ArcGIS & LADM (ISO 19152): From Conceptual to Implementation

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SUMMARY

The Land Administration Domain Model (LADM) is a conceptual information model. It provides common ontology and can be used by professionals and consultants that are implementing a physical information model. Transforming the conceptual model into a physical model in a production system is challenging. Beyond the need to have a good understanding of LADM, the system designer has to account for additional requirements that are not covered by the standard. As a result, most country profiles are never implemented in a production system.

ArcGIS has been implemented and is being used in operational systems by thousands of government organizations and by the majority of cadastral agencies. It is a complete geographic approach that enables people to implement the LADM and quickly get up and running – no matter where you fall on the land rights continuum. ArcGIS takes cadastre beyond field data collection and management by enabling data sharing among organizations and with the public. The extendibility and configuration of ArcGIS can be used to implement a cadastral system that conforms to LADM while leveraging and implementing capabilities required in an operational and distributed system.

This paper will discuss in detail how LADM is implemented within ArcGIS in the context of the ArcGIS Parcel Fabric and the context of Fit for Purpose field data collection. Next, migrating, extending, and configuring LADM within ArcGIS will be detailed. Quality management best practices, implementation lessons learned, and suggested implementation patterns will be explained. Finally, the road ahead for LADM and ArcGIS will be addressed.

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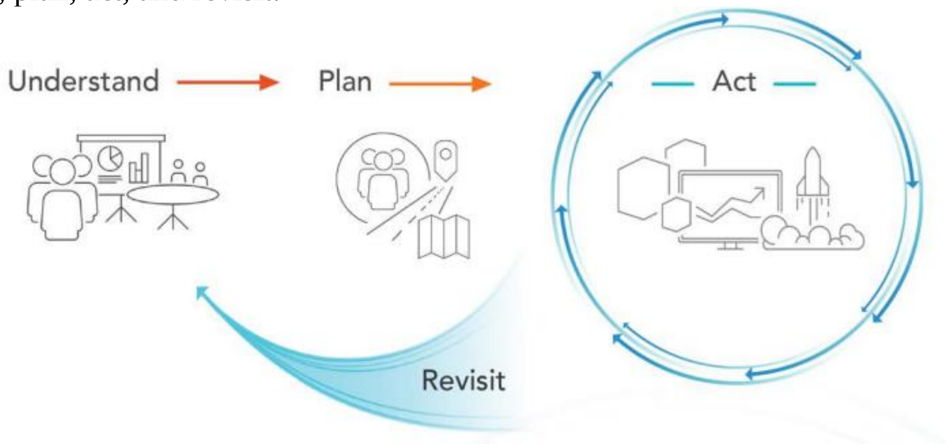
1. THE GEOGRAPHIC APPROACH

Geographic Information Systems (GIS) have continuously evolved to mirror evolution within the computer science domain. The capabilities of a GIS are directly dependent upon the available computing capacity of hardware – whether that hardware is supporting a Software as a Service (SaaS) system such as ArcGIS Online in the cloud or maintained by individual organizations on premises. As computing power has evolved, so has GIS. To manage and maintain a geographic information system, its necessary to consider a geospatial approach that deals in a more holistic sense with what is now coming to be known as geospatial infrastructure: "As GIS becomes more interconnected, it forms a geospatial infrastructure, which supports collaboration and helps transform workflows and decision making at many scales." This is to say that GIS is now much more than points, lines and polygons in a two-dimensional static space.

2. ARCHITECTING AN APPROACH FOR LAND ADMINISTRATION

What does this mean for LADM or land administration, in applied terms? There are several possible ways to architect a geographic approach for any industry. Architecture prototyping typically comes before implementation and involves a series of business decisions that any organization wishing to implement must consider. This series of decisions can be referred to as a geospatial strategy, "Faced with a variety of GIS solutions and options, a geospatial strategy can help you define the best way to use GIS to overcome your business challenges and achieve your organization's mission."

There are two main considerations when creating a geospatial strategy – the right people and an iterative mindset. Developing and executing a geospatial strategy involves four phases: understand, plan, act, and revisit.



Creating a team that engages this pattern enables organizations to be flexible as technology moves forward and as business needs shift.
Within a cadastre, different parties may be required to understand and plan versus those who act - for example, a government policy and executive may drive the understanding of a cadastral agencies goals: to maintain accurate property boundaries and determine what success looks like (ex. maintaining legal data in an attribute table or running a QAQC process to identify and rectify errors). Planning may take place by considering the current state of the cadastre – Are some cadastral maps on paper only? What type of effort would it require to ingest new data from CAD or other sensors? What rules are in place to guarantee the required level of quality and service? How will new property boundaries be documented and maintained? Who are the system’s users and stakeholders? For example, in a fit for purpose setting, SaaS using web services may be adequate, while a formal cadastre may require more hardware that can support an enterprise system. And finally, there is the work itself, in the act phase. Who will be updating parcels within GIS? Who is collecting field data to input and how? How is the data being shared with others? What type of training and support is needed for each user group? What set of privileges are assigned to each group? What language is used for the systems’ interface? What environment is used by each group (desktop, web, mobile)? Revisiting each phase on a regular basis can help streamline the process and provide space to update workflows and technology with the latest advancements.
Standards and frameworks such as the Land Administration Domain Model (LADM) provide a common language to start answering the implementation related questions above. The remainder of this paper will focus on walking through the “Act” portion of the iterative geospatial method detailed above.

