On the Design of a Modern and Generic Approach to Land Registration: The Colombia Experience

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SUMMARY

A significant number of undocumented people-to-land relationships exist in many countries; they constitute an important barrier to economic development, especially that of rural areas. Although countries often have established procedures to register these relationships, typically, procedures involve outdated, costly and time-consuming workflows, and in many cases, require workflow resources that are simply unavailable. The vital, underlying technology and standards to collect and manage the required data are complex and sometimes inaccessible, or if available, tools do not comply with adopted (inter)national standards. If we continue down this path, the registration of undocumented people-to-land relationships will take significantly more time and money than governments are willing to afford and be held responsible for. While each issue mentioned above presents a substantial challenge, it is only by addressing them holistically that a significant impact can be obtained. Using the post-conflict Colombia as a pilot area and fit-for-purpose land administration as philosophy (FIG/World Bank, 2014; UN Habitat/GLTN/Kadaster, 2016), we have developed and tested a simplified, community-based, standards-compliant methodology and supporting technology, to register people-to-land relationships in a fast and economically viable way.

A country cannot afford to be non-compliant with the ISO's 19152 standard, which defines a reference land administration model (LADM). Its adoption, however, adds a whole level of complexity to existing procedures. We therefore developed a multi-level data model based on LADM, in which each level is optimized for the procedural step where it is used. These steps are: data collection, post-processing, validation and recording. At the end of the last step the data complies fully with the standard and, in the case of Colombia, with the corresponding country profile. The developers of this profile made relevant observations for the development of the second edition of LADM — commented in this paper.

Conventionally, in countries with very traditional institutions like for example Colombia, land administration data collection is carried out by specialists who use sophisticated measuring equipment and high-detail forms following a multi-purpose cadastre philosophy. We propose a multi-layer approach in which the base data on people-to-land relationships is collected first, and then data associated with other land administration aspects is optionally added as part of normal government agencies operations. For the data collection, we worked with Esri and Trimble and developed technology that satisfies two intrinsic objectives. The first is to create

the ability to collect data that meets the requirements of the data collection data model, and the second is to install the ability in landowners/rightholders and community members to collect the data themselves. Contrary to conventional point-based land surveys, our data model uses polygons as the basis of surveying. In addition, geometric and legal data are collected simultaneously, and this includes evidence documentation. All types of people-to-land relationships are captured: formal, informal, customary, etc. Since the community is responsible for the data collection, several activities are organized to ensure data collection is carried out according to methodological requirements. A data collection plan is devised to allow multiple survey teams (five were used in the pilot tests) to work in parallel over a period of a week to cover a complete administrative area.

Since every landowner surveys her/his own land, boundaries between neighbouring parcels are collected twice. In practice, during a survey either neighbour aims to approximate the boundary by staying on her/his own property and maximising land extent, which may lead to little intersection between the surveyed baoundaries. Also, points where multiple people-to-land relationships converge are surveyed multiple times. To generate the dataset that complies with the post-processing data model, we developed a customized library of functions that are used to transform surveyed data into topologically correct representations of real-world land parcels in a semi-automated way.

Traditionally, the quality of the surveyed data is determined only by the accuracy of the observations made. Since we do not follow such a classical approach, we included an additional validation step that is executed in a public forum to which the community is invited by the local authorities to corroborate the results of the post-processing. During this forum event, neighbour landowners or right-holders check and approve their shared boundary with a digital signature. This procedure uses a big screen so that results are openly presented for the whole community to witness and comment on, making the procedure fully transparent. Authorities also use this forum to check and validate identities, neighbouring relationships and supporting evidence.

The last step in the process leads to the recording of different types of people-to-land relationship in the official government systems. This step includes the legal analysis of the evidence of rights provided by the citizens and the evidence existing in government information systems to determine the official type of right for each recorded relationship. Some of the people-to-land relationships can be immediately formalized and lead to land titles. Others fall into different categories of rights that require some kind of follow-up procedure, but they can potentially lead to a title also.

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1. INTRODUCTION

Colombia has a deeds-based land administration system with a history of sporadic approaches for the establishment of cadastral records (Paez, 2016). According to Paez, the percentage of parcels that are properly registered and surveyed in urban areas is 66%, the percentage of parcels that are legally occupied, but not registered or surveyed is 8% in urban areas and the percentage of parcels that are informally occupied without legal title is 26% in those areas. For rural areas, these numbers are 16%, 10% and 74%, respectively (as given in the Cadastral Template[1] for Colombia).

There is a need for system reform — the existing system is outdated (Dinero Magazine, 2014; Paez, 2016). It should be observed that with the current approach, it costs hundreds of USD to measure and register an average parcel in Colombia. The number of parcels still to be formalised is difficult to estimate but it may be more than 5 million. Following conventional approaches, this will take a substantial amount of time, exceeding the 7 years set out by the government in the peace treaty with the FARC.

Land title deeds in rural areas are issued by the *Agencia Nacional de Tierras* (ANT), which falls under the Ministry of Agriculture. The registry of the land titles deeds is taken care of by the *Superintendencia de Notariado y Registro* (SNR), of the Ministry of Justice. SNR provides on-demand documents on real estate with its historical chain of deed. Parcel mapping and land valuating is accomplished by the *Instituto Geografico Agustin Codazzi* (IGAC), under the department of statistics DANE (*Departamento Administrativo Nacional de Estadística*). There are independent cadastres in the cities of Bogotá, Cali and Medellín, and in the Department of Antioquia (Molendijk et al., 2018). The implementation of a nationwide multipurpose cadastre was approved by the national government in 2016 (DNP 2016).

The country is looking for the most efficient processes in land administration, using innovative techniques. Fit-For-Purpose (FFP) methods and techniques are being explored, tested, and evaluated with a view to be implemented as soon as possible. Fit-For-Purpose approaches in land administration deliver, amongst others, secure tenure rights within a relatively short time at affordable costs, see (FIG/World Bank 2014; UN Habitat/GLTN/Kadaster, 2016).

[1] http://cadastraltemplate.org/Colombia.php

In all stages of the FFP pilot, collaboration with all institutions (ANT, IGAC, SNR, DNP), and local authorities is crucial to improve the methodology and to ensure acceptance of the results. Most crucial is the participation of land rights claimants (typically farmers) themselves in all stages to ensure trust in the obtained results.

The continuum of land rights approach to land tenure is also important as it incorporates rights that are documented as well as undocumented, formal as well as informal (informal occupation), including individuals and groups, and slums and settlements which are legal as well as extra-legal. The term 'continuum' applies to land rights, but also to other key dimensions relevant in land administration: a continuum of (participation of) parties, of representation of spatial units, of data acquisition methods/technologies (with a related continuum of geometric accuracy), of recording/contents/quality, of information management/organisation and a continuum in purposes of land administration. All this fits well with the concepts of the Land Administration Domain Model — LADM (ISO, 2012).

An overview of existing people-to-land relationships based on Fit-For-Purpose Land Administration and the continuum of land rights is currently being tested in Colombia. This is in support to all requirements related to processes of formalisation, restitution, regular maintenance and quality improvement. All existing people-land relationships are proposed to be included: formal ownership and real rights, possession, occupancy and informal land use. Creating overview of the existing situation could even include overlapping claims, disputes and conflicts. A nationwide overview implies also an overview of the human footprint.

The fact that many of the people-to-land relationships are not yet documented implies that access to land can't be enforced nor guaranteed nationwide. Conventional approaches in production and maintenance of land information do not perform — alternatives are needed. The focus of this paper is on alternative data acquisition and data handling approaches that can be adopted within the context of purpose, budgets and availability of human resources. All this in the context of a real LADM implementation as is ongoing in Colombia.

