






## Article

# Geospatial Tool and Geocloud Platform Innovations: A Fit-for-Purpose Land Administration Assessment

Mila Koeva <sup>1,\*</sup>, Mohammed Imaduddin Humayun <sup>2</sup>, Christian Timm <sup>2</sup>, Claudia Stöcker <sup>1,3</sup>,  
Sophie Crommelinck <sup>1</sup>, Malumbo Chipofya <sup>1</sup>, Rohan Bennett <sup>4,5</sup> and Jaap Zevenbergen <sup>1</sup>

- <sup>1</sup> Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, 7514 AE Enschede, The Netherlands; claudia.stoecker@uni-muenster.de (C.S.); sophie.crommelinck@gmail.com (S.C.); m.c.chipofya@utwente.nl (M.C.); j.a.zevenbergen@utwente.nl (J.Z.)
- <sup>2</sup> Hansa Luftbild, Nevinghoff 20, 48147 Münster, Germany; humayumo@hansaluftbild.de (M.I.H.); timm\_chr@web.de (C.T.)
- <sup>3</sup> Institute for Geoinformatics, Westfälische Wilhelms-Universität Münster, Heisenbergstrasse 2, 48149 Münster, Germany
- <sup>4</sup> Swinburne Business School, Swinburne University of Technology, Hawthorn, VIC 3122, Australia; rohanbennett@swin.edu.au
- <sup>5</sup> Kadaster Netherlands, The Dutch Cadastre, Land Registry, and National Mapping Agency, 7300 GH Apeldoorn, The Netherlands
- \* Correspondence: m.n.koeva@utwente.nl; Tel.: +31-53-487-4410



**Citation:** Koeva, M.; Humayun, M.I.; Timm, C.; Stöcker, C.; Crommelinck, S.; Chipofya, M.; Bennett, R.; Zevenbergen, J. Geospatial Tool and Geocloud Platform Innovations: A Fit-for-Purpose Land Administration Assessment. *Land* **2021**, *10*, 557. <https://doi.org/10.3390/land10060557>

Academic Editors: Stig Enemark, Robin McLaren, Christiaan Lemmen and Francisco Manzano Agugliaro

Received: 14 April 2021  
Accepted: 19 May 2021  
Published: 26 May 2021

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

**Abstract:** The well-recognized and extensive task of mapping unrecorded land rights across sub-Saharan Africa demands innovative solutions. In response, the consortia of “its4land”, a European Commission Horizon 2020 project, developed, adapted, and tested innovative geospatial tools including (1) software underpinned by the smart Sketch maps concept, called SmartSkeMa; (2) a workflow for applying unmanned aerial vehicles (UAV); and (3) a boundary delineator tool based on the UAV images. Additionally, the consortium developed (4) a platform called Publish and Share (PaS), enabling integration of all the outputs of tool sharing and publishing of land information through geocloud web services. The individual tools were developed, tested, and demonstrated based on requirements from Rwanda, Kenya, Ethiopia, and Zanzibar. The platform was further tested by key informants and experts in a workshop in Rwanda after the AfricaGIS conference in 2019. With the project concluding in 2020, this paper seeks to undertake an assessment of the tools and the PaS platform against the elements of fit-for-purpose land administration. The results show that while the tools can function and deliver outputs independently and reliably, PaS enables interoperability by allowing them to be combined and integrated into land administration workflows. This feature is useful for tailoring approaches for specific country contexts. In this regard, developers of technical approaches tackling land administration issues are further encouraged to include interoperability and the use of recognized standards in designs.

**Keywords:** fit-for-purpose; land tenure; land administration; UAV; feature extraction

## 1. Introduction

Land tenure security supports orderly land dealings, poverty reduction, dispute minimization, and overall sustainable development. Delivering “tenure security for all” is one of the implied objectives of the sustainable development goals (SDGs)—target 1.4—set by the United Nations (UN) [1]. It can influence household income, food security, and equality [2,3]. However, millions of people-to-land relationships are still not recorded and remain unknown to governments [4].

This situation, unfortunately, is a fact in Sub-Saharan African countries [5]. With conventional cadastral surveying and mapping approaches, full completion would take decades, if not centuries [6]. Furthermore, there are many legal, social, and historical differences between the countries: it is hard to develop a unique scalable approach.