3. THE PARCEL FABRIC INFORMATION MODEL

The parcel fabric provides a comprehensive framework for managing, editing, and sharing parcel data in both a multiuser and single-user environment. In a multiuser environment, the parcel fabric can be edited and maintained using web services and services-based architecture. A services-based architecture allows you to share the parcel fabric across all platforms (desktop, mobile, and web) and enable different workflows in different types of clients (field, public, the back-office).

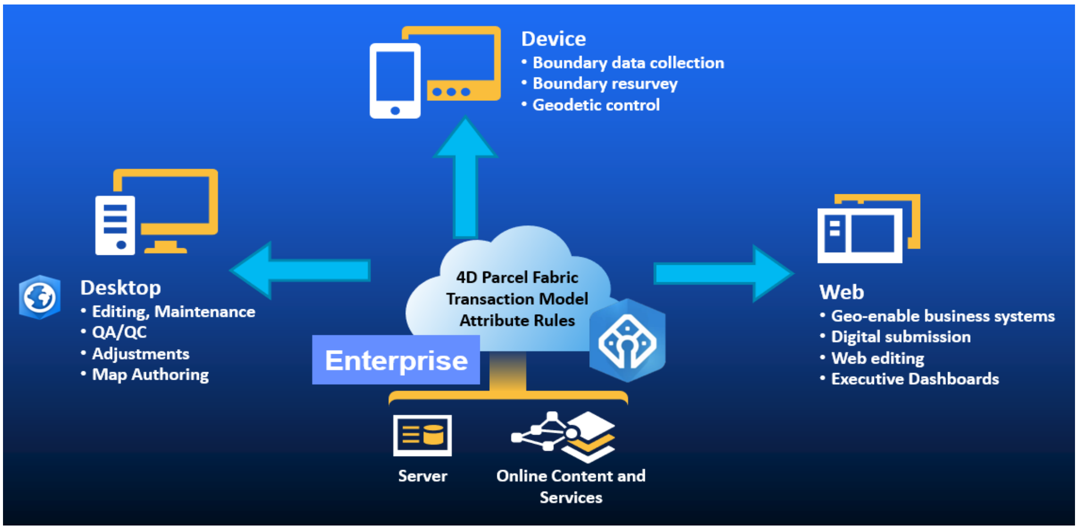


Diagram 1: Services allow you to share the parcel fabric across all platforms (desktop, mobile, and web)

A parcel fabric stores a dataset of connected parcels or parcel network. A "parcel" can represent any of the 3Rs – Rights, Restrictions and Responsibilities. Like the LADM, Parcels are composed of polygon features, line features, and point features. Parcels are added to the parcel fabric as parcel types. Each parcel type is composed of a polygon and line feature class that is defined by your organization. Points and connection lines are shared by all parcel types and help maintain the topological integrity and densify the survey network for LSA.

When a parcel fabric is created, a geodatabase topology is also created. Geodatabase topology rules define the spatial relationships between parcel features, and attribute rules define behavior that is specific to parcel features. The parcel fabric uses a set of predefined geodatabase topology rules and attribute rules to define parcels and model their behavior.

3.1 The parcel fabric data model

A parcel fabric is a data controller that controls all the participating feature classes. All cadastral features are associated to their source which is the 'record'. A parcel fabric also has built-in quality rules for geometry and attributes that generate error features. The parcel fabric is extendable and configurable – organizations can create their parcel types, extend the schema and configure the quality rules.

