Best Practices of Cadastral Systems Using GIS

Kees DE ZEEUW & Amir BAR-MAOR, Esri

Key words: Cadastre, GIS, professional practice, land management, trends and innovation, digital transformation.

SUMMARY

The use of GIS in the development and management of cadastral systems is a common practice. Globally, guiding principles (like IGIF and FELA), methods (like Fit for Purpose Land Administration) and standards (like LADM) are available for setting-up, maintaining, and developing land administration systems. This regards the systems of records, insight, and engagement using a geospatial database. National and local implementations should envisage to provide citizens access to tenure security and proper land management services, through formal or customary land registry and cadastral systems.

In this paper, insight is given on how GIS can be used in cadastral system development and management. Based on evolving challenges and requirements, a range of solutions is given, allowing for scalable and sustainable cadastral support. The challenges are discussed (from security issues to capacity needs, form data quality assurance to IT capabilities) and examples are given. Also, standardization of processes versus customization of solutions is debated and experience with approaches to successful implementations are shown.

Given examples are taken from the different continents, focusing on the recording and mapping of cadastral data. This can range from systems for first-time registration and data collection in the field to system modernization, including GeoAI and 3D requirements.

Best Practices of Cadastral Systems Using GIS

Kees DE ZEEUW & Amir BAR-MAOR, Esri

1. INTRODUCTION

We live in an insecure era with climate change, conflicts, dense populations, and increasing poverty and inequity. Good land administration is a basic requirement for governments and societies to address these challenges (de Zeeuw *et al.*, 2019). National and local implementations should envisage to provide citizens access to tenure security and proper land management services, through formal or customary land registry and cadastral systems.

A number of guidelines, frameworks, standards, methods, and approaches is available, that can be used and consulted for the design and development of land administration systems. The IGIF (https://ggim.un.org/igif) and FELA (https://ggim.un.org/meetings/GGIM-committee/10th-Session/documents/E-C.20-2020-29-Add_2-Framework-for-Effective-Land-Administration.pdf) from UN-GGIM provide globally recognized guidelines for both the development of Spatial Data Infrastructures and Effective Land Administration systems. Methods like Fit-for-Purpose Land Administration (FIG/WorldBank, 2014; UN Habitat/GLTN/Kadaster, 2016) and the Land Administration Domain Model (LADM, Lemmen *et al.*, 2015) help define a required approach for land administration authorities. However, this context is strongly influenced by external factors that differ from place-to-place (de Zeeuw and Jones, 2023).

A Geographic Information System (GIS) can be used in the design and development of a cadastral system. This regards the systems of records, insight, and engagement using a geospatial database.

In this paper the role of GIS in cadastral systems is explained in chapter 2. A possible platform is described, and examples of different components are given. In chapter 3 both the demand drivenness and the technology push on user requirements are discussed, as well as the process of system requirement gathering. Although there is no 'one recipe' for successful implementations, some 'ingredients' to be considered for practical implementations are given in chapter 4. In Chapter 5 future trends and expected developments are explored, and in chapter 6 the related agenda for innovation is discussed. Finally, this paper gives three examples of international implementations, in which Esri support is being given.

2. THE ROLE OF GIS IN CADASTRAL SYSTEMS

The global differences in land administration systems are vast. From first time registrations to upgrading existing registration systems, to aligning systems to the changes society continues to demand. But all systems have the common denominator that they link the past, present and future of land tenure within society. To do so, a system of record, a system of insight and a system of engagement must be interconnected and aligned with the legal, geospatial, and institutional context. The level of technology chosen is context-specific and can range from simple paper-based systems to enterprise digital systems, including cloud solutions and artificial intelligence, and everything in between (de Zeeuw and Jones, 2023).

A modern land administration system is based on a digital platform where all relevant and available data sources can be consulted, people-land relations are registered and rights, restrictions and responsibilities can be managed. If this is done in a local environment or by the sharing of distributed data and services, depends on the available resources and user requirements. This also goes for the level of integration between the land registry and cadaster. Likewise, decisions should be made on the setting up of a local setup or a web-based service and the relation to a National Spatial Data Infrastructure (NSDI). Figure 1 gives an example of a commonly used platform setup for land administration.