Across the 2000s and 2010s, significant effort was undertaken to improve the situation. In support of the development of an efficient land administration system, the Land Administration Domain Model (LADM), aimed at establishing a common ontology of land administration concepts, was proposed [7,8]. In addition, the Fit-For-Purpose (FFP) approach was developed, encouraging participatory, innovative, and scalable methods that match the needs [9] and challenges of a specific country context [4]. One of the key principles of FFP was to use “general” rather than “fixed” boundaries, using participatory mapping based on image interpretation [10]. Good examples of implementation of the FFP for land administration are found in Ethiopia, Rwanda, Namibia, and Indonesia, among others [11,12]. FFP includes principles that cover spatial, legal, and institutional country aspects [13]. The seven main elements based on the FFP concept [14] that the land administration system should take into account are:

- **Flexible** in the spatial data capture process to provide information about the different uses and occupations of the land;
- **Inclusive** in the extension to cover all types of tenure and all types of land;
- **Participatory** in the manner to capture and use data, ensuring community support;
- **Affordable** operation for the government and society to use it;
- **Reliable** regarding the information, it should be authoritative and updated;
- **Attainable** to create a system within a short time frame and with the available resources;
- **Upgradable** regarding improvement over time to respond to social and legal needs as well as economic opportunities.

In response to the need for innovative solutions based on FFP principles, the “its4land” H2020 project was initiated [15,16]. The project aimed to develop technologies that consider the needs and readiness of the users that are implementable and scalable. They include (1) smart Sketch maps—also known as SmartSkeMa; (2) a UAV workflow and ortho generator; (3) a boundary delineator tool based on the UAV images; and (4) the Publish and Share (PaS) platform providing geocloud services.

In the following section, the development of the tools is briefly described, referring to the publications over the years [5,16–19]. More emphasis is put on the description of the PaS platform, which was the last to be developed in the design sequence and has therefore undergone less formal assessment. Subsequently, the methods for assessing the tools and the platform against the seven fit-for-purpose elements are described. In Sections 4–6, from an academic perspective, a critical results assessment, feedback, and ways forward, in terms of future research and scaling activities, are provided. From a practical standpoint, it is suggested that the work at hand can help in improving the geospatial tool and geocloud platform solutions, and that focus should be placed on ensuring interoperable tools to support the successful upscaling to the its4land toolbox (suite of tools) and Fit-For-Purpose Land Administration (FFPLA) more generally.

## 2. Background: “its4land” Tools and Platform

### 2.1. SmartSkeMa

SmartSkeMa was developed to document land rights information, taking into account the local knowledge of the communities. SmartSkeMa tool includes: (1) a developed domain model that uses the land tenure characteristics as described by communities that live with them; (2) a spatial model based on hand-drawn sketchmaps; (3) a method for recognizing and georeferencing the sketchmaps and embedding them into the land information system (spatial datasets) [20]. The tool can be used in two ways (1) by overlaying the vector data on top of the Sketch maps; or (2) by aligning the sketches with an orthophoto image [21]. In addition, the nonspatial information can be processed via local domain model (LDM) which is connected to the Land Administration Domain Model (LADM). Spatial information is extracted via the object detection techniques. An example of the workflow and its implementation can be found in [15,16].

## 2.2. UAVs

The UAVs solution involved developing a workflow to incorporate the tasks of choice of the vehicle, investigation of the regulations and policies, pilot training and certification, flight permissions, data capture, processing, and quality assessment. During the project, numerous flights and missions were completed and assessed depending on the country aim. In Kenya, where pastoralism is a dominant land use and spatial information is not mapped numerous flights have been done and scientific comparison of the results was performed. More details on the data acquisition in September 2018 Kajiado and March 2018 Mailua with RGB sensors using DT18, a fixed-wing UAV and DJI Phantom 4 can be found in [16]. In Rwanda, the aim was cadastral map updating using UAV data, since the country supported by international donors, mapped over 12 M parcels in 2007/2008. Therefore, detailed explanations on the application of UAV data acquisition in Rwanda 2017 and 2018 can be found in [22]. In addition, in collaboration with the World Bank a joint survey and data quality assessment was performed in Zanzibar in July 2019. Moreover, the its4land team developed a tool called “OthoGenerator” which is based on the open-source image processing software called “OpenDroneMap” [23]. The tool integrates the processes of generating point clouds, digital surface models, and orthomosaics from images. This tool is integrated into the PaS platform, where the user must specify the required resolution of the output, overlap, context of the scene, and the mode for georeferencing.

## 2.3. Boundary Delineator

The “boundary delineator,” or also called in some of the publication “automatic feature extraction” tool, was developed as an independent QGIS plugin. It incorporates a boundary extraction machine learning method based on RGB satellite, aerial, or UAV images. The methodology includes image segmentation, boundary classification, and interactive delineation [24–27]. The source code is available for download [25]. Numerous examples on the application of the tool have been shared for Kenya and Rwanda in [28–30]. A detailed explanation of the sequence of the work, with the individual tools integrated into the platform, for a case study in Ethiopia, is explained in [15].