2. LADM COLOMBIA COUNTRY PROFILE

Important inputs for this section are derived from the paper by Baron, Mejía and Jenni presented to the LADM Workshop in 2018 in Zagreb, Croatia (Baron et al., 2018). In this paper, suggestions are made for the development of LADM Edition II. Those observations are relevant and are commented on below.

The principle of 'legal and institutional independence of data providers and stakeholders' was introduced in the Cadastre 2014 publication by Kaufmann and Steudler (1998). The principle stipulates that legal land objects, being subject to the same law and underlying a unique adjudication procedure, have to be arranged in one individual data layer, and that every adjudicative process defined by a certain law, requires the creation of a special data layer for the legal land objects underlying this process. In order to overcome the stakeholders' fear of losing control over their own data, it is important to respect their legal and institutional independence and to recognize it as a crucial element for cooperation and data interoperability. Technocrats often neglect this effect and blockages are provoked, which then take months or even years to overcome (Steudler, 2014). This necessary legal and/or institutional independence requires that each institution assumes the responsibility for its own data and puts in place an adequate way to guarantee interoperability.

According to (Baron et al., 2018) the ISO 19152:2012 does not describe how to manage these sets of legal spatial objects, so that the achievement of this objective cannot simply be delegated to LADM (Bajo et al., 2017). It has to be commented here that the class "LA_Level" can be used for this purpose. This is a set of spatial units, with a geometric, and/or topological, and/or thematic coherence (ISO, 2012). As stated in the introduction of the LADM ISO standard, one of the considerations in its design is that it will be based on the conceptual framework of 'Cadastre 2014' of the International Federation of Surveyors (FIG). Class LA_Level is designed for the implementation of the principle of legal independence and this should be included as an example to its definition in the standard.

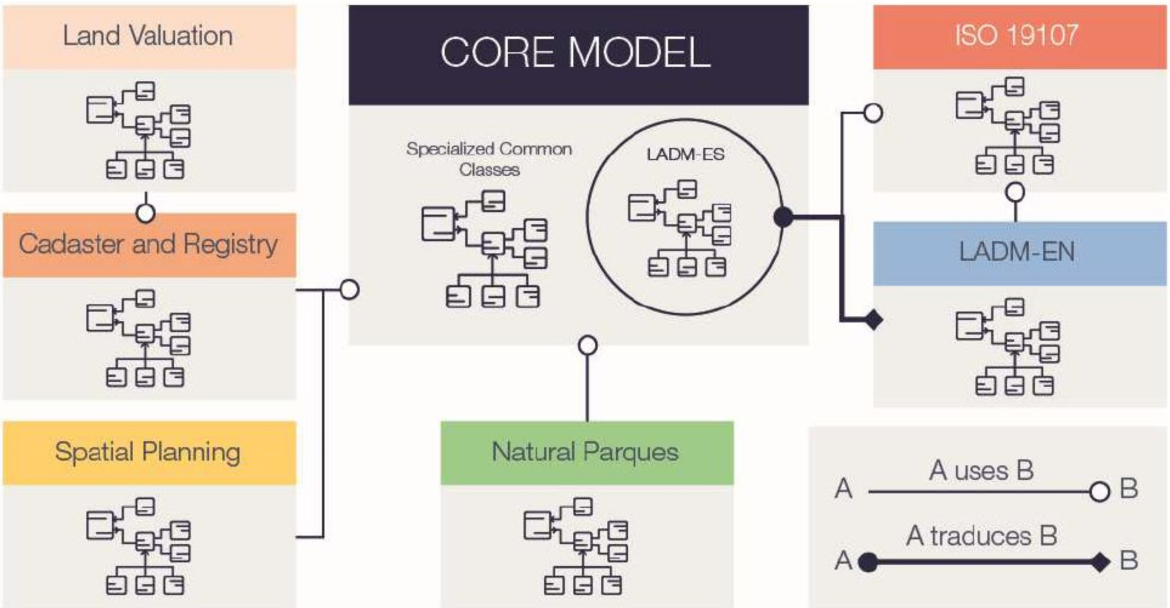

Figure 1 — Modules in the Colombian LADM Profiles (Baron et al., 2018)

In LADM-COL, the principle of legal independence is achieved in another way: by modularizing the LADM, allowing each institution to work with its own legal spatial objects that fall within its competence according to the current legal framework (Baron et al., 2018).

In this way, all the resulting modules per topic (Figure 1) are created around the same ontological principles and the same semantics defined by LADM (Bajo et al, 2017). It is nice to observe that a similar approach is included in the proposal of Edition II of LADM (Lemmen et al., 2019). The Colombian modularisation approach is followed in Edition II for the packages Spatial Planning and Valuation, each with its own spatial units.

Within the particularities of the Cadastre-Registry module of the LADM-COL, emphasis is placed on the administrative package, in which the Basic Administrative Unit class (BAUnit) is represented by the parcel (spatial unit), which is defined as "the parcel not separated by another public or private parcel, with or without buildings and other constructions, belonging to natural or legal persons. The property maintains its unity even though it is crossed by public water currents" (IGAC, 2016).

The following types of rights are identified: collective property, right of ownership, leasehold, property, possession, occupation, mere tenure and mining right. Each of the types of rights has different associated domains that correspond to relative contracts, such as leasing, a contract associated with the right of mere tenure.

In the domain model, restrictions are listed in a general classification of types of legal acts that involve a limitation or burden with respect to the right of ownership over real property, for example: easements, embargoes and environmental restrictions. Now, in relation to responsibilities, LADM establishes that a responsibility is a formalized obligation to do something, therefore, responsibilities of constitutional, legal, administrative, judicial or contractual origin have been identified in the Colombian profile. However only the last three are subject to registration.

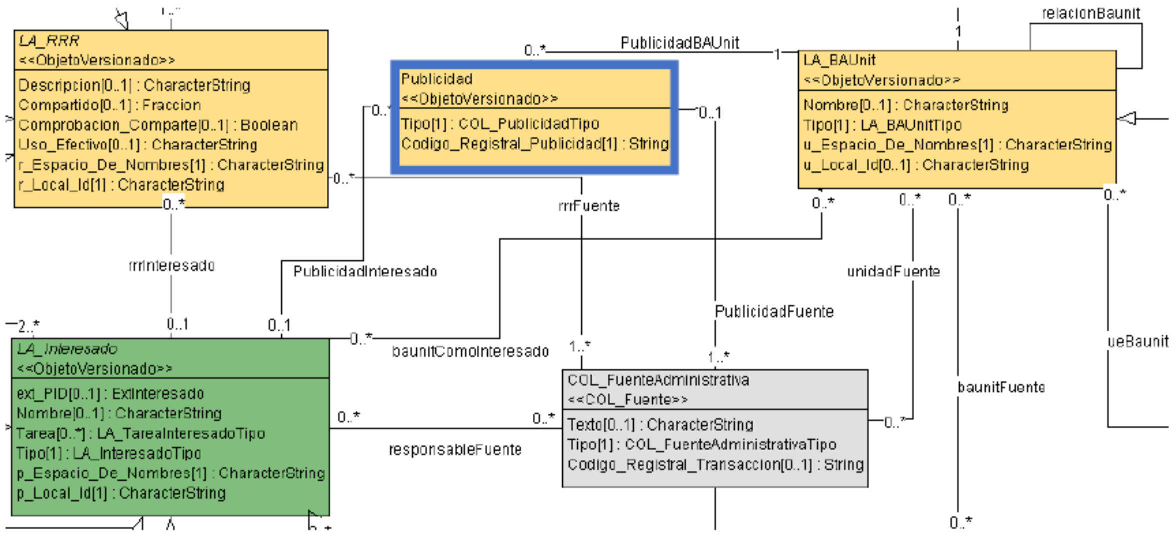

Figure 2 — Publicity class of the Cadastre-Registry model of LADM-COL (Baron et al., 2018)

ISO 19152:2012 establishes that a right or responsibility is directly associated with exactly one (1) party and exactly one (1) basic administrative unit (BAUnit). Baron et al. (2018) state that restrictions will be associated with zero or one (0..1) party, and exactly one BAUnit. In this regard, they consider that the treatment of the restrictions should be the same as that of the responsibilities, considering that if the rule establishes that LA_PartyType can be a BAUnit, in the case of an existing restriction the association should also be exactly one (1) party and exactly one (1) basic administrative unit. However, in practical life it is found that a BAUnit does not always have an associated responsibility or a restriction, therefore the responsibilities as well as the restrictions should be associated with zero or one (0..1) party and exactly one BAUnit. This is a good proposal for consideration during the development of Edition II of the LADM.

