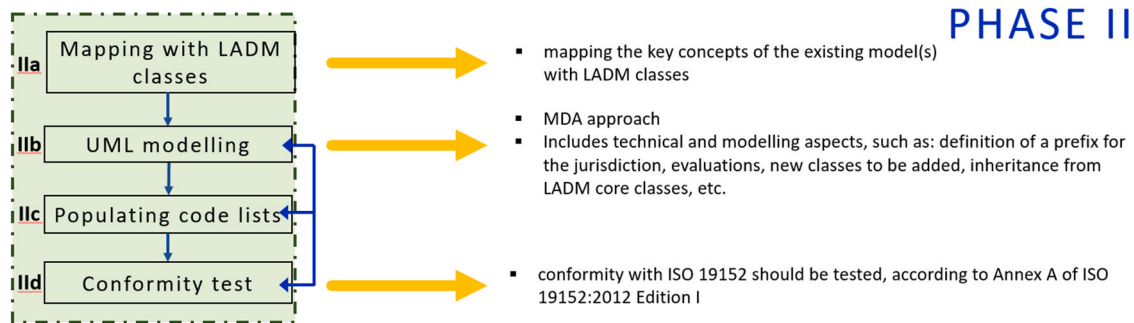


Fig. 7. Phase II - Creation of the country profile.

6.1. Phase I - scope definition

In the first phase of the development process, the scope definition is one of the decisions that needs to be made. The scope, thus, whether the model will describe the existing situation and/or a future situation, determines who should be involved in the development. The identification of the stakeholders (Fig. 6 Ia) and the definition of the scope (Fig. 6 Ib) are a bit of a 'chicken-and-egg problem'. Therefore, after starting with an initial team of 'most obvious stakeholders' the design process remains open for new stakeholders possibly combined with widening of the scope. Common practice, till today, has shown that the profiles have been developed by members of academia, LA authorities responsible for the cadastral system development and/or governmental organisation.

The fundamentals for developing the LADM country profile depend on the status of the LAS and its description. UML models of the existing LAS facilitate the development of the profile, as the classes representing spatial units as well as associations between them, have already been defined. It is possible to focus directly on mapping or generalizing classes from the LADM and identifying the most important associations. Then simplification of the existing diagrams may take place. If UML schemas or diagrams do not exist or if they are not accessible, the development of the profile has to start from scratch, usually founded on documentation or definition of the LAS provided from various legal regulations. Reverse engineering based on the physical data model is an alternative.

For a jurisdiction where a LAS/CIS exists, one of the first steps is the analysis of the requirements defined in the national legislative framework and other relevant regulations (Fig. 6 Ic). Rights, Restrictions and Responsibilities (RRRs) are to be derived from the legislative framework. For those with a (well-) functioning LAS, its documentation, data model and data dictionaries should be studied and analysed for code lists developments.

Specifically, for the latest case that a jurisdiction may wish to include concepts and elements that are not currently included at its CIS, such as archaeological or other protected sites, utilities, spatial plan information, marine space, air-parcels, etc., the LADM Edition II will provide separate packages that allow inclusion of such information.

6.2. Phase II - creation of the profile

Having analysed the existing situation, legislation, data model and the vision/scope of the country profile, the modelling process begins by mapping the key concepts of the existing model(s) with LADM classes (Fig. 7 Ia). Experience shows that this modelling is not always one-to-one relationship and that it can be a difficult task. It may be the case that more than one classes/concepts of current cadastral model corresponds to a LADM class and vice versa, or that there is no existing class that can be mapped with LADM concepts. This step is considered to be the most important, as it is the basis for conceptual modelling. An important decision is related to language and selection of terminology:

will the UML model (Fig. 7 I Ib) with its class names, attribute and association names be in English or be translated to the national language (s). Then via the mapping of concepts, the meaning should become clear also to outsiders.

Appointing a modelling working group based on an interinstitutional agreement is helpful in streamlining the efforts and in getting results in less iteration rounds. The process of modelling a LADM country profile should begin with establishing a common set of initial definitions and agreements on the modelling approach. During the modelling workshops, the key players must be the domain specialists of the involved institutions, guided by experts with experiences in the implementation of the LADM. It is recommended that the development of a country profile is carried out individually with each institution, focusing in a first instance on Cadastre and Registry and identifying the semantics in the national context (Jenni et al., 2017). The created profile can be then extended with new classes which have no equivalent in LADM. These classes enable to capture all the semantics and requirements from legislation of a particular country.