Figure 1. A platform for Land Administration (Source: Esri)

Examples can be given on the use of GIS tools within this platform for Land Administration if it comes to the collection of data (ArcGIS Field Maps, ArcGIS Drone2Map), parcel management (Parcel Fabric) and the platform itself, using an organizational portal on ArcGIS Enterprise or ArcGIS Online.

ArcGIS Field Maps (formally known as Collector for ArcGIS) is a powerful tool for field data collection tasks. It offers a wide range of features that make field data collection and mapping more efficient and accurate. By using the app, field workers can easily capture GNSS coordinates, take photos, and record attribute data directly on their mobile devices. The ability to work offline is particularly useful in remote areas or locations with limited internet connectivity (for example in remote areas in Colombia). The Land Registry in the United Kingdom implemented a digital mapping system using ArcGIS Field Maps to create a comprehensive and accurate cadastral map of England and Wales. This digital mapping system has improved the efficiency and accuracy of land administration processes in the country.

One example of a parcel management system would be the ArcGIS Parcel Fabric. This solution for parcel management has been in use and continual development for over 10 years. The old ArcMap Parcel Fabric has been deployed mainly in the USA, Canada, and Australia. The second generation of the Parcel Fabric, which is LADM conformant, includes many improvements and enhancements, and has been already put into use in the Middle East, Caribbean, Europe and Africa (Tourtelotte *et al.*, 2023). As an example, the Rwanda Natural Resources Authority (RNRA) has successfully implemented a platform (LAIS, Land Administration and Information System) to improve their land administration system and cadastral mapping. They have used ArcGIS Hub to create a centralized platform for managing land records, conducting land surveys, and providing access to land information for citizens and government agencies. This has helped streamline the land administration process, reduce land disputes, and promote transparency in land transactions.

3. REQUIREMENTS OF A GIS BASED LAND ADMINISTRATION SYSTEM

It is critical to understand that land administration is about people-to-land relationships, and there is legal and non-spatial data involved as well. This means that platforms, communities, software, and hardware should be interoperable and configurable. The use of open standards, proven technology, and long-lasting professional communities support this (de Zeeuw and Jones, 2023).

The requirements are not only demand driven, but are also defined by the used technology, the capacity, knowledge level and available resources. A land administration system should always be scalable, sustainable, and evolvable as both supply and demand are not static and change over time. There is no such thing as one-size-fits-all. One could think of systems in the range of a first-time registration towards a high-end 3D cadastral system.

In the process of system requirement gathering, the starting point is often based on known and used business processes, workflows, and habits. This tends to result in highly customized systems, complicating the adoption to future trends or innovative approaches we don't know about today. In case of software updates and upgrades (both in GIS and system integration applications) the sustainability of land administration systems may become in danger. For example, system security issues by hacking or data misuse, or lost expertise due to retirements and career development. It is for that reason that a clear strategy on customization versus configuration should be part of cadastral system design and development. This goes for both Open-Source applications as in the use of Commercial Of The Shelf (COTS) software.

Finally, the availability of resources has a high impact on the chosen solution for a land administration system. Although a good Return on Investment (ROI) can be expected from a land administration system, most initiatives depend on budget constraints and the possible investment to be made. Different offerings and pathways are available. For example, Esri's Land Administration Modernization program (LAMP) is supporting over 80 eligible developing countries in starting-up a GIS land parcel management system, More information to be found at: https://www.esri.com/en-us/industries/government/departments/land-administration/modernization-overview.

4. A RECIPE FOR SUCCESSFUL IMPLEMENTATION?

Of course, the frameworks and approaches described in chapter 1, can be considered a recipe for the development of a successful implementation of a land administration system. But with implementations 'on the ground' there is always the need for creativity, improvising and tailor-made solutions. This is also the place where land administration professionals meet with IT staff and traditional workflows and processes, that are not easily changed overnight. If it comes to the implementation of a digital platform for land administration the following - very practical - aspects need attention of the development team:

- Platforms are built by people. Speaking the same language and creating the right environment to perform is crucial. Also, team members have different responsibilities and positions. These should be recognized.
- There is a variety of development methods available, from Agile to Scrum, to Waterfall. It is important to choose a development method that aligns with the specific needs and goals of the GIS platform project.
- By developing Proof of Concepts (PoC), risks are reduced, the learning curve becomes steeper, and champions can grow faster.
- Use a configuration first approach. Instead of building everything from scratch, the team better leverages pre-built configurations, templates, and frameworks to expedite the development process. Create a platform that is designed for users, not for IT experts (and certainly not for auditors).
- Organize the technical support from the start of the development process, including training.
- There is a growing awareness of the need for a FAIR data policy (Findable, Accessible, Interoperable, and Reusable). Evaluate the platform against these principles.