## 2.4. PaS Geocloud Platform

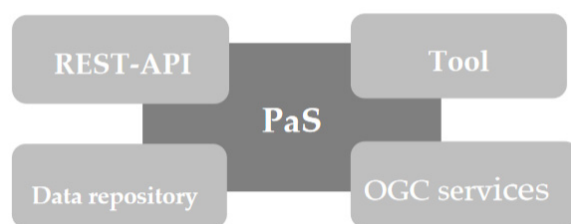
The most recently developed tool in the its4land suite was the “PaS” platform. It aims to support workflows in projects related to land administration [31]. It was premised on the idea that while land administration systems worldwide may differ in detail, most of them have in common some generalizable requirements, functions, and outputs [12,32]. In this regard, a typical definition of land administration refers to “the processes of determining, recording and disseminating information about the ownership, value, and use of land when implementing land management policies” [31]. Every land administration system requires a generalized spatially related reference system as a basis. In contemporary systems, this spatial reference is provided and maintained by a GIS database. PaS focuses on providing the spatial reference for a land administration system.

The PaS platform offers a core set of features that can be customized and extended. The functionalities of PaS are primarily targeted at independent software vendors (ISV) or integrators to create services or applications for end-users. PaS provides a set of high-level geocloud-based services for developers of land administration systems to use or integrate spatial references for tenure registration. Using these services allows a vendor to concentrate on functionalities required by their customer instead of re-implementing existing solutions for common problems. These services are based on the concepts introduced by LADM. To improve or assist land administration workflows and tasks, four different usage models for the platform were developed:

- **Application:** A self-contained application for an end-user which uses the Application Programming Interface (API) provided by the platform.
- **Integration:** PaS functionality is used to host a Land Administration workflow, or parts of it.

- **Tools:** Applications with self-contained functionality, which use the API for integration with other tools or applications.
- **Platform extension:** Adding new core functionalities to the platform.

The platform is capable of hosting and integrating tools and data to facilitate land tenure recording services and applications. This allows the complementary tools and methods, developed in the its4land project—which use images captured by UAVs [33–36], qualitative data processing using Sketch maps [21], and Boundary Delineation [18,37–40]—to be integrated coherently into existing or new land administration workflows. For seamless integration with existing systems, PaS is implemented on standards such as Representational State Transfer (REST) [41], LADM, and Open Geospatial Consortium (OGC) Web Services (OWS). It is composed of technical components shown in Figure 1.



**Figure 1.** Components of the PaS platform.

In more detail, these PaS elements are:

- A public REST over HTTP API that allows tools and applications to interact with the PaS platform. The choice of an HTTP API allows applications to be developed in a wide variety of programming languages;
- A tool runtime environment for Smart Sketchmaps, UAV image processing, boundary delineation, and other tools. Since computing resource usage of some of the tools can be quite demanding, they are started on-demand via the API;
- A data repository for alphanumeric, geo, binary, and image data. Data are added or manipulated via the API;
- OGC services for data dissemination. These allow usage of GIS such as QGIS to access maps and query data via services such as WMS/WFS.

The implementation of the PaS platform follows a toolbox approach (integration of tools) and provides a framework consisting of standard APIs and services used by all other its4land tools. From this toolbox, users can select those its4land tools fitting their tasks best. All components developed for PaS are open-source (<https://github.com/its4land/publish-and-share>, accessed on 24 May 2021). The components can be hosted in a cloud environment such as Amazon Web Services, Microsoft Azure, or a private cloud environment.

The development of the PaS platform was one of the key exploitable results of the its4land project. The utility of the platform in implementing abstract concepts from LADM in a programmatic manner enables building usable land administration systems on top of it. Additionally, the platform also demonstrated how innovative tools serving a niche purpose could be tied together, enabling the use of innovative methods where traditional land tenure recording methods fall short or require immense effort.

The geocloud services provided by PaS are based on the conceptual model introduced by LADM. These concepts are abstract, and their concrete meaning depends on country-specific interpretation. By providing a means to define and implement concepts from LADM, PaS can provide the necessary information to a land administration system that is needed for legal registration. A developer familiar with LADM will recognize concepts such as SpatialUnits or AdminSources and can map them to the structures and localized meanings needed by a specific land administration system.

The current version of PaS focuses on the capture of data for subsequent registration