The conceptual modelling to capture concepts in the LAS is the next step. It is important to note that the more LADM classes are being used, the less complex the profile will be. One of the LADM objectives is to provide generic classes that may serve the purposes of various LASs across the world. At a next stage it can be considered to further categorise the purposes of the different LASs (deeds, titles, strata titles, etc.) and provide a more detailed matching with LADM classes. The modelling includes attention to aspects as: definition of a prefix for the jurisdiction, code lists and evaluations that will be used, new classes to be added, inheritance from LADM classes, etc. The conceptual modelling should be performed in UML using tools that support the MDA-based approach, such as the Enterprise Architect (EA), INTERLIS tools, Visual Paradigm, DIA, etc.

During the conceptual modelling, the activities to be undertaken are:

1. introduce inheritance from LADM core classes into the relevant country-specific classes using a prefix denoting the country, based on ISO 3166 (Country Codes),
2. provide explicit schema mapping between the country profile and LADM classes in case inheritance is not used,
3. create new classes serving the specific needs that are not supported in the LADM,
4. add new attributes to address the national needs and requirements,
5. introduce new associations based on specific country's needs,
6. adjust multiplicities according to if needed and define relevant constraints to be imposed,
7. add new values to existing code lists, and new code lists if required from new attributes (Fig. 7 I Ic),
8. introduce external classes to link the model with the current external registries,
9. test conformity (Fig. 7 I Id) of the conceptual model based on the criteria in ISO 19152 Annex A.

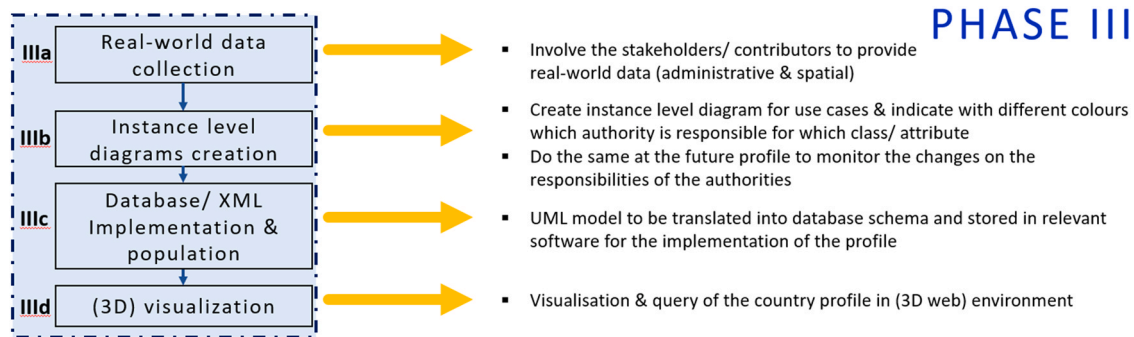


Fig. 8. Phase III - Testing of the country profile.

6.3. Phase III - testing the profile

This is an iterative process and when needed the country profile is adjusted and improved. After an initial prototype, the next iteration could be a (operational) pilot for a limited area/ duration, this can be in parallel processing with the old operational system, in case the new (pilot) system has flaws. After a successful pilot, the developed system is ready for full operation.

The conceptual model of the country profile in UML will then be translated into the corresponding database schema and managed in a relevant software environment allowing its implementation of using technical encodings. Through this process, the correspondence of classes, data types, multiplicities and associations from the conceptual model to the technical model is defined. Depending on the method used to derive the technical model, transformation rules, parameters and mapping entries should be defined, as well as the encoding rules applied for creating a target schema.

Conversion of the conceptual model to a technical model (database schemas, exchange formats, GUIs) can be partly automatic, but usually manual steps are needed. This is due to the difference between the expression power of UML class diagrams and the schema language of the implementation. Further, technical and performance related challenges need to be addressed, one should take care of implementing primary keys, foreign keys, association multiplicity, attributes multiplicity, data types, spatial data types, indexes, spatial indexes, constraints, and inheritance (Zulkifli et al., 2014; Alattas et al., 2018). Then, in cooperation with involved stakeholders, sample data will be prepared (created or converted from existing real-world data, Fig. 8 IIIa + 8 IIIb) and loaded (Fig. 8 IIIc) to test the access, use, update of data via prototypes (Fig. 8 IIId).