One of the singularities of the Cadastre-Registry data-model of the LADM-COL relies in the definition of a new "Publicity" class that refers to annotations external to the Rights, Restrictions and Responsibilities, mainly related to post-conflict processes (restitution alerts, victims or displacement processes). These alerts are recorded as informative and do not in themselves establish a restriction, right or responsibility. Figure 2 illustrates the UML diagram with the class "Publicity" (Publicidad; highlighted in the blue boxed class) of the Cadastre-Registry data-model of LADM-COL.

The LADM-COL has been developed by the Swiss Development Cooperation, *Agencia Nacional de Tierras* (ANT), the *Superintendencia de Notariado y Registro* (SNR) and the *Instituto Geografico Agustin Codazzi* (IGAC).

3. The Fit-For-Purpose Methodology

The overall procedure for land registration following the Fit-For-Purpose (FFP) philosophy consist of six major steps (see Figure 3).

The first step is *Socialization*. During this step, leaders of the community (-ies) located in the work area are contacted to organise a general meeting in which the FFP team explains the nature of the work, the responsibilities of the different actors and the flow of activities. A critical result of this step is the identification of young adults from the community that will be trained to become grass-root surveyors and help the community execute the work.

Figure 3 — Major steps of the FFP methodology

The second step is *Planning & Training*. After the explanation of the work, a social mapping exercise is carried out through which the various landowners or claimants identify the location and the approximate area of their parcels (spatial units) on a base map. After all the data has been collected, these stakeholders are informed of when their survey will happen, and which of the grass-root surveyors will accompany them.

Simultaneously, these young surveyors are introduced to the functioning of the required equipment (mobile app & handheld GPS), and they receive explanation of the specific steps to follow to survey parcels. A number of test runs are executed to guarantee complete understanding of the procedure. Special training material has been developed and is available for this task.

The third step is *Data Collection*. Following the previously drawn plan, various survey teams are dispatched to cover the whole area and to collect simultaneously the spatial and administrative/legal data of all of the private land in the work area. For simplicity reasons, in the reminder of this paper we use the term 'private land' to refer to land for which there exist right claims, by a citizen, either formal or informal, all types of rights are included (see Section 4). All other land, either owned by the government or with no claim, is referred to as public land.

The fourth step is *Post-Processing*. This step is used to transform surveyed data into topologically correct representations of real-world land parcels in a semi-automated way. Additionally, an analysis on the various classes of rights is made and compared with existing government registers when applicable.

The fifth step is called *Public Inspection*. During this step, the processed results are presented to the community in a public forum for approval. Signatures are collected as validation of the results, which indicate agreement between the parties.

The sixth and last step is *Registration*. All parcels that received approval by the authorities and the community are incorporated into the national registers so that official documents can be generated for the various rightholders. In some cases, the right can be immediately formalized and leading to land titles. For others, which fall into different categories of rights, a different procedure applies, but they can potentially lead to titles too.

4. FIELD DATA COLLECTION

Data may be collected in the field or gathered in the village, using aerial or satellite images or GNSS devices. Using imagery, the boundary surveys may be done by professional surveyors and legal experts or by supervised grass-roots surveyors and paralegals, who are trained in subsidiary legal matters but may not be fully qualified. The process workflow may be fully digital or with interfaces to paper-based approaches. In GNSS-based approaches, the surveys can be done by the people themselves, walking along the perimeter of their parcels with a handheld device; points can be measured using an app with a very simple interface. Mapping and recording options can be combined in data collection applications in many ways — but all should be supported by standards in exchange (see Figure 4). Volunteer-based land administration and crowdsourcing can be modelled in LADM with party role types and quality labels. In general, processes for data acquisition and maintenance and distribution require support — this will receive attention in Edition II of LADM.

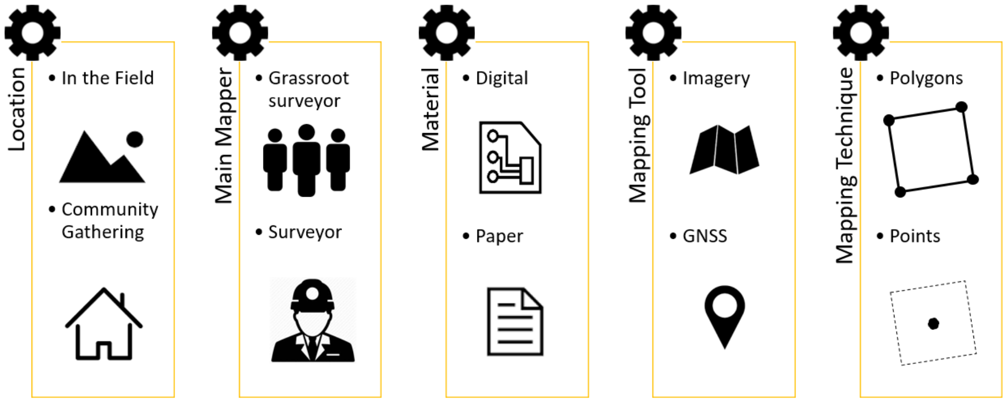

Figure 4 — Options in Cadastral Spatial Data Acquisition (Source: Lemmen, Unger and Bennett)

Some of the content of this section is based on internal project documentation (Kadaster International, 2017) and published papers (Jones et al., 2017; Molendijk et al. 2018, Molendijk et al., 2018, De Zeeuw et al. 2019). Field data collection succeeds by procedural steps such as project block selection, preparations, awareness raising, announcement, as well as training.

A field data collection process to create an overview of the existing people-to-land relationships should be fast, reliable and affordable. This is the only alternative in support to the establishment of a nationwide land administration in Colombia within the defined timeframe of the peace treaty. The presented methodology is fast and designed to meet this requirement — a nationwide land administration. It is reliable because the focus is on a quality link in the data between land and people. It is affordable because high precision and time-consuming conventional field surveys are avoided, and so are highly complex bureaucratic procedures. It is participatory, because people themselves are actively involved in the data collection.

Community involvement is fully supported; the very nature of cadastral survey requires the participation of neighbours, family members, etc. Therefore, the mayor or a representative of the local authority is informed in advance to ensure awareness and involvement of all parties.