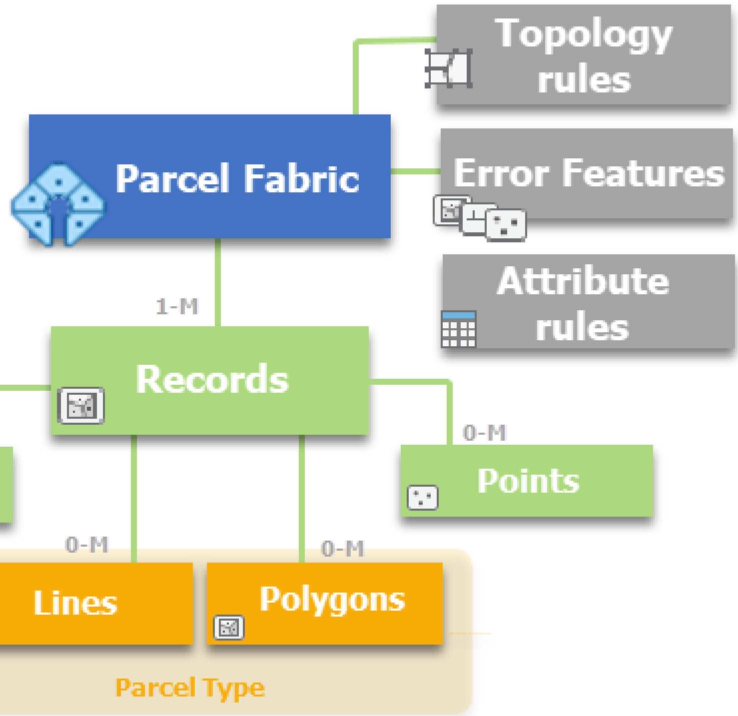


Diagram 2: Parcel fabric conceptual information model

3.2 Records

Like LADM, all parcel fabric data is associated to the source from which it came from. In non-customary cadastre such information is recorded (registered) and is stored in the record feature class. Parcel data is usually recorded on records such as plans, plats, deeds, and records of survey. The parcel fabric preserves historic and parent parcels. By capturing the legal record that created or retired a parcel, the parcel lineage can be tracked in both directions.

3.3 Parcel Types

Parcels are added to the parcel fabric as parcel types. Each parcel type has its own polygon and line feature class. The polygon feature class is defined by the parcel lines (metes and bounds) and/or by points. The line feature class represents parcel boundaries and can store survey measurements (COGO) from the recorded document.

You can add as many parcel types as necessary for your organization. For example, your organization may manage both ownership, tax parcels and easement parcels.
A parcel type can be designated as 'Administrative' and used to manage administrative boundaries. An administrative parcel type usually involved very large and complex geometries and is implemented to guarantee superb performance.

For each parcel type, the polygon and line feature classes come with a minimal set of predefined system attribute fields that can be extended with user-defined attributes, domains, and related tables.

3.4 Points

Points represent physical, coordinated x,y,z locations on the ground. Points in the parcel fabric are used to model parcel corners, endpoints of connection lines, points along a road centerline, survey control, tie points, and other forms of cadastral reference points.

Points in the parcel fabric have the following characteristics:

- Points represent single locations for connecting the ends of multiple parcel boundary lines. They maintain connectivity and topological integrity between parcels.
- Points can exist independently of parcels.
- Points can be fixed or nonfixed. Points with fixed shapes do not move.

3.5 Connection lines

Connection lines are used to represent dimensions between points that are not parcel boundaries. Connection lines are associated with the legal record that created or retired them. When running LSA (Least Squares Adjustment) connection lines densify the survey network and improve the solution.

Connection lines are typically used for the following:

- Connect parcel corner points to control points.
- Connect parcel corner points across rights-of-way (roads).
- Represent road centerlines.

3.6 Topology and attribute rules

The parcel fabric uses geodatabase topology rules and attribute rules to define parcels and model their behavior. Geodatabase topology rules define the spatial relationships between parcel features, and attribute rules can be configured to define behavior that is specific to parcel features. Attribute rules can also be configured to define enforce data quality in the parcel fabric. You can define additional topology rules and attribute rules to enforce data quality standards in your organization.

3.7 Adjustments

Least-squares adjustments can be run on the parcel fabric to evaluate and improve the spatial accuracy. When a least-squares adjustment is run, the results of the adjustment are stored in adjustment feature classes for analysis and visualization purposes. If the results in the adjustment feature classes are acceptable, they can be applied to the parcel fabric feature classes.

Adjustment results are stored in the following feature classes:

- AdjustmentLines—Stores and displays adjusted and statistical data for adjusted parcel type and connection lines
- AdjustmentPoints—Stores and displays adjusted and statistical data for parcel fabric points
- AdjustmentVectors—Stores and displays the shifts between parcel fabric points and their adjusted points

4. MIGRATING, EXTENDING AND CONFIGURING THE LADM WITHIN THE PARCEL FABRIC

The parcel fabric was designed in line with the conceptual Land Administration Domain Model (LADM). Customers can create their own LADM compliant schema by creating a new parcel fabric and adding their required parcel type. Another quick alternative is to import an LADM readymade schema by importing an XML Workspace document.