7. Conclusions and discussion

This paper provides generic guidelines and methodologies, by proposing a three-phase approach, to set a framework for LADM-based country profile development and implementation. The framework builds on the results of a quantitative comparative analysis that is conducted based on a set of characteristics that has been developed. The paper analyses and reviews approaches, and experience gained from existing country profiles, involves experts through consultation interviews and distils good practices.

General conclusions are:

1. The flexibility and adaptability of the LADM have proved to meet LA needs worldwide.
2. The development of the profiles has been primarily led by academia; only a limited number of profiles is developed by LA authorities in synergy with the academia.
3. Depending on the scope of a country profile, different spatial profiles have been developed.

4. In a majority of countries examined, the LADM is used for the establishment of a common understanding between professionals and organisations, as a foundation for the development of vocabularies, the interpretation of existing legislation and the development of modern and harmonised systems.
5. The LADM has been adopted by jurisdictions with a variety of land tenure systems and is used to register and record both formal and informal rights.
6. The profiles are mostly mature at a conceptual level. Technical implementations appear in the last years, and the concept of the LADM has gained ground.
7. Both 2D and 3D implementations based on LADM have been developed.

Some representative LADM-country profiles that are very accessible, facilitate the development of new profiles and provide more in-depth technical insight to LADM implementations. For instance, the application schema of the Polish cadastral system in UML that was used for creating the Polish LADM-based profile is accessible in legal regulations (pdf), as well as in downloadable *.eap, file, while the Malaysian profile is available through the LADM wiki page.

The proposed three-phase iterative approach for the developing of LADM-based country profiles, includes scope definition, profile creation (modelling phase), profile testing and validation (implementation phase). A responsible authority/organisation to perform the conformance test and validation does not exist. It should be agreed whether this will happen at national (Ministry or National Standardisation Authority) or international level (ISO, FIG or another organisation), or in both.

In this context and as LADM Edition II goes beyond a conceptual model, comprising of a part (Part 6 of LADM Edition II) devoted to implementation, attention shall be paid to LADM compliant software solutions. The proposed methodology in paper will be forwarded for inclusion in Part 6 of LADM Edition II. Various technical models are revised to support better interoperability with LADM, while 'LADM compliant solutions' appear from the industry. Indicatively, referring to the latest advances in ESRI's data collector app, in compliance with ISO 19152, 'Giselle- Turn – key LA suite' developed by Sinergise (2020) a LA solution that integrates with any existing tax system for validation and exchange of information, based on LADM and STDm. The growing interest from the industry to provide LADM-compliant solutions is expected to emerge in the coming years, also due to the upcoming revision of the model. Thus, it is crucial to set criteria and rules to vendor providers, a norm to become LADM compliant. In this respect, it shall be considered whether it is possible that the respective authorities may provide a certification of 'LADM compliance', also for the implementation phase.

Another aspect to be discussed is the way in which the LADM-based country profiles, and their versions that will evolve over time, will be handled by interested parties, including LA authorities/ organisations, academia and industry.

CRediT authorship contribution statement

Conceptualization, E.K. and K.J.; Methodology, E.K., C.L., E.D., M.K. and P.v.O.; Investigation, E.K. and C.L.; Writing - original draft preparation, E.K. and K.J.; Writing - review & editing, M.K., E.D., J.B., A.R., N. V., D.S., M.G., C.L. and P.v.O.; Supervision, E.D., C.L. and P.v.O. All authors have read and agreed to the published version of the manuscript.