5. FUTURE TRENDS

Many countries are in the process of digital transformation. By converting paper-based systems (or missing data) into digital systems, the practice of good governance becomes more realistic and work processes can become faster and more efficient. The use of GIS in this process should be scalable and sustainable. If the present purpose of the system can be reached with a desktop solution, no need for a complex system of systems is required.

However, in the process of development, it should be possible to evolve a system into that direction as the purpose of the system will change over time. Figure 2 shows a logical path of development. Fortunately, land administration systems have a tendency being designed more and more with a user-centric approach, focusing on usability, accessibility, and user experience. This is also in favor of the mentioned FAIR data policy.

Figure 2. Setting up a scalable and sustainable GIS environment for a land administration system, that is evolvable (fit for purpose) over time.

There is a growing interest in 3D cadasters. A 3D data system enables the representation and management of land rights, restrictions, and responsibilities in three dimensions. Especially in densely populated areas, it can provide a more comprehensive understanding of land parcels and their associated attributes, allowing for better analysis, visualization, and decision-making. They are particularly useful in urban planning, infrastructure development, and land development projects. Also, hardware and software developments more and more allow for this development.

Artificial Intelligence and Machine Learning technologies will develop fast, and can automate repetitive tasks, analyze large datasets, and provide insights for decision-making. They can help in land valuation, land use planning, and detecting anomalies in land records.

There is a trend of moving from SDI development into the creation of so-called dataspaces. This also affects the integration of Land administration Systems into National Spatial Data Infrastructures (NSDI). Data spaces are platforms that enable the integration, sharing, and collaboration of diverse data sources. Public and private data become more integrated. After the identified trend on using block chains in land administration, the use of data spaces might become a more realistic next step in land administration system design, where data harvesting is becoming a new component in land administration practices. As this data is location based, it is likely that the use of GIS and geospatial oriented infrastructures will become an important part of this development.

The LADM (Land Administration Domain Model) will become a multipart standard (ISO 19152) and will be of great value to land administration systems design. It is organized into multiple parts. Each part is addressing different aspects of land administration, and the multipart standard will not conflict with the existing standard (LADM:2012). The different parts of LADM cover topics such as conceptual models, information models, party and rights models, spatial units, and workflows. The multipart structure allows for a modular approach to implementing LADM, where specific parts can be adopted based on the requirements of a particular jurisdiction or organization. The six parts are: Part 1: Overview and Principles; Part 2: Extended Model; Part 3: Spatial Schema; Part 4: Valuation; Part 5: Rights, Restrictions, and Responsibilities; and Part 6: Administration and Maintenance Procedures (Lemmen *et al*, 2020).

The development of software and tools is both demand and technology driven. This means that new opportunities will occur continuously for digital transformation, efficiency improvement, and land administration practices in general. In the evolution of Esri's Parcel Fabric software module in ArcGIS, one can see there is a regular updating of the software and a gradual broadening of the possibilities in parcel management over time. Following these developments, the focus of users should be on the configuration of software rather than customization of tools. This allows for a better responsiveness of organizations to future demands and technological developments, but it also requires a shift in thinking. Institutional development (training, change of work processes and workflows) becomes more important, and IT development by users becomes less predominant.

6. INNOVATION IN PARCEL MANAGEMENT SYSTEMS

Esri dedicates substantial resources and means to Research and Development (R&D) of software and tools. This includes the components and tools that can be used for parcel management and field data collection. By working closely with a community of experts, real world problems can be solved, using the latest and most robust technology available.

Here are a few of the innovative characteristics of the Parcel Fabric that have been requested by many organizations:

- LADM – the Parcel Fabric is a physical implementation of the conceptual Land Administration Domain Model. The Parcel Fabric can integrate to a land registry system that stores the 'party' package and their relationship (RRR) to land. Like LADM, the Parcel Fabric Information Model can easily be extended to support different country profiles and successfully deployed in a production environment.