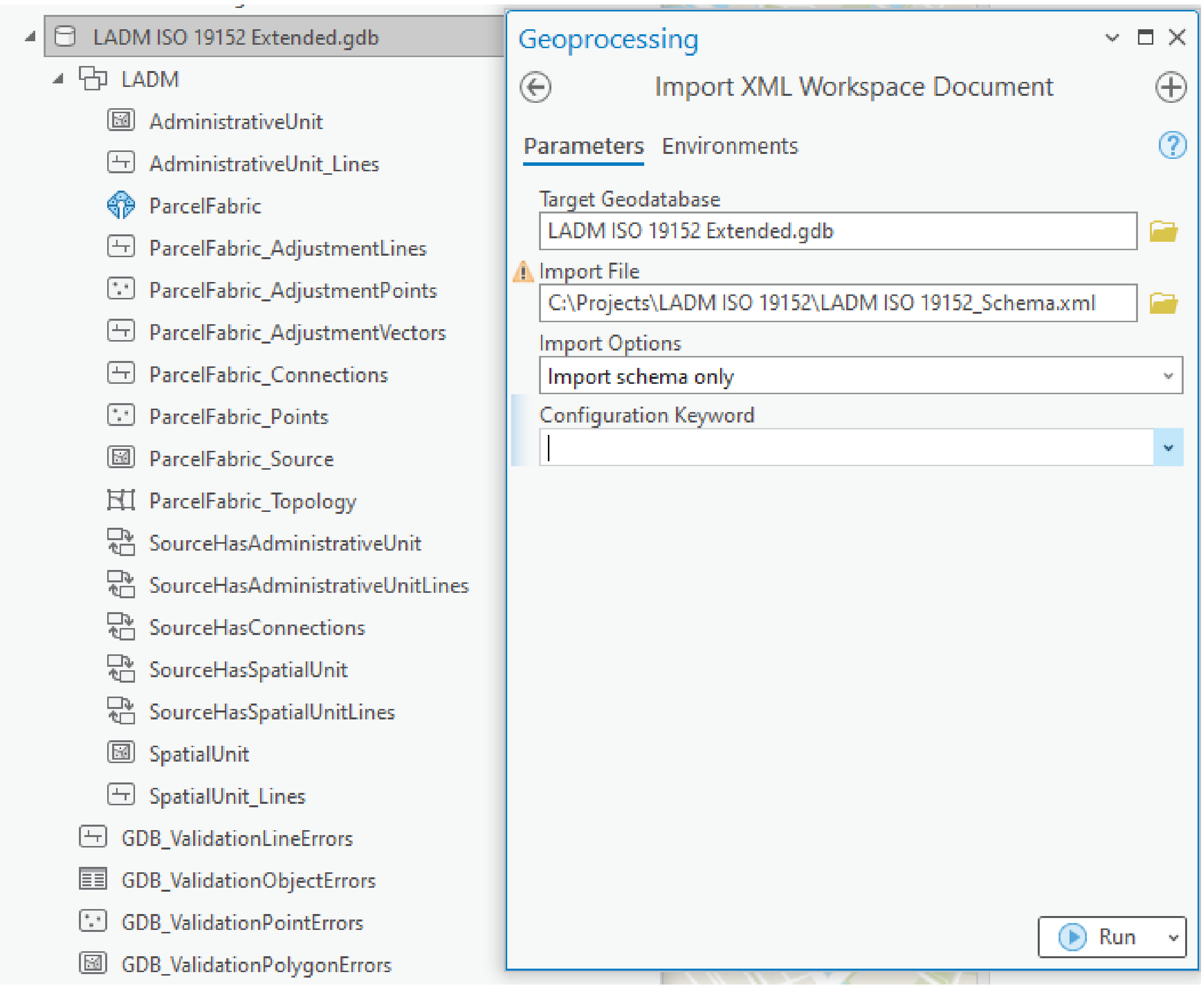


Diagram 3: Importing an LADM schema from an XML Workspace file

Naming LADM entities such as spatial units and administrative unit names can be assigned in a variety of ways. They can either prefixed or assigned with an LADM name convention but aliased with their user-friendly meaningful name. LADM naming can also be described as part of the feature class metadata. These allows for the LADM ontology to coexist side by side with the common customer specific ontology.
Migrating to existing data is a simple process that does not require prior data cleanup. This allows organizations to move their existing data with any issues it might have into an efficient production system and then evaluate its quality and fix it in their own pace.
The parcel fabric information model can easily be extended with additional fields, domains (called values in LADM), topology rules, attribute rules, contingent values and any other required property.

Domains: LADM ISO 19152 Extended

Domain Name	Description	Field Type	Domain Type	Split Policy	Merge Policy
Attribute Rule Type	The attribute rule type that created the error record.	Short	Coded Value Domain	Default	Default
LA_AdministrativeSourceType	Various administrative source types, such as deed or title,	Long	Coded Value Domain	Default	Default
LA_AreaType	Various area types, such as official or calculated	Long	Coded Value Domain	Default	Default
LA_BuildingUnitType	Various building unit types, such as private or commercial	Long	Coded Value Domain	Default	Default
LA_DimensionType	Various dimension types, such as 2D or 3D	Long	Coded Value Domain	Default	Default
LA_InterpolationType	Point interpolation types, such as start, end or mid arc	Long	Coded Value Domain	Default	Default
LA_LevelContentType	Various level content types, such as primary right or customary	Long	Coded Value Domain	Default	Default
LA_MonumentationType	monumentation	Long	Coded Value Domain	Default	Default
LA_PointType	arious point types, such as control or cadastral, applicable in a specific land administration profile implementation	Long	Coded Value Domain	Default	Default
LA_SpatialSourceType	Various spatial source types, such as survey plan or aerial photograph	Long	Coded Value Domain	Default	Default
LA_StructureType	Various spatial structure types, such as point or polygon	Long	Coded Value Domain	Default	Default
LA_SurfaceRelationType	Various surface relation types, such as above or below surface	Long	Coded Value Domain	Default	Default
LA_UtilityNetworkStatusType	Various utility network status types, such as planned or in use	Long	Coded Value Domain	Default	Default
LA_UtilityNetworkType	Various utility network types, such as electricity or gas	Long	Coded Value Domain	Default	Default
LA_VolumeType	Various volume types, such as official or calculated	Long	Coded Value Domain	Default	Default