Data collection is organised by a 'fit-for-purpose' professional (generally a surveyor), and it is executed as a sweep of an administrative area, during which all people-to-land relationships within the area are surveyed. A plan for the survey is made up together with the community, based on the number and area of the parcels, and the available survey teams. A survey team is composed of a locally trained grass-root surveyor and the rightholder of the parcel being surveyed. The survey unit uses a handheld GPS and the 'Fit-for-purpose App', which enables them to walk the perimeter of the parcels to survey their boundaries. For each acquired vertex of the boundary, coordinates and GPS accuracy values are stored. A boundary delimits a homogeneous set of people-to-land relationships. Upon completion of the boundary survey, the rightholder can see in the FFP app the shape of the spatial unit and its area. Grass-root surveyors are young adults from the villages, trusted by the communities who have been trained on the 'fit-for-purpose' procedure to survey parcels and are trained and guided by professionals.

The FFP App makes use of an orthophoto of the specific area and can include additional base data needed to support the data collection. After the boundaries have been surveyed, an identifier of the spatial unit (parcel) is linked with a recorded minimal set of administrative attributes. Data collection is done in an integrated way: the boundary is stored together with the type of right or people-to-land relationship (ownership, possession, occupation, informal, dispute, etc.), combined with a photo of the owner or claimant and a photo of the id of the owner or claimant. This means that names and other relevant attributes and boundaries (representing measured parcels) can be linked. Digital photos can be attached; existing documents like passports or ID cards, face photos, photos of groups of owners, photos of existing legal documents like deeds or titles and photos of the boundaries can all be linked to the polygon. Often there is more than one claimant for a specific parcel — for example in case of a married couple. For this reason, a share in a right can be recorded for each individual claimant. This can be done during field data collection or afterwards during the public inspection. Data collection can be done online or offline, based on local conditions, in both cases the data gets finally stored in a cloud repository where it can be accessed to follow the process remotely — this 'remote participation' is important for the involvement of stakeholders who cannot be on site.

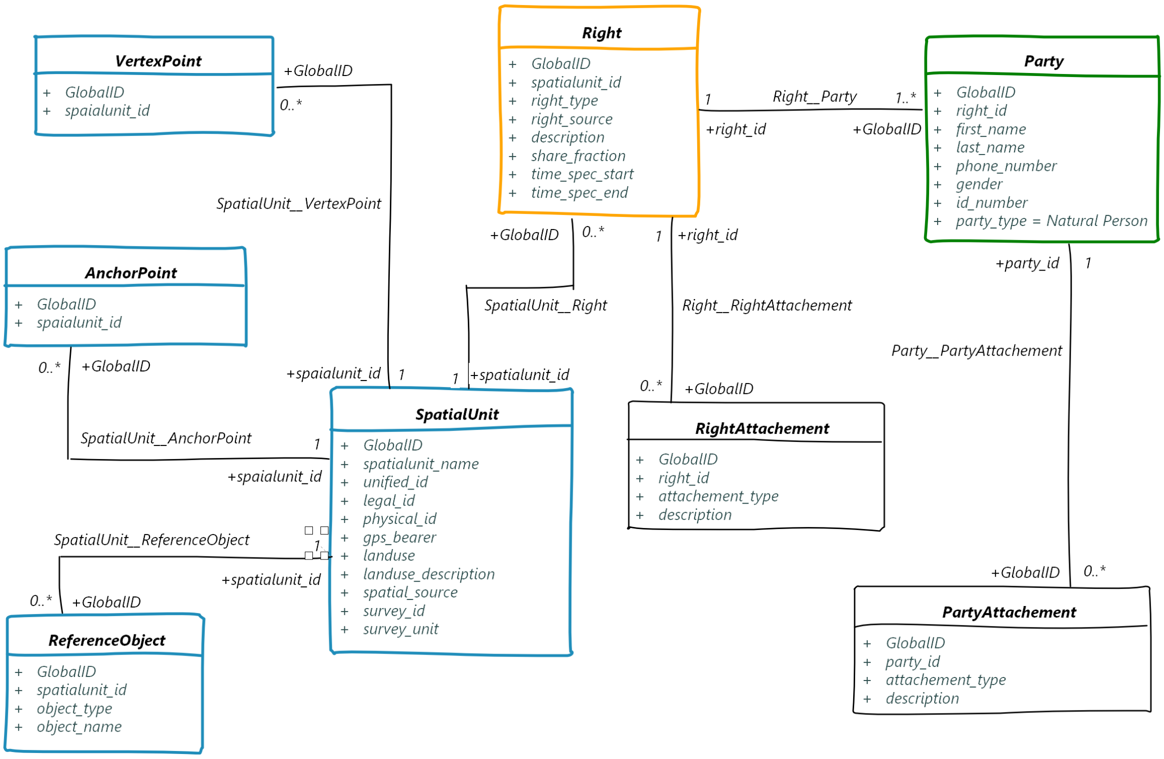

Figure 5 — Data collection data model

To get the required accuracy, regardless of the availability of a local station, the handheld GPS uses Point-to-Point Communication Protocol to communicate with an operations centre through a satellite link or through the internet. The operations centre takes care of generating and delivering precise satellite corrections, which gives the GPS unit real time position at various levels of accuracy. This type of measuring solution is known as Real Time eXtended or RTX (Leandro, et.al., 2011). In the case of Colombia, Trimble R2 devices are used for data collection.

Table 1 – Classes of the data collection data model

Class Name	Class Description
SpatialUnit	Description of a piece of land
VertexPoint	Vertices forming the boundary of a spatial unit
AnchorPoint	Vertices at the intersection of 3 or more spatial units
Reference object	Point representing a non-private object e.g. river, road
Right	Type of relationship associated with a spatial unit
RightAttachment	0 or more images of documents in support of a right
Party	Identity of the person or group associated with a right
PartyAttachment	0 or more images of identity documents of the party

The interface of the FFP App has been adapted to comply with the proposed method and it has also been adapted for the type of users performing the work. Internally, the FFP App uses a specific data model (see Figure 5, which takes care of all the constraints and relationships between the various data objects being collected. The data model shown in Figure 5 has been optimized for efficient data collection. Later, during the post-processing stages, the data is transformed to comply with the LADM standard, or in the case of Colombia, with the LADM-CO profile.

Figure 6 — Data collection result (at the end of stage 3)

Figure 6 shows the spatial data that is collected for every spatial unit. The purple area represents the surveyed spatial unit. Green markers correspond to measured vertices. Orange markers are vertices where neighbouring relationship of the spatial unit changes. A red marker is a reference point, indicating that on that side the spatial unit is not neighbouring private land. In this case, the icon corresponds with a road, but it can also be a river, a national park, a beach, or otherwise. The areas shaded in blue represent other spatial units and are simply shown as reference information.

The FFP professional who coordinates the data collection process is also responsible for checking the data quality. Checks are carried out on the accuracy labels of the surveyed points and also on completeness, which includes the administrative/legal data.

The simplification of the App's interface and its optimization for efficiency have a side-effect in that no application of the shelf can be used. The closest platform that can support the data collection process as stated by the FFP methodology presented here is the Esri field data collection suite. To make the suite fully compliant with our purposes, Esri incorporated the necessary changes to the software into their latest version. Figure 7 shows a couple of screenshots of the Esri Collector App.