References

- Abdoye, A., Oyetayo, B., Alia, A., Tan, C., 2017. Land administration domain model in review towards the adoption as a reference model for land administration system in Nigeria. *Am. J. Geogr. Inf. Syst.* 6 (5), 178–186.
- Adad, M.A., Semaili, E.H., El-Ayachi, M., Ibannaina, F., 2020. Supporting land data integration and standardization through the LADM standard: case of Morocco's country profile MA-LADM. *Land Use Policy* 97 (September), 104762.
- Adi, R., Shnaidman, A., Barazani, S., 2018. Implementation of the 3D Cadastre in Israel, in: 6th FIG Land Administration Domain Model Workshop, 2–8 October 2018, Delft, The Netherlands.
- Aien, A., Kalantari, M., Rajabifard, A., Williamson, I., Shojaei, D., 2012. Developing and testing a 3D cadastral data model: a case study in Australia, ISPRS Annals of the Photogrammetry, R.S.A.S.I S., ed. XXII ISPRS Congress, 2012 Melbourne, Australia.
- Alastar, R., 2019. A new register for Scotland. Available online: <https://geonconnexion.com/publication-articles/a-new-register-for-scotland> (Accessed on: 20 May, 2020).
- Alattas, A., van Oosterom, P.J.M., Zlatanova S., 2018. Deriving the technical model for the indoor navigation prototype based on the integration of IndoorGML and LADM conceptual model, in: 7th International FIG Workshop on the Land Administration Domain Model, Zagreb, Croatia, pp. 245–267.
- Alattas, A., van Oosterom, P.J.M., Zlatanova, S., 2020. 2D country profile for the Kingdom Saudi Arabia based on LADM, in: FIG Working Week 2020.
- Alkan, M., Polat, Z.A., 2017. Design and development of LADM-based infrastructure for Turkey. *Surv. Rev.* 49 (356), 370–385.
- Andrade, A.J.B., Carneiro, A.F.T., dos Santos, J.C., 2013. LADM specification of a relational database for the Republic of Cape Verde, in: 5th FIG Land Administration Domain Model Workshop, 24–25 September 2013, Kuala Lumpur, Malaysia.
- Babalolaa, S. O., Rahman, A.A., Choona, L.T., van Oosterom, P.J.M., 2015. Possibilities of Land Administration Domain Model (LADM) implementation in Nigeria, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, volume II-2/W2, 2015.
- Balas, M., Murta, J., Matlava, L., Marques, M.R., Joaquim, S.P., Carrilho, J., Lemmen, C., 2017. A fit-for-purpose Land Cadastre in Mozambique, in: 2017 World Bank Conference on Land and Poverty, The World Bank - Washington DC, March 20–24, 2017.
- Baron, L., Mejía, F., Jenni, L., 2018. Legal Independence, Modularity and Implementation of LADM using INTERLIS – Case Study of the Colombian ISO 19152 Profile, in: 7th International FIG Workshop on the Land Administration Domain Model, 11–13 April 2018, Zagreb, Croatia.
- Biljecki, F., Kumar, K., Nagel, C., 2018. CityGML application domain extension (ADE): overview of developments. *Open Geospat. Data Softw. Stand.* 3, 13.
- Budisusanto, Y., Aditya, T., Muryanto, R., 2013. LADM implementation prototype of 3D cadastre information system for multi-level apartment in Indonesia, in: 5th FIG Land Administration Domain Model Workshop, 24–25 September 2013, Kuala Lumpur, Malaysia.
- Buuveibaatar, M., Kim, M., Lee, Y., Junehan, K., 2018. A study on the design of LADM-based cadastral data model for Mongolia. *J. Cadastre Land Inf.* 48 (No.2), 2018.
- Bydłosz, J., 2015. The application of the Land Administration Domain Model in building a country profile for the Polish cadastre. *Land Use Policy* 49, 598–605.
- Dos Santos, J.C., Carneiro, F.T.A., Andrade, J.B.A., 2013. Analysis of the application of LADM in Brazilian Urban Cadastre: a case study for the City of Arapiraca, Brazil, in: 5th FIG Land Administration Domain Model Workshop, 24–25 September 2013, Kuala Lumpur, Malaysia.