Code	Description
1	Feild Sketch
2	GNSS Survey
3	Orthophoto
4	Relative Measuement
5	Topomap
6	Video

Diagram 4: LADM value lists can be configured using geodatabase coded value domains

The parcel fabric has no hidden system tables – all the feature classes are simple feature classes that can be published in a variety of open formats using web services and consumed by different types of clients. If needed, certain fields and tables can be hidden from certain groups of users or provisioned with 'read-only' privilege.
When a parcel fabric is created it is created with default quality rules that can be configured. The quality rules are defined using a topology engine and an attribute rules engine. Additional rules are provided and can be imported and configured, for example the allowed difference between the legal area and the shape (geometry)
area.

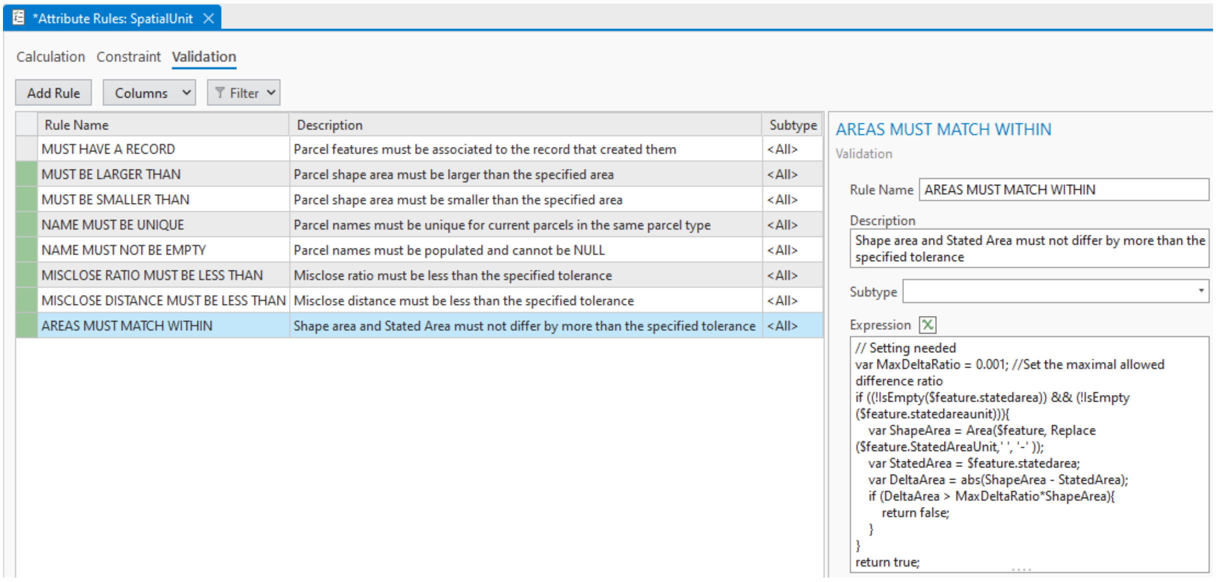


Diagram 5: Quality rules can be configured as part of the information model

The parcel fabric is scalable and robust. Using web services it can disseminate millions of parcels to hundreds of concurrent editors and many more viewers. It can be implemented on premise or on the cloud.

Data migration goes beyond moving data to a new system. A modernization project should start with education and a Proof Of Concept (POC) that makes sure the workflows and goals are met before plunging into a new production system. Data migration also includes training of the workforce, technical support and continuing education. The [parcel fabric community](#) and the [parcel fabric meetup](#) provide help support this growing community of knowledge.

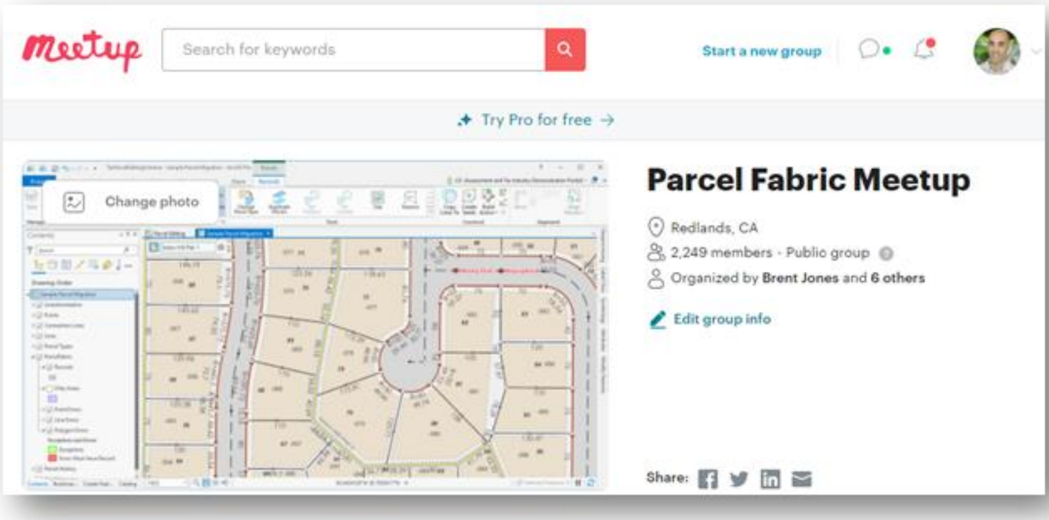


Diagram 6: Growing a community of knowledge https://www.meetup.com/Esri-Parcel-Fabric-Meet-Up/