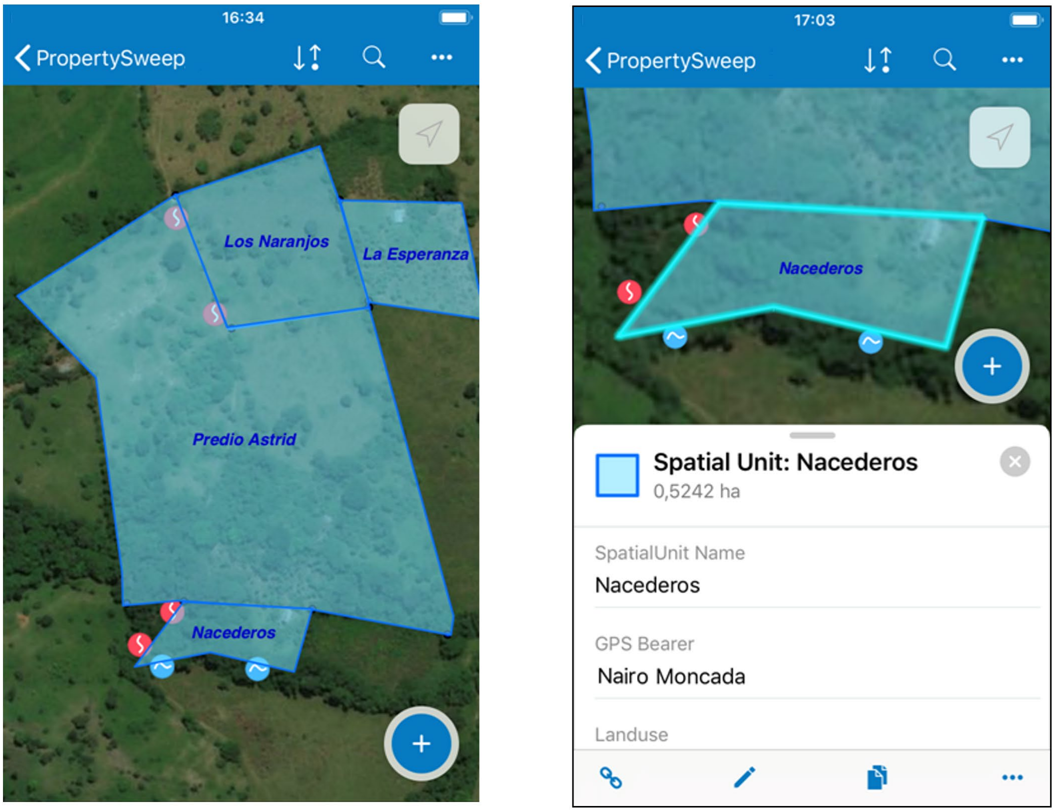

Figure 7 — Screenshots of the Esri Collector App

Walking polygons and observing and collecting boundary points is a process that is easy to explain to, master and execute by farmers and grass-root surveyors. The polygon approach is elegant. Farmers understand from the results that the boundary observations are correct, and they also learn a more precise estimate of the area of their land in being involved. These are crucial factors when it comes to trust in the data that has been collected. Parcel data collected like this, falls under LA_Source class of the LADM standard, just like fingerprints, photos of ID cards, photos of legal documents, etc. do. In the end, all data collected in the field will serve as evidence to support the results of the land registration process.

5. POST-PROCESSING

Citizens collaborate in collecting parcel boundaries and reference points using mobile devices and handheld GPS devices in situ. Reference points serve to record and identify the existence of public or government-owned land not claimed by private landowners. The acquisition protocol assumes the study area is fully partitioned, so gaps without reference points will be flagged as collection error. Examples of area marked with reference points are: roads and other transport infrastructure, rivers and other water bodies and their fringes, public lands incl. reserves, and so forth. The exact coordinates and accuracy of observations for reference points is immaterial. Parcel boundaries are composed of vertex and anchor points. These points are fully georeferenced and carry an accuracy label. The RTX technology used to collect vertex and anchor points provides different levels of accuracy based on the service level that is chosen. Thus far, given the conditions of the terrain and the requirements for surveys in rural areas, all anchor and vertex points have been collected with a service level that provides submeter accuracy.

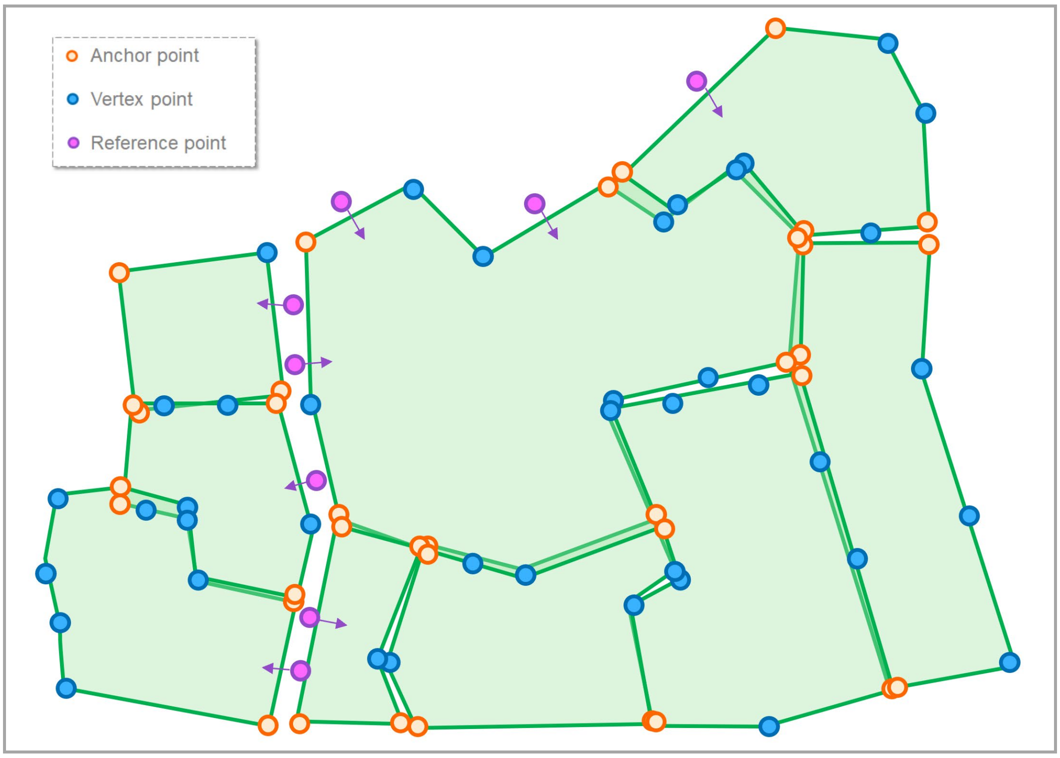

Figure 8 — Schematic representation of the data collected in the field.

Since every landowner surveys her/his own parcel (spatial unit), the boundaries between adjacent parcels are collected twice. Similarly, anchor points, which represent an intersection between multiple spatial units are collected multiple times, by different survey teams, at different times, with different accuracy and possibly with different survey equipment. This provides an excellent control mechanism on the quality of these particular observations. Figure 8 shows a schematic representation of the results of the data collection.

The aim of the post-processing stage is to consume the raw data from the field and then derive, in a semi-automatic way, a topologically valid planar partition of these parcels, that is perceived as accurate reflection of reality, and that it does justice to all landowners and that presents no unfair advantages to any landowner. Original surveyed points are linked to the resulting vertices of the planar partition as sources of the computed value. The approach used here is based on the notion of conflation, which provides a systematic way to process the data, and typically consists of three phases of computing: (1) feature matching, (2) filtering of found matches, and (3) spatial alignment. The result is then a partial topological tessellation of the surveyed study area seen as a multipolygon. The parts are either private land parcels, or public land parcels, with some function, based on the typification of reference points. The tessellation is partial because not all public lands can be expected to have been surveyed. The tessellation is topological in that it has no slivers: no two parts are spatially overlapping, and no unassigned holes are left between two or more parts. The analytic workflow that is execute for every parcel in arbitrary order is:

- Step 1: *Raw data correction*, which aims to clean the originally acquired data from obvious mistakes.
- Step 2: *Public parcel inference*, which aims to create polygonic representatives of public space as suggested by reference points.
- Step 3: *Neighbourhood inferencing*, which aims to identify which parcels (private and public) are each other's neighbour.
- Step 4: *Topological anchor point derivation*, which aims to identify and position the fundamental vertices of parcel boundaries.
- Step 5: *Boundary/boundary reconciliation*, which aims to derive for each shared boundary component the best compromise of where it is positioned.