- Elia, E., A., Zevenbergen A., J., Lemmen, C.J., H., van Oosterom, P.J.M., 2013. Towards common basis for 3D Cadastres from legal perspective. *Surv. Rev.* 45, 410–418.
- Elizarova, G., Sapelnikov, S., Vandysheva, N., Pakhomov, S., van Oosterom, P.J.M., de Vries, M., Stoter, J., Ploeger, H., Spiering, B., Wouters, R., Hoogeveen, A., Penkov, V., 2012. Russian-Dutch project "3D cadastre modelling in Russia", in: 3rd International Workshop 3D Cadastres: Developments and Practices, Shenzhen, pp. 87–102.
- FAO, 2020a. The multipurpose cadaster will become a reality with the financial support of the World Bank and the Inter-American Development Bank. Available online: (<http://www.fao.org/in-action/herramienta-administracion-tierras/news/detail-event/s/en/c/1269999/>) (Accessed on 28 June 2020).
- FAO, 2020b. FAO capacity development. Available online: <http://www.fao.org/capacity-development/resources/good-practices/en/> (Accessed on: 6 February 2021).
- Felus, Y., Barzani, S., Caine, A., Blumkine, N., van Oosterom, P.J.M., 2014. Steps towards 3D Cadastre and ISO 19152 (LADM) in Israel, in: Proceedings of the 4th International Workshop on 3D Cadastres, 9–11 November 2014, Dubai, United Arab Emirates. ISBN 978-87-92853-28-8.
- Flego, V., 2018. Model of Integrated Marine and Land Administration as a Basis for Interoperability of Registers (Ph.D. Thesis). University of Zagreb, Faculty of Geodesy, Zagreb, Hrvatska.
- FME Software, 2020. Safe Software Inc. Available online: (www.safe.com). (Accessed on: 2 May 2020).
- Germann, M., Kaufmann, J., Steudler, D., Lemmen, C., Van Oosterom, P., De Zeeuw, K., 2015. The LADM based on INTERLIS, in: The FIG Working Week 2015 - From the Wisdom of the Ages to the Challenges of the Modern World, Sofia, Bulgaria, 17–21 May 2015.
- Govedarica, M., Radulović, A., Sladić, D., Popović, D., 2018. LADM – experiences and challenges in implementation, in: The 7th Land Administration Domain Model Workshop, Zagreb, Croatia.
- Gózdź, K., Pachelski, W., van Oosterom, P.J.M., Coors, V., 2014. The possibilities of using CityGML for 3D representation of buildings in the cadastre, in: the 4th International Fig. 3D Cadastre Workshop, 9–11 November 2014, Dubai, United Arab Emirates.
- Gózdź, K.J., van Oosterom, P.J.M., 2016. Developing the information infrastructure based on LADM - the case of Poland. *Survey Review*, 48. Maney Publishing, pp. 168–180 (348).
- Griffith-Charles, Ch., Edwards, E., 2014. Proposal for taking the current cadastre to a 3D, LADM based cadastre in Trinidad and Tobago, in: Proceedings of the 4th International Workshop on 3D Cadastres, 9–11 November 2014, Dubai, United Arab Emirates. ISBN 978-87-92853-28-8.
- Guo, R., Ying, S., Li, L., Luo, P., van Oosterom, P.J.M., 2011. A multi-jurisdiction case study of 3D cadastre in Shenzhen, China, in: 2nd International Workshop on 3D Cadastres 16–18 November 2011, Delft, the Netherlands.
- Hanafi, F.M., Hassan, M.I., 2019. The integration of 3D spatial and non – spatial component for strata management. *The International Archives of the Photogrammetry, Remote Sensing and Spatial. Inf. Sci.* XLII-4/W16, 2019.
- Hespanha, J., van Bennekom-Minnema, J., van Oosterom, P., Lemmen, C., 2008. The model driven architecture approach applied to the land administration domain model version 1.1 - with focus on constraints specified in the object constraint language, in Proceedings of the Integrating Generations, FIG Working Week, Stockholm, Sweden, 14–19 June 2008.