5. QUALITY MANAGEMENT WITHIN ARCGIS

All cadastral systems are a 'system of record' and data quality and assessment is of high importance. In a multi user editing environment, multiple people are editing concurrently, in isolation from each other using 'Branch Versioning'. Each editor can create their own isolated version while other editors perform their edits in their versions without locking up the system. Like the LADM 'versionObject', once the version passes quality control, it is saved to the master copy (the 'default version'). Branch versioning support viewing the data in 'historic moments'. This includes geometry and attribute changes and provide a true 4D cadastre capability.

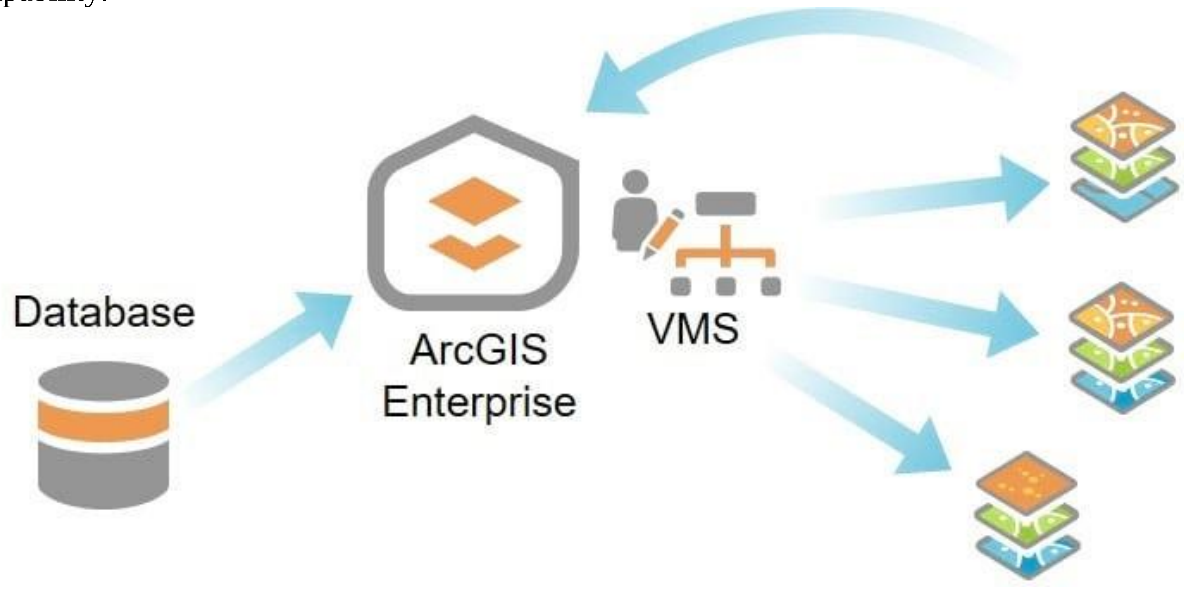


Diagram 7: Branch Versioning uses web services for editing on different clients (desktop, web, mobile)

When parcels are divided or merged, historic parcels are created and parcel lineage is established. All newly created parcels, boundaries and points are associated to their source, that is called a 'record' in the parcel fabric. Parcel lineage and historic parcels, provide additional quality capabilities: they support the chain of title research and can also be compared with the land registration system which manages the parties and the 3'R's (Rights. Responsibilities, Restrictions).
In a system of record accountability and security are important to prevent both malicious and accidental edits by non-authorized users. All parcel fabric feature classes use editor tracking to track when and who created new features or modified existing features. While many can view the data without any authentication, an editor must have a known identity and login to the cadastral system.
Access to data includes localization. The portal administrator can centrally manage privileges using Groups and Roles. Access to data also requires dissemination in multiple languages. The portal can be configured in more than 30 languages.

The parcel fabric ships with preconfigured [topology rules](#) and [attribute rules](#). The parcel fabric topology is validated using the predefined set of geodatabase topology rules. You can define additional topology rules and attribute rules to enforce data quality standards in your organization. Attribute rules are geodatabase rules that can be used to automatically populate attributes, restrict invalid edits during edit operations, and perform quality assurance checks on features. Since different organizations have different business requirements, [optional attribute rules](#) are shipped that can be imported and configured.
Storing the quality rules as part of the information model guarantees the required uniform parcel behavior when a portion of the data is given or updated in a different client, for example. It is copied with the data because it is part of the schema.
Beyond the information model, there are set of dedicated functionality to identify common problems with cadastral data, likes gaps and overlaps, and tools for fixing those common issues.
Least Squares Adjustment (LSA) is used to assess the measurement consistency for incoming data as well as assess and improve the overall accuracy using constrained weighted LSA. The LSA uses the DynAdjust LSA engine and exposes the results visually.