5.1 Raw Data Correction

The objective of this step is to detect errors in the input data that affect the parcel boundary linestrings. Input data can have errors of different type though: a simple error arises when some private land parcel is surveyed twice, or it is not surveyed at all. These cases too require detection. In the case of boundary linestrings, they should:

- Use only coordinate pairs within the study area,
- Be closed linestrings,
- Not have any self-intersection,
- Not have segment lengths below a stated threshold,
- Not delimit areas below a threshold size,
- Only delineate the outer boundary (i.e., for now we exclude cases where parcels have holes),
- Have appropriately labelled survey points in terms of anchor, vertex and reference points.

5.2 Public parcel inference

The objective of this step is to identify public land that neighbours private land. This is required as the workflow needs to provide protection of public land not being claimed as private illegitimately. Unfortunately, the government in Colombia does not properly maintained spatial records on public lands.

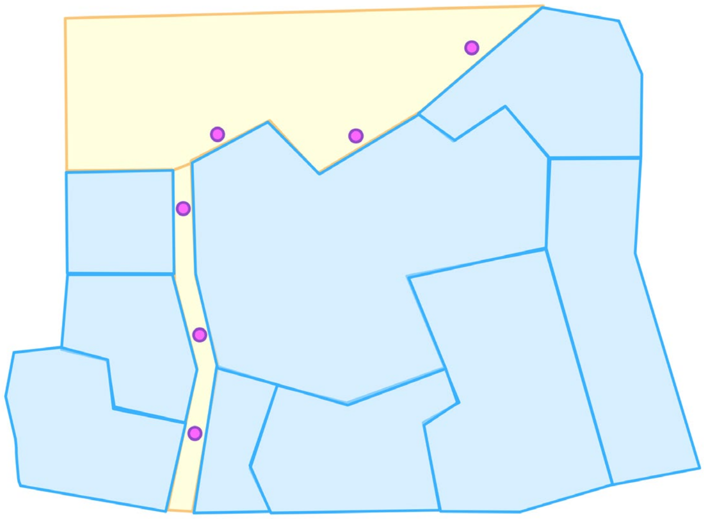

Figure 9 — Public space inference

Private parcels are explicitly georeferenced, but public lands are not. Instead, their existence is marked with one or more reference points (see Figure 9). A set of internal data constraints (relationships between types of points in a spatial unit) and external data constraints (relationships between points of the same type in adjacent parcels) help to define inconsistencies in the specification of reference points that might arise by errors or intentional omissions in the data collection. Ideally, the survey procedure flags every piece of land with public function with two or more reference points. Each point marks the existence of public land from the perspective of all the landowners adjacent to it. We use the term "public land function" here to allow discrimination between public roads and paths, school yards, sports grounds, waterways and other public land functions.

5.3 Neighbourhood inferencing

The objective of this step is to find pairs of land parcels that neighbour each other. There are three cases here. First, a pair of land parcels may be incident in a single point, or they may neighbour along an edge. With the raw (non-crisp, and topologically unresolved) data in hands, these cases may not be so separable directly. Secondly, one (and only one) of the land parcels may be public (The case of the two being public is not of interest as there is no geometric dispute to be resolved.).

When one the two parcels is public, there is no geometry to reconcile against, and so the survey points of the private land parcel define the outcome. Third, there are parcels at the edge of the survey area for which two options exist. Their boundary can be reconciled against the official administrative boundary of the area. Or they can only be reconciled when the adjacent administrative area is also surveyed.

5.4 Topological corner point derivation

The objective of this step is to identify and properly position the anchor points forming the eventual topological tessellation. This is the first step where we use geometric conflation. Anchor points denote locations where three or more parcels meet. The common case is that of three parcels meeting (see Figure 10). The case of four is still frequent, and higher numbers become gradually more unlikely. These cases should be derived from the results of the neighbourhood inferences of Step 3. Each derived and positioned anchor point should have a fixed (reconciled) position and possibly a precision assessment, that is derived from the precisions associated with the contributing raw survey points.

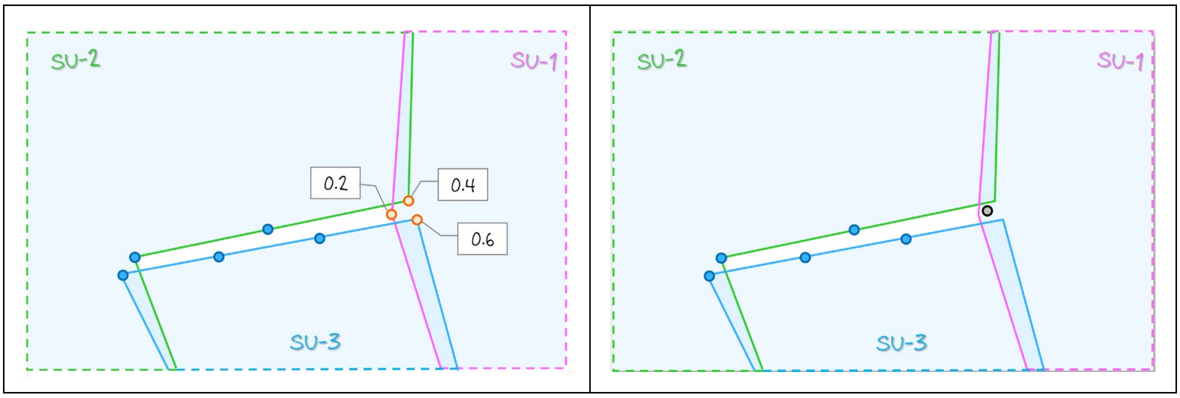

Figure 10 — Observed anchor points with accuracy labels (left), derived anchor point (right)

Reconciliation of a corner point aims to determine its most-likely position, which can be done in different ways. Here this is done using the associated precision metrics (accuracy labels) of the participating points, which are used to derive a weighted average position. This assumes we are working in a metric (projected) coordinate system.

5.5 Boundary/boundary reconciliation

The objective of this step is to identify and properly position the shared boundary edges between pairs of neighbouring parcels.

There are two cases here: the more general private/private pair, and the more degenerate private/public pair. In the latter, no geometry needs to be reconciled because public lands do not contribute survey points to the process.

The reconciliation process aims to do justice to the survey points at both contributing sides. At this stage, the principle of "assigning equal area" can be implemented, and we have chosen to pursue such (see Figure 11). This principle can be phrased as the combination of the following rules:

- In the shared boundary zone, no land is assigned to the neighbour parcel if it is not contested by the neighbour vertex points presented.

- The contested part of the boundary zone is defined as the union of overlaps and "un-derlaps," and it is divided in such a way that an equal (or fair) amount of land area is assigned to the two neighbours.
- Deviation from the equal area principle is possible, but only on the basis of vertex point precision metrics, recognizing that a higher precision is a firmer establishment of a vertex point location.