- ICDE, 2018. Guía de elaboración de modelos extendidos del estándar ISO 19152:2012 y del perfil colombiano LADM-COL, Infraestructura Colombiana de Datos Espaciales. Available online: <http://www.icde.org.co/sites/default/files/GuiaElaboracionModelosExtendidos.pdf#page=10&zoom=100,58,1> 97 (Accessed on 17 June 2020).
- Indrajit, A., Eresta Jaya, V., Van Loenen, B., Lemmen, C.H.J., Van Oosterom, P.J.M.; Ploeger, H., Theodore, R., 2020. The role of land administration domain model and spatial data infrastructure in improving ease of doing business in Indonesia, in: Annual World Bank Conference on Land and Poverty 2020.
- INSPIRE, 2009. D2.8.I.6 INSPIRE Data Specification on Cadastral Parcels – Guidelines. 2009-09-07.
- INTERLIS, 2020. INTERLIS The Geolanguage. Available online: (<https://www.interlis.ch/en>). (Accessed on: 5 April 2020).
- ISO. ISO 19106:2004, 2004. Geographic information — Profiles, International Organisation for Standardisation: Geneva, Switzerland, 2012.
- ISO. ISO 19109:2015, 2015b. Geographic information – Rules for application schema, Geneva: Standard, International Organization for Standardization; 2015.
- ISO. ISO 19118:2011, 2011. Geographic information – Encoding, Geneva: Standard, International Organization for Standardization; 2011.
- ISO. ISO 19136:2007, 2007. Geographic information – Geography Markup Language (GML), Geneva: Standard, International Organization for Standardization; 2007.
- ISO. ISO 19152:2012, 2012. Geographic Information–Land Administration Domain Model (LADM), International Organisation for Standardisation: Geneva, Switzerland, 2012.
- Janečka, K., Souček, P., 2016. Country profile for the cadastre of the Czech Republic based on LADM, in: The 5th International Fig. 3D Cadastre Workshop 2016, Athens, Greece, 18–20 October 2016.
- Janečka, K., Souček, P., 2017. A country profile of the Czech Republic based on an LADM for the development of a 3D Cadastre. *ISPRS Int. J. Geo Inf.* 6 (5), 143. <https://doi.org/10.3390/ijgi6050143>.
- Janečka, K., Bydłosz, J., Radulović, A., Vučić, N., Sladić, D., Govedarica, M., 2018. Lessons learned from the creation of the LADM based country profiles, in: The 7th Land Administration Domain Model Workshop, Zagreb, Croatia.
- Jenni, L., López, A., G., Ziegler, S., Pérez, V., M., B., 2017. Development and employment of an LADM implementing toolkit in Colombia, in: 2017 World Bank Conference on Land and Poverty, The World Bank - Washington DC.
- Jeong, D.H., Jang, B.B., Lee, J.Y., Hong, S.I., van Oosterom, P.J.M., de Zeeuw, K., Stoter, J., Lemmen, C., Zevenbergen, J., 2012. Initial Design of an LADM-based 3D Cadastre: Case study from Korea, in: 3rd International Workshop on 3D Cadastres: Developments and Practices 25–26 October 2012, Shenzhen, China.
- Kalantari, M., Kalogianni, E., 2018. Towards LADM Victoria country profile – modelling the spatial information, in: The 6th Fig. 3D Cadastres Workshop, Delft, The Netherlands.
- Kalantari, M., Dinsmore, K., Urban-Karr, J., Rajabifard, A., 2015. A roadmap to adopt the Land Administration Domain Model in cadastral information systems. *Land Use Policy* 49, 552–564.
- Kalogianni, E., 2016. Master Thesis: Design of a 3D Multipurpose Land Administrative System for Greece in the Context of LADM (Master's thesis). National Technical University of Athens.
- Kalogianni, E., Dimopoulou, E., Quak, W., Germann, M., Jenni, L., Van Oosterom, P.J.M., 2017. INTERLIS language for modelling legal 3D spaces and physical 3D objects by including formalized implementable constraints and meaningful code lists. *ISPRS Int. J. Geo Inf.* 6 (319), 319.
- Kalogianni, E., Kalantari, M., Dimopoulou, E., van Oosterom, P.J.M., 2019. LADM country profiles development: aspects to be reflected and considered, in: The 8th