- Multi-user editing is made possible by using the new Branch Versioning – Branch Versioning allows hundreds of users to be editing the same data on different clients (desktop, web, mobile) in isolation from each other. Once edits meet the quality assurance criteria they can be pushed (posted) to the default version. The temporal nature of Branch Versioning supports 4D cadastre; The data can be viewed in any historical moment in time.
- Web Services and Service Oriented Architecture – Working against local files is dangerous from many perspectives and inefficient. Web services offer better collaboration and transparency. Any person (or system) with the right privilege can access the data in real time without having to create another copy of the data. Web services also expose capabilities through a set of REST APIs which allow developers and systems to automate many workflows. Storing the data in a centralized location, on premise or on a cloud, and the appropriate security measures to manage user access, makes it easier for IT managers to do their job.
- Offline Parcel fabric – A portion of a Parcel Fabric can be taken offline while maintaining the parcel data integrity. The offline copy is saved locally on a mobile geodatabase (SQLite) and then edited. The common reasons to take data offline are: Intermittent internet connection, bypass any server or network related performance issue, ability to take the data to the field, or subcontractors that provide services on a portion of the data. All edits are synced to a version and can be reviewed before they are pushed to the default published version.
- SaaS (Software as a Service) – ArcGIS Online is Esri's SaaS infrastructure which is managed in the cloud. With ArcGIS Online you don't need to manage your own IT infrastructure (personnel and hardware). In 2024 we plan to release the parcel fabric on ArcGIS Online. This will make it easy for organizations to collect field data using Fit for Purpose methodology and be able to maintain it and leverage the parcel fabric capabilities. Like the enterprise deployment, you can view and edit your data from the desktop or the web client.
- Strata parcels – All the parcel fabric feature classes are Z enabled. But editing parcels in 3D is not easy and not always necessary. This is why many organizations choose to use an attribute driven approach to visualize and analyze their strata parcels below and above ground. Beyond easier editing this approach is guaranteed to always be in the correct elevation relative to the latest surface definition.
- Parcel Lineage Depiction – In the Parcel Fabric, like in LADM, every cadastral feature is defendable and can be associated to its source. The Parcel Fabric term is a 'record' and records often retire parent parcel(s) and create new child parcel(s). This happens automatically and creates the parcel lineage which can be depicted using Link Charts. The Link Chart shows which parcels were retired and created by each legal record and support the chain of title research process.