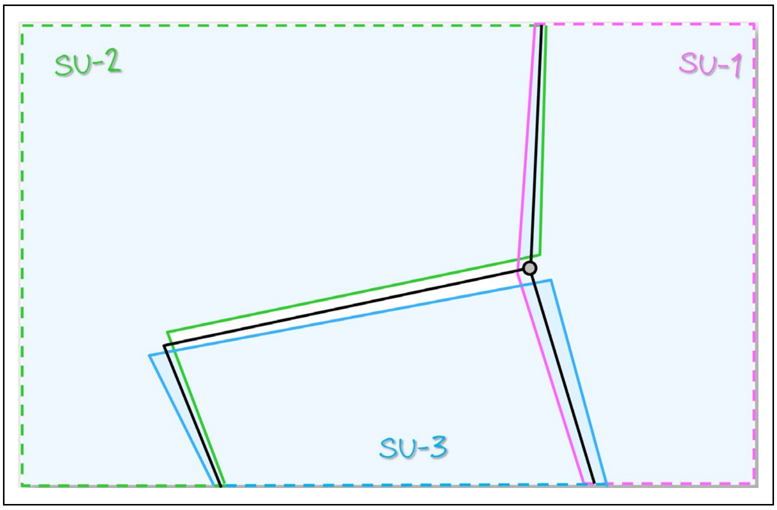

Figure 11 — Reconciled boundary

In the former case of private/private parcels, a shared boundary edge should be produced for each neighbour pair. This will use the already reconciled corner points of Step 4. A shared boundary edge is always non-self-intersecting. In the common case, it is not closed either. A probably rare case is that where a private land parcel is completely nested within public lands, and then the shared boundary edge is actually closed.

The functionality required for post-processing has all been implemented and coded within a database management system using SQL or PL/pgSQL. Figure 12 shows a schematic representation of the data before and after post-processing. On the right, it shows the resulting tessalation including all private parcels but excluding all inferred public land.

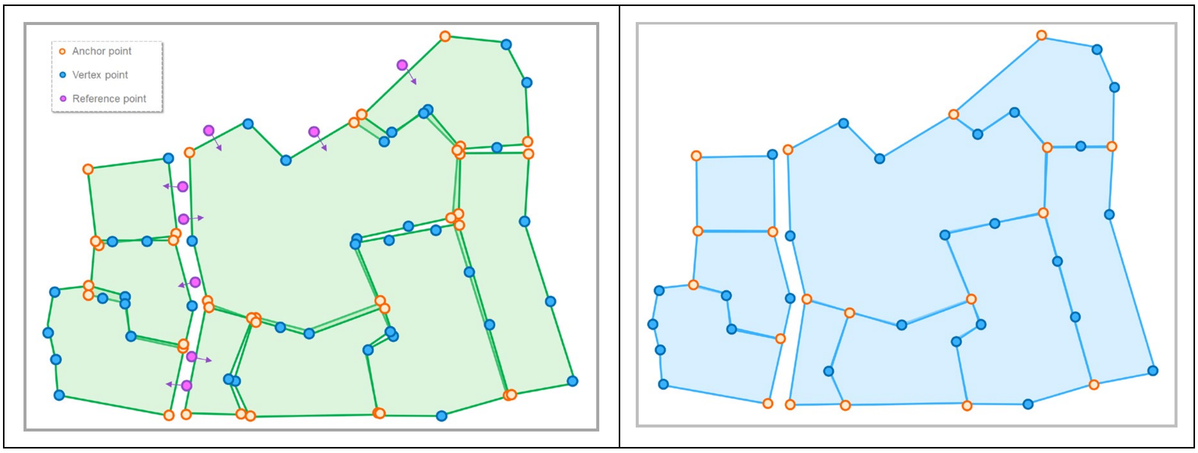

Figure 12 — Original data (left), final tesselation excluding public function land (right)

It is fundamentally important to get an overview of parcels or boundaries where the opinions about a boundary's location differ between neighbouring rightholders. These differences (overlaps) are shown in a map as spatial units with a shared conflict right by participating parties. These parties should try to agree during the public inspection on the location of the boundary that generates the discrepancy. This is done with the participation of an expert who facilitates the process. In cases where no agreement is reached, the corresponding authorities can then act according to the regulations to address the issue. During the FFP pilots, two boundaries whit discrepancies were mapped and in both cases the parties came to an agreement during the public inspection.

6. PUBLIC INSPECTION

Once a proper topological representation of the parcels in the surveyed area has been obtained, it is necessary to share the results with the community to obtain their approval. This is achieved by the execution of the so-called public inspection. Procedures such as public inspections, are conducted at village meetings accompanied by authorities. The community members gather to view all the collected and derived data on a big screen and to discuss and reconcile the results. It is important that all owners and claimants are present during the event — for example, in case of a married couple that both partners, husband and wife, are available to provide their approval.

During the public inspection, all owners and claimants are called forward to validate the data about their parcels. In this occasion, the claimant is requested to show her/his ID card. This must to the card photographed in the field during data collection. Then, for each shared boundary of the parcel, the claimants are requested to check and validate its geometry, and to verify the names of the claimants of the neighbouring parcel. The claimant will digitally confirm her/his approval by providing a digital signature or a digital fingerprint. Figure 13 shows various screenshots of the Public Inspection App interface.