- International FIG workshop on the Land Administration Domain Model 1–3 October 2019, Kuala Lumpur, Malaysia.
- Kara, A., Çağdaş, V., Işıkdağ, Ü., van Oosterom, P., Lemmen, C., Stubkjær E., 2018b. The LADM valuation information model based on INTERLIS, in: The 7th International FIG Workshop on the Land Administration Domain Model, Delft, The Netherlands, 2–4 October 2018.
- Kara, A., Işıkdağ, Ü., Çağdaş, V., van Oosterom, P., Lemmen, C., Stubkjær, E., 2018a. A database implementation of LADM valuation information model in Turkish case study, in: The 7th International FIG Workshop on the Land Administration Domain Model, Delft, The Netherlands, 2–4 October 2018.
- Kara, A., Kathmann, R., van Oosterom, P.J.M., Lemmen, C., Isikdag, U., 2019. Towards the Netherlands LADM Valuation Information Model Country Profile, in: FIG WW 2019 - Geospatial information for a smarter life and environmental resilience. Hanoi, Vietnam, April 22–26, 2019.
- Karamessouti, M., Schultz, C., Chipofya, M., Jan, S., Murcia Galeano, C.E., Schwering, A., Timm, C., 2018. The Maasai of Southern Kenya domain model of land use. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* IV-4, 105–112.
- Karki, S., 2013. 3D Cadastral Implementation Issues in Australia (Master's Thesis). University of Southern Queensland, Toowoomba, Australia.
- Kebede, S.; Orlova, N., Dekeyne, C., 2018. Ethiopian Land Administration Domain Model, in: 2018 World Bank Conference on Land and Poverty. The World Bank - Washington DC, March 19–23, 2018.
- Kim, S., Heo, J., 2017. Development of 3D underground cadastral data model in Korea: based on land administration domain model. *Land Use Policy* 60, 123–138.
- Kim, T.J.; Lee, B.M., Lee, Y.H., 2013. A Strategy for Developing the Cadastral System of Cadastral Resurvey: Project based on International Standard (LADM) in South Korea, in: 5th Land Administration Domain Model Workshop, 24–25 September 2013, Kuala Lumpur, Malaysia.
- Koers, J., Cerrato, R., de Tierras, P.I., 2013. LADM-based implementation starts working - an information system for an integral approach to land management. Available online: (<https://www.gim-international.com/content/article/ladm-based-implementation-starts-working>) (Accessed 4 June 2020).
- Kuria, D., Ngigi, M., Gikwa, C., Mundia, C., Macharia, M., 2016. A web-based pilot implementation of the africanized land administration domain model for Kenya—a case study of Nyeri County. *J. Geogr. Inf. Syst.* 8, 171–183.
- Le, P.T., Zevenbergen, J., Lemmen, C., Uitermark, H., Tran, Q.B., 2012. Investigating the conformity between the land administration domain model and the Vietnamese land administration system. *FIG Peer Rev.* J.
- Lee, B., M., Kimb, T., J, Kwak, B., Y., Lee, Y., H, Choi, J., 2015. Improvement of the Korean LADM country profile to build a 3D cadastre model, in: *Land Use Policy*, Volume 49, pp. 660–667.
- Lemmen, C., Van Oosterom, P.J.M., Kara, A., Kalogianni, E., Shnaidman, A., Indrajit, A., Alattas, A., 2019. The scope of LADM revision is shaping-up, in: The 8th International FIG workshop on the Land Administration Domain Model 1–3 October 2019, Kuala Lumpur, Malaysia.
- Mader, M., Vučić, N., Vranić, S., Ročić, M., 2018. Initial 3D Cadastre Registration in the Republic of Croatia by Cadastral Resurvey, in: The 6th Land Administration Domain Model Workshop, 2–8 October 2018, Delft, The Netherlands.
- Mekking S., Koublenou V., Vranken M., Kossou F., Van den Berg C., 2020. Upscaling land administration in Benin towards national coverage, balancing between time, quality and costs, This paper has been accepted but not published yet at the FIG Working Week 2020, Amsterdam.
- Morales, J., Lemmen, C.H.J., De By, R., Molendijk, M., Oosterbroek, E.P., Ortiz Davila, A. E., 2019. On the design of a modern and generic approach to land registration: the colombia experience, in: The 8th Land Administration Domain Workshop, 1–3 October 2019, Kuala Lumpur, Malaysia.
- OGC, 2019. OGC White Paper on Land Administration. Available online: (<https://docs.openeospatial.org/wp/18-008r1/18-008r1.html>) (Accessed on 7 February 2021).
- Paixao, S., Hespanha, J.P., Ghawana, T., Carneiro, A.F., Zevenbergen, J., Frederico, L.N., 2015. Modelling indigenous tribes' land rights with ISO 19152 LADM: a case from Brazil. *Land Use Policy* 49, 587–597.
- Pržulj, D., Radaković, N., Sladić, D., Radulović, A., Govedarica, M., 2017. Domain model for cadastral systems with land use component. *Surv. Rev.* 51, 135–146. <https://doi.org/10.1080/00396265.2017.1393602>.
- Psomadaki, S., Dimopoulou, E., van Oosterom, P.J.M., 2016. Model driven architecture engineered land administration in conformance with international standards – illustrated with the Hellenic Cadastre. *Open Geospat. Data Softw. Stand* 1, 3.