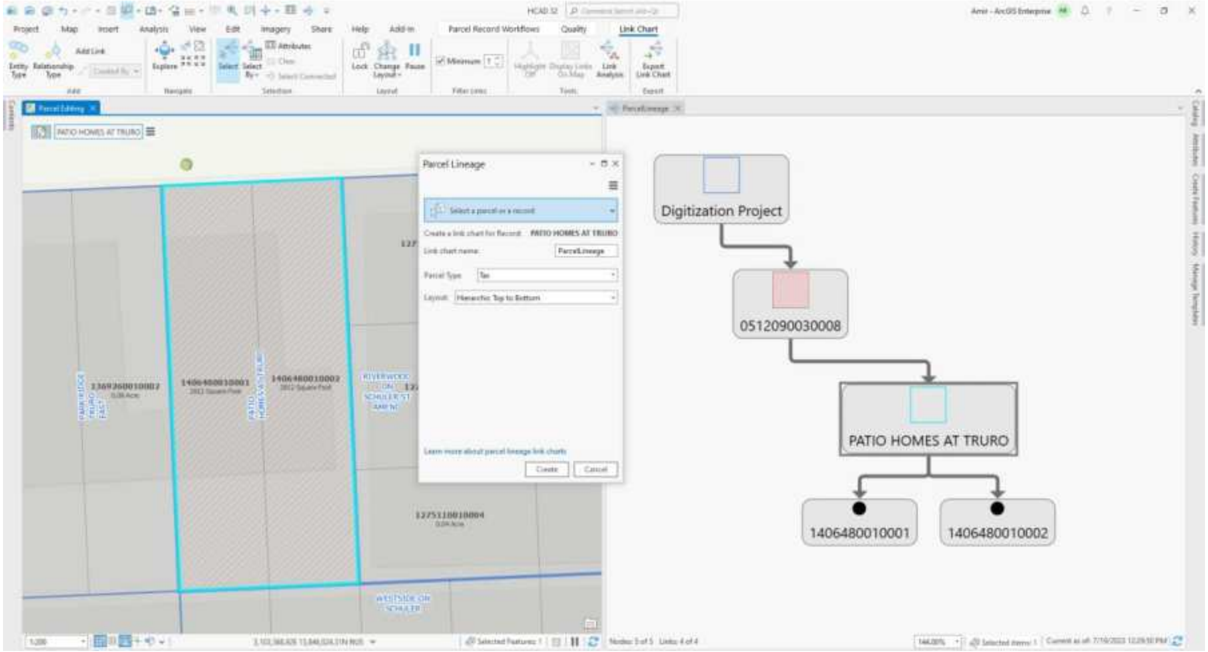

Figure 3. Parcel Lineage Depiction.

- Title Map – Many countries include a map that depicts the parcel boundaries and points as part of their title documents. It is common to have the coordinates of each point enumerated sequentially and included in a table. This can be easily created and automated, even to a PDF file, using the geoprocessing tool Export Sequential Parcel Features.

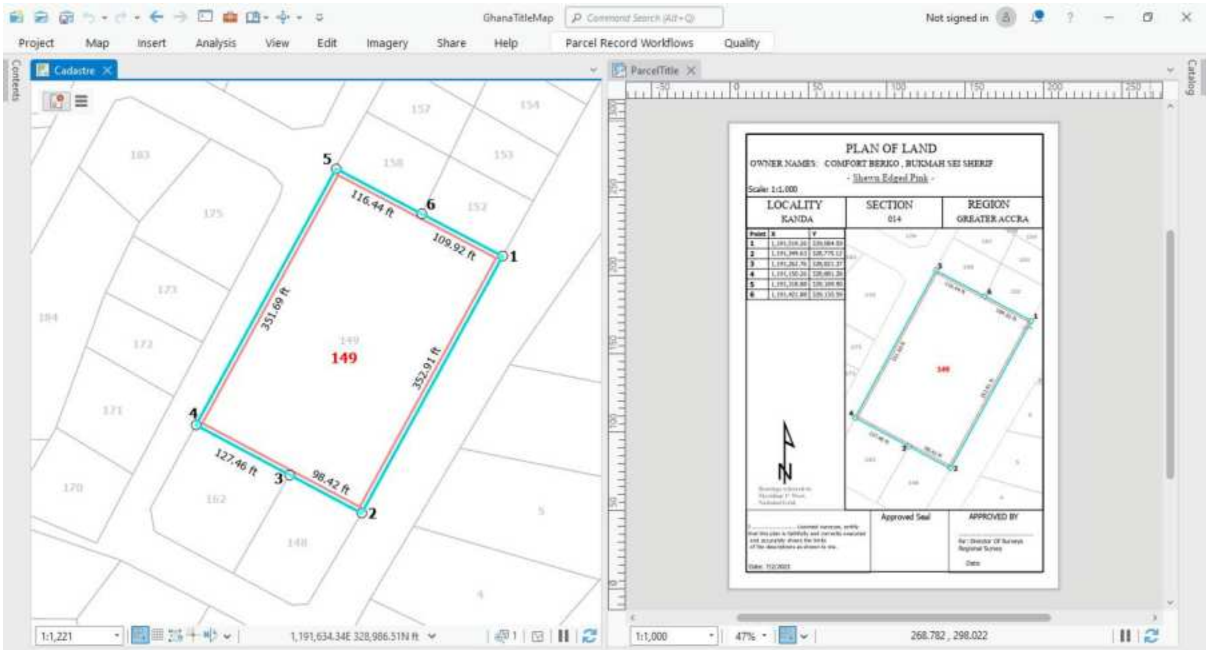

Figure 4. Example of automated title map creation.

- Least Squares Adjustment (LSA) – LSA is used by many cadastral agencies to check the consistency of measurements within a single submitted plan as well as evaluate and improve the spatial accuracy of their data. The Parcel Fabric uses the robust DynAdjust LSA engine created by GeoScience Australia. This LSA engine can process hundreds of thousands of observations, handle disconnected network 'islands' and support a wide variety of observation types. Instead of sifting through traditional LSA result files, the power of GIS is harnessed to display error ellipses as well as detect outliers for the different measurement types. The analysis results are written to feature layers that can be further explored using the rich data exploration capabilities in ArcGIS.