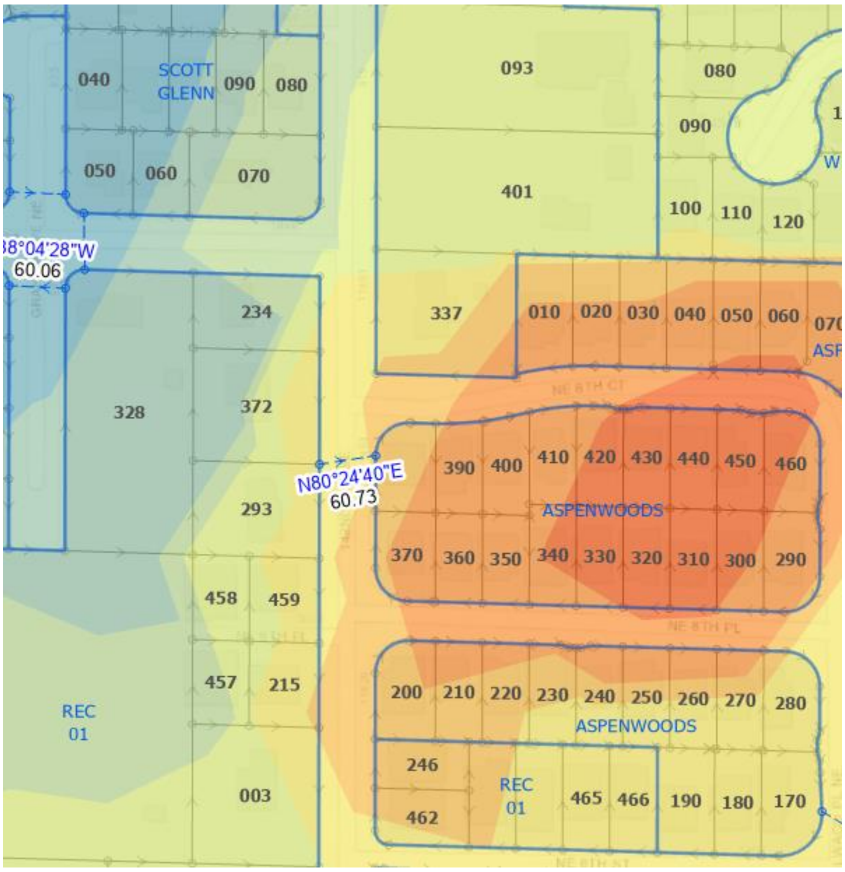


Diagram 8: Example of spatial accuracy heatmap

6. IMPLEMENTATION PATTERNS

6.1 Fit for Purpose Implementation

Due to the intricacies involved in applying a country profile to data, a precedent was set for providing a simplified version of the LADM to expedite field data collection by GLTN with the Social Tenure Domain Model. An ArcGIS LADM Core Configuration has been proposed that reduces the initial data collection fields in LADM and is enabled by a web service sharing model. Both the STDM and LADM Core implementation can be published as web services within ArcGIS Online. Web services, "are software components that can be accessed over the Web through standards-based protocols such as HTTP or SMTP for use in other applications." Web services can be deployed in the field for data collection and provide a single source of truth or dial-tone from which to work. This method is preferred as it reduces duplication and error over time.

Consider the following use case in a fit for purpose environment. Using a web service, a field manager accesses an editable spatial layer containing LA_SpatialUnit geometry and related LA_Party and LA_RRR tables, creates a map with the service within ArcGIS online, creates a Field Maps project and enables the project for editing in a connected or disconnected state. The field data collector accesses the data collection project via an app on their mobile device and collects spatial tabular data with photo attachments with a GNSS receiver connected by Bluetooth to the mobile device. As the field data collector updates each parcel in the field, the manager views their progress in a dashboard. Another analyst in the office views the parcels being collected and performs QAQC on them, ensuring all data is being collected accurately, using a web application.

This process may utilize either the SpatialUnit polygon published as a feature service from the Parcel Fabric or a LADM Core Configuration web service to begin collecting data. In the mid-term future, the Parcel Fabric will be able to be shared as a web service in its entirety and edited directly in the field, making a seamless editing and monitoring experience for both collector and manager. It should be noted at this time that implementation with either deployment of the LADM requires either retroactively appending the SpatialUnit feature service back to the host Parcel Fabric or migration to the Parcel Fabric and addition of a country profile after collection if using the Core Configuration. In either case, the Parcel Fabric presents a flexible data model that can be configured to honor LADM ontology.

Projects that have used various parts of this conceptual implementation model to collect field data include work done in Colombia by Kadaster International and work done in Zambia by Medeem. In the case of Colombia, the field data collection workflow noted above was used, and QAQC was performed using a custom JavaScript application using web services. These web services were then shared with the community for feedback in a dashboard, as well as the custom JavaScript application. In the case of Medeem, parcel data was collected in the field (disconnected) using high accuracy GNSS and a mobile application based on Esri technology, then imported into the Parcel Fabric and used to create a title map.

6.2 Formal Cadastre Implementation Case Studies

Two current Esri implementations of the Parcel Fabric will be discussed in this section. The first will focus on Harris County Appraisal District located and comprised of the City of

Houston, Texas, USA. The second will focus on the United States Bureau of Land Management, a national agency charged with managing US public lands that is often leased for mining, grazing, and oil and gas leases.
Harris County Appraisal District has implemented the Parcel Fabric for everyday maintenance of their cadastral record which is composed of 1.4 million parcels. Instead of using a SaaS environment like ArcGIS Online – addressed above – Harris County has deployed the Parcel Fabric on an Enterprise environment managed in house behind a firewall. Instead of a web service, the Parcel Fabric is managed using an Enterprise geodatabase dependent on a MS SQL Server relational database. When initially deployed, the Parcel Fabric was published to ArcGIS Enterprise, creating an in-house web service. The use of this service-oriented architecture enables a multi-user editing environment, allowing several (10-20) editors to concurrently edit the Parcel Fabric. The parcels from this fabric are published as a separate web service that is view only and included in public facing applications that anyone can access.
After a few failed attempts to develop a customized system, the Bureau of Land Management decided to adopt the ArcMap parcel fabric to maintain the Public Land Survey System (PLSS) using the national CAD NSDI format. The implementation involves millions of parcels in multiple spatial reference systems. The success of using COTS improved the collaboration between esri and BLM resulting in the implementation of BLM's business requirements for geodetic direction types, among other.

7. IMPLEMENTATION LESSONS LEARNED

Esri has been collaborating with LADM experts to identify the possible gaps between the Parcel Fabric and LADM. The current (second) generation of the Parcel Fabric conforms with LADM abstract test suite (level 1-3). Since the parcel fabric is LADM compliant, one might argue that there are currently dozens of LADM implementations in production.
Implementation of a standard will always have variations on a theme that reflects the reality of the country or institution implementing. The Parcel Fabric supports these variations and honors the language and intent of LADM.

8. ROAD AHEAD

Both LADM and ArcGIS continue to evolve. Through collaboration between Esri and the authors of LADM, a common vision has been established that will help more organizations implement the LADM. Web GIS and the use of Service Oriented Architecture, allows all client types (desktop, web, and mobile devices) to access in real time the current authoritative data. Service can be published using esri JSON format as well as OGC WMS and KML.
Using the parcel fabric REST API, thin clients like web browsers can be used to run LSA for digital submissions on a web browser suing a parcel fabric that is hosted on the cloud (Azure, AWS, …).
ArcGIS and the parcel fabric offer a rich set of well documented APIs that can be accessed using Python, C# .Net, and JS. While SDK is well documented and fully supported, most organizations prefer to configure the parcel fabric to meet their business requirements and avoid using any custom code.

9. CONCLUSION

ArcGIS has been used for decades to successfully implement real world systems and can be configured to implement the LADM. In fact, since the parcel fabric was designed in line with LADM, one can argue any implementation of the parcel fabric is also an implementation of LADM. Like LADM, ArcGIS and the Parcel Fabric are agnostic to the legal systems, surveying techniques and offer the needed flexibility and extendibility. The parcel fabric itself conforms with the abstract test suite for a subset of the LADM packages. Unlike LADM the parcel fabric is a physical information model that can be easily extended. Organizations can choose to use LADM ontology for their parcel types or use both (their own and LADM ontology).

ArcGIS Online which is a SaaS (Software as a Service) platform, has also been used to implement and collect spatial units, party information and their relationship to their property using mobile technology. Likewise, the Parcel Fabric has been implemented on premises successfully around the globe.

LADM and ArcGIS will continue to evolve and representatives from both sides are working on a common vision for implementation that accounts for sharing and management mechanisms well into the future.

BIOGRAPHICAL NOTES

Amir Bar-Maor graduated with a degree in geodesy from the Technion – Israel Institute of technology in 1999 and a masters degree in geodesy in 2002. After working for several years designing and implementing GIS technology, he joined esri in 2008 – initially as a project manager and consultant for cadastral projects and later as a product engineer in software development. Amir is a licensed cadastral surveyor and a licensed real estate appraiser.

Katherine Smyth graduated with a degree in anthropology from the University of Colorado at Boulder in 2007 and a MSc in Geographic Information Systems from the University of Redlands in 2013. After working for seven years supporting archaeological surveys with field data collection, predictive analysis and database management, she returned to university to gain her masters degree, after which she worked as a contractor creating custom JavaScript widgets for spatial web applications, managing databases and automating analytical tools with Python. Katherine joined Esri in 2016, where she has supported land administration on state and local levels within the United States and now supports national cadastres globally.

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