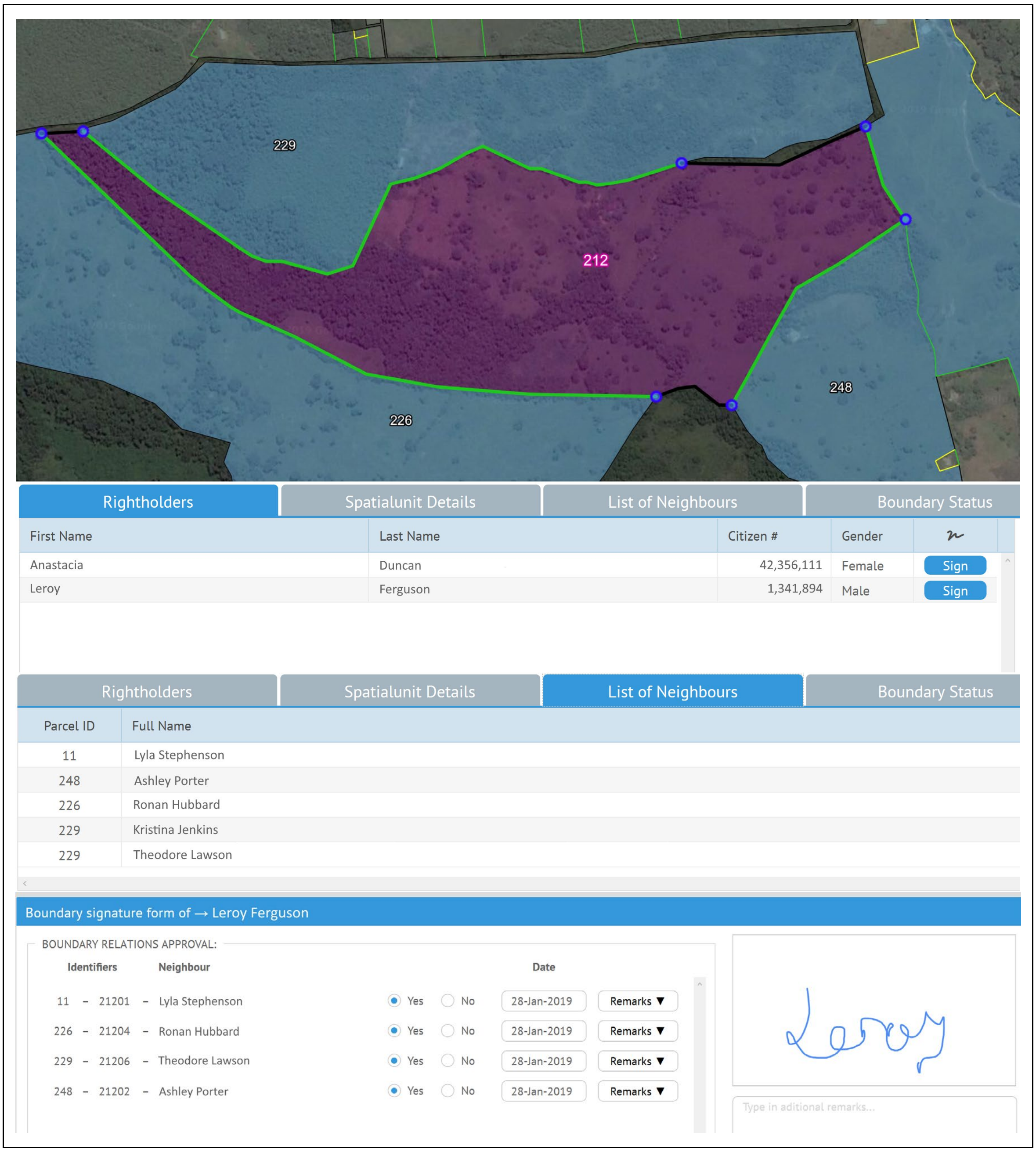

Figure 13 — Interface of the Public Inspection Aap (names have been made up by the authors)

During the approval process, the map displaying the parcels is constantly updated to show the status of the process. At the beginning of inspection, all parcel boundaries appear black on the map. The black colour indicates that none of the claimants sharing that boundary has given approval. Once one or more of the claimants have processed and approved the various aspects of the data of the boundary, the colour of that boundary will turn yellow. When all claimants from both parcels have followed the procedure and approved the boundary data, the colour of the boundary will change to green. In case any of the claimants disagrees with the data, the colour of the boundary will change to red. In such case, the public inspection app allows the claimant to provide detailed arguments on which s/he bases the disapproval. Subsequently, mediation by a government actor and the village board is required and, in most cases, the dispute is then quickly resolved.

An example of the intermediate state of boundaries of a parcel during the public inspection is shown in Figure 14. Participation of the entire community and transparency of the FFP process contribute to agreeing on the boundary data. Despite general expectation to the contrary, we are seeing a low number of objections to boundaries in practice.

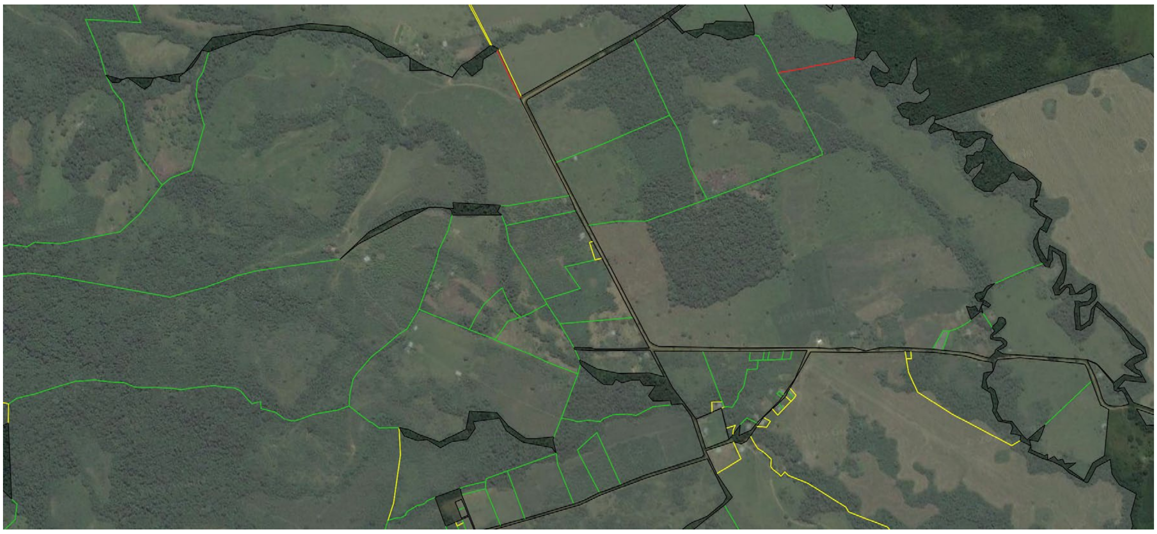

Figure 14 — Intermediate stage of the boundary approval during public inspection

The Public Inspection App is a Web application so that it is easily accessible for the approval process. This allows the process to be followed remotely by external actors. If the approval process takes a few days, the whole community can check its status over the Web. It also makes it possible for the boundary approval to be done at different moments in time, in case when a claimant cannot be present during the public inspection.

Once all the boundaries of a parcel have turned green, a so-called boundary act ('Acta de Colindancia') can be produced. The boundary act, which contains the approval signature of all neighbours around the parcel, is a precondition for acquiring a land title.

7. CONCLUSION

Several pilot projects have been executed in Colombia to test, adapt and optimise the FFP methodology presented here. Modifications have been made to the various steps as well as to the technology that supports them. Additional pilots are in the pipeline that aim to extend the methodology to cover a number of ad hoc cases. The creation of community awareness is a crucial success factor in these pilots. Especially in post-conflict areas, people tend to mistrust governmental plans and actions. The communities have shown an eagerness to cooperate and have welcomed the authorities investing in the development of their areas. At the same time, these experiences and lessons learned have to be reflected in the national policy plans so that the methodology can be scaled up and out in the country. The parties involved are Kadaster

International, ITC Faculty of University of Twente, the National Land Agency (ANT), the Colombian Register (SNR), the Colombian Mapping Agency (IGAC), the Cadastre of the Department of Antioquia, the Amazon Institute for Academic Research (SINCHI), the Distrital University in Bogotá and the Colombian National Planning Agency (DNP). This network receives support from the Dutch Ministry of Foreign Affairs and the Dutch Embassy in Bogotá.

The polygon approach is elegant. Farmers immediately understand from the presented results that the boundary observations are correct, and they also get to know a more precise estimate of the area size of their land at the moment of survey. These is crucially important for the trust it builds in the data that is collected. The inclusion of grass-root surveyors has allowed us to execute a fast and reliable data collection process. Similarly, they help the municipality with the maintenance of its cadastral system by repeating the survey process when modifications such as parcel splits and merges take place. The community has come to understand the importance of properly recording all land transactions in the cadastral system, to retain legality of documents and associated rights, and to allow their legal protection by the government.

The software technology for field data collection has benefited from the pilot projects, and the versioning cycle of the Collector app has shown improving functionality and robustness. This application not only provides support for sophisticated professional surveys, but now also for more basic surveys that comply with FFP methodology. For these settings, robustness and ease of use are key characteristics. This development undoubtedly opens opportunities to address the many data collection problems that are so common in developing economies.

The project's methodology has proven to be applicable and produces land titles and tenure security for the rural population of Colombia as we speak. The first land titles based on this methodology were handed out in late 2018 in attendance of the Dutch Prime Minister, the Colombian Minister of Agriculture, ANT's director, the Dutch Ambassador in Colombia and Kadaster representatives. High level commitment has turned out to be crucially important for the awareness at national political level about the surge to speed up land titling and switch from traditional methods of land titling to Fit-For-Purpose methods. Institutional cooperation is established in the context of the Kadaster project and other land administration projects in Colombia. It should be noted that Colombia developed a land administration infrastructure based on an International Standard: The Land Administration Domain Model — under implementation in Colombia with cooperation from Switzerland.

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