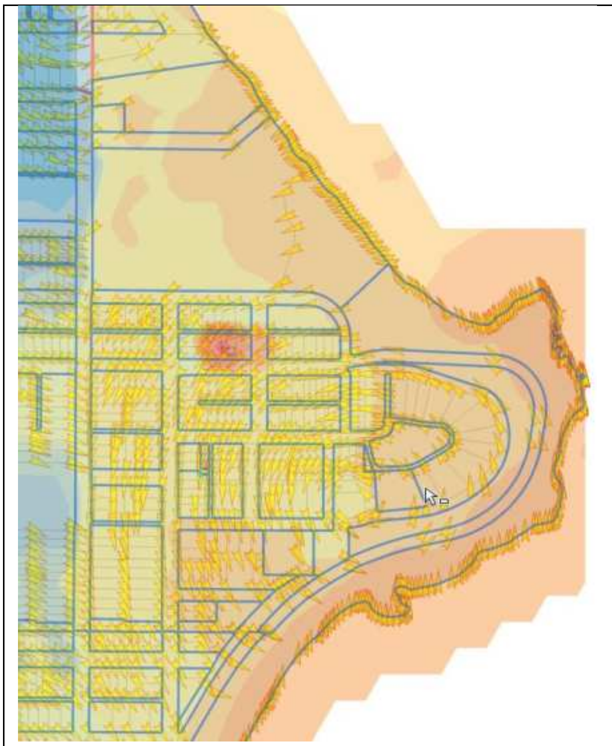	
Spatial accuracy heat map and displacement vectors visualization	Outliers are visually detected in a new plan where users entered the wrong measurements

Figure 5. Least Square Adjustments using DynAdjust.

- Web Apps – The use of web services enables the use of web apps. You can use the Dashboard app to view cadastral transactions - and other KPIs - or use ArcGIS Experience Builder to create your own web app without any coding. Editing is not limited to the desktop client. Developers can build dedicated editing apps where each named user works against their editing version and uses a variety of tools to explore and edit their data.

In the development of software, a focus on user success is essential, following research and technological trends pragmatically: Separating the hype from the real necessity.

7. EXAMPLE COUNTRY IMPLEMENTATIONS

Land administration implementations are executed in different parts of the world. As requirements, resources and policies differ from place to place, the development strategy is always situational. For inspiration, in this paper three examples are given of national agencies, developing their cadastral system with the use of GIS.

The Department of Lands and Survey (DLS) in Cyprus has gone through a digital transformation of the Cyprus Land Information System (CLIS) using the Parcel Fabric. A service-based architecture has been introduced, allowing for customer transactions, the use of dashboards and reporting and the integration of the legal and fiscal system. More information can be found at: https://portal.dls.moi.gov.cy/en/enimerosi/land-information-system/geografiko-yposystima/

In Morocco the National Agency for Land Conservation, Cadastre and Cartography (ANCFCC, https://www.ancfcc.gov.ma/) has designed a National Economic (Multipurpose) Cadaster, called SI-CAD-ECO. It has a cloud-first architecture, supports the Spatial Data Infrastructure (SDI) of Morocco and includes the development of GeoAI Workflows for Feature Extraction. A media explanation of the system can be found at: https://medias24.com/2023/01/17/un-cadastre-economique-en-preparation-par-lagence-fonciere/

The Lands Department in Hong Kong (https://www.landsd.gov.hk/en/index.html) has a clear vision on the development of a Land Information System (LIS), and will transform its Second Generation Land Information System (2GLIS) into a Third Generation Land Information System (3GLIS) over time. This will feature a 3D system of records and Next Generation Workflow Management. The LIS also serves the national Common Spatial Data Infrastructure (CSDI) portal of Hong Kong: https://portal.csdi.gov.hk/csdi-webpage/

8. CONCLUSIONS

A Geographic Information System (GIS) can be used in the design and development of a cadastral system. This regards the systems of records, insight, and engagement using a geospatial database.

Land Administration Systems (LAS) should be evolvable (Fit for Purpose) over time. The use of GIS can make it scalable and sustainable.