- Purificação, N.R.S., Carneiro, A.F.T., Julião, R.P., 2019. A proposal for modeling and implementing an integrated system for brazilian cadastres according to ISO 19152: 2012 land administration domain model. *Bol. Ciências Geodésicas* 25, 4.
- Radulović, A., Govedarica, M., Pavičević, B., Šoškić, S., Kovačević, D., Ljumović, M., 2015. Unapređenje katastarskog informacionog sistema uprave za nekretnine Crne Gore (Improvement of Cadastal Information System in Montenegro), Proceedings of III Cadastre Congress in Bosnia and Herzegovina), Mostar, Bosnia and Herzegovina.
- Radulović, A., Sladić, D., Govedarica, M., 2017. Serbian Profile of the Land Administration Domain Model, in: Proceedings of the FIG Working Week 2017, Helsinki, Finland, 29 May–2 June 2017.
- Radulović, A., Sladić, D., Govedarica, M., Ristić, A., Jovanović, D., 2019. LADM based utility network cadastre in Serbia. *ISPRS Int. J. Geo Inf.* 8 (5), 206. <https://doi.org/10.3390/ijgi8050206>.
- Rajabifard, A., Agunbiade, M., Kalantari, M., Yip, K. M., Atazadeh, B., Badiee, F., Isa, D., Adimin, M., Chan, K., L., Aien, A., Olfat, H., Shojaei, D., Anaraki, M.R., 2018. An LADM-based approach for developing and implementing a national 3D cadastre – a case study of Malaysia, in: 7th International FIG Workshop on the Land Administration Domain Model, 11–13 April 2018, Zagreb, Croatia.
- Reid, A., 2019. A new register for Scotland. Available online: (<https://geoconnexion.com/publication-articles/a-new-register-for-scotland>) (accessed on: 20 May 2020).
- Shnaidman, A., van Oosterom, P.J.M., Lemmen, C., Ploeger, H., Karki, S., Rahman, A.A., 2019. Analysis of the third Fig. 3D cadastres questionnaire: status in 2018 and expectations for 2022, in: FIG Working Week 2019: Geospatial Information for a Smarter Life and Environmental Resilience, 22–26 April 2019, Hanoi, Vietnam.
- Sinergise, 2020. Giselle - turn-key land administration SUITE. Available online: (https://www.sinergise.com/sites/default/files/attachments/giselle_turn-key_brochure_short_web_.pdf). (Accessed on: 29 June 2020).
- Sladić, D., Radulović, A., Govedarica, M., 2020. Development of process model for Serbian cadastre. *Land Use Policy*. <https://doi.org/10.1016/j.landusepol.2019.104273>.
- Soon, J.H., Tan, D., Khoo, V., 2016. Initial design to develop a cadastral system that supports digital cadastre, 3D and provenance for Singapore, in: 5th International FIG Workshop on 3D Cadastre. 18–20 October 2016, Athens, Greece.
- Tjia, D., Coetzee, S., 2013. Application of the land administration domain model to the city of Johannesburg land information system. *South Afr. J. Geomat.* 2 (3), 260–279.
- Tjia, D.E., 2014. Towards a Land Administration Domain Model (LADM) Profile for South Africa (Master Thesis). Faculty of Natural and Agricultural Sciences, University of Pretoria.
- UN-Habitat/GLTN/Kadaster, 2016. Fit-for-purpose land administration: guiding principles for country implementation: e-book. Nairobi, United Nations Human Settlements Programme (UN-HABITAT), 2016.
- Vučić, N., Markovinović, D., Mičević, B., 2013. LADM in the Republic of Croatia-making and testing country profile, in Proceedings of the 5th FIG International Land Administration Domain Model Workshop 2013, Kuala Lumpur, Malaysia, 24–25 September 2013.
- Vučić, N., Ročić, M., Mader, M., Vranić, S., van Oosterom, P.J.M., 2017. Overview of the Croatian Land Administration System and the possibilities for its upgrade to 3D by existing data. *ISPRS Int. J. Geo Inf.* 6 (7), 223. <https://doi.org/10.3390/ijgi6070223> (223-1).
- Xu, Z., Zhuo, Y., Liao, R., Wu, C., Wu, Y., Li, G., 2019. LADM-based model for natural resource administration in China. *IJGI* 8, 456.
- Yan, J., Soon, K.H., Jaw, S.W., Schrotter, G., 2019. An LADM-based 3D underground utility data model: a case study of Singapore, in: 8th FIG Workshop on the Land Administration Domain Model. 1–3 October 2019, Kuala Lumpur, Malaysia.
- Zhuo, Y., Zhimin, M., Lemmen, C., Bennett, R., 2015. Application of LADM for the integration of land and housing information in China: the legal dimension. *Land Use Policy* 49, 634–648.
- Zulkifli, N., A Rahman, A.A., Siew, C.B., 2019. Database design and development of 3D cadastral registration based on LADM, in: The 8th International FIG workshop on the Land Administration Domain Model 1–3 October 2019, Kuala Lumpur, Malaysia.
- Zulkifli, N.A., Rahman, A.A., Jamil, H., Teng, C.H., Tan, L.C., Looi, K.S., Chan, K.L., van Oosterom, P.J.M., 2014. Towards Malaysian LADM Country Profile for 2D and 3D Cadastral Registration System. In: Proceedings of XXV FIG International Congress 2014, Kuala Lumpur, Malaysia.