A modern Land Administration System (LAS) is based on a platform where the available data sources can be consulted and Fit for Purpose analysis, data management, and data sharing can be done. Examples are given in this paper for the collection of data (ArcGIS Field Maps), parcel management (Parcel Fabric) and the platform itself, using ArcGIS hub.

A land administration system should always be scalable, sustainable, and evolvable as both supply and demand are not static and change over time. A clear strategy on customization versus configuration should be part of cadastral system design and development.

UNGGIM's IGIF and FELA give great guidance in the process of platform development. The Fit for Purpose Land Administration approach and the LADM standard give good guidance too. But with implementations 'on the ground' there is always the need for creativity, improvising and tailor-made solutions.

There is a growing interest in 3D cadasters, Artificial Intelligence and Machine Learning technologies, and there is an observed trend of moving from SDI development into the creation of dataspaces.

The Parcel Fabric in ArcGIS is given as an example on how innovation goes hand in hand with software development, in order to allow for user success and to keep up with users demands and technological developments.

Finally, in this paper three examples are given (Cyprus, Morocco, and Hong Kong) of cadastral system development using GIS.

REFERENCES

FIG/World Bank, 2014. Fit-for-purpose land administration: Copenhagen, International Federation of Surveyors (FIG), 2014. FIG publication 60, ISBN 978-87-92853-11-0.

Lemmen, C., Oosterom, P. v. & Bennett, R., 2015. The Land Administration Domain Model. Land Use Policy, Volume 49, pp. 535-545.

Lemmen C., P. van Oosterom, E.M. Unger, E. Kalogianni, A. Shnaidman, A. Kara, A. Alattas, A. Indrajit, K. Smyth, A. Milledrogues, R. Bennett, P. Oukes, H.C. Gruler, D. Casalprim, G. Alvarez, T. Aditya, K.G.A. Sucaya, J. Morales, M. Balas, N.A. Zulkifli and C.J. de Zeeuw, 2020. The land administration domain model: advancement and implementation. World Bank Conference On Land And Poverty, The World Bank - Washington Dc, March 16-20, 2020.

Tourtelotte B., 2022. GIS in Land Administration Can Help You Implement the FELA and Support the SDG's. FIG Congress 2022, Volunteering for the future - Geospatial excellence for a better living Warsaw, Poland, 11–15 September 2022.

Tourtelotte, B., K. Pickett and C.J. de Zeeuw, 2023. FELA-based Geospatial Knowledge Infrastructure. FIG Working Week 2023 Protecting Our World, Conquering New Frontiers Orlando, Florida, USA, 28 May–1 June 2023.

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.

Zeeuw C.J. de, P. Dijkstra, C.H.J. Lemmen, E.M. Unger, M. Molendijk, E.P. Oosterbroek, C. van den Berg, 2019. Bridging the security of tenure gap: Fit for purpose initiatives. World bank conference on land and poverty. The World Bank - Washington DC, March 25-29, 2019.

Zeeuw C.J. de and B. Jones, 2023. Decision support for the practical implementation of land administration systems. FIG Working Week 2023, Protecting Our World, Conquering New Frontiers Orlando, Florida, USA, 28 May–1 June 2023.

BIOGRAPHICAL NOTES

Kees de Zeeuw is Principal Consultant at Esri Global. Since 2022 he is the Practice Lead on Land Administration at the Geospatial Authorities department of Professional Services. He holds an MSc degree in land and water management (1989). After long term assignments in Rwanda and Bolivia he has been working more than 10 years in environmental and geo-information sciences at Wageningen University and Research Centre in The Netherlands. At Cadastre, Land Registry and Mapping Agency in The Netherlands (2007 – 2022), he has been for 12 years the director of Kadaster International. His expertise is on Land administration and NSDI. He made contributions to Fit for Purpose, LADM, IGIF and FELA.

Amir Bar-Maor is a Senior Principal Product Engineer at Esri. Amir is part of the software development team where he acts as the product owner for the ArcGIS Parcel Fabric and Tasks in ArcGIS Pro. Amir graduated with a degree in geodesy from the Technion – Israel Institute of technology in 1999 and a master's 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.

CONTACTS

Kees de Zeeuw
Esri Global – The Netherlands
Email: kdezeeuw@esri.com
Web site: www.esri.com

Amir Bar-Maor
Esri Global – The Netherlands
Email: ABarMaor@esri.com
Web site: www.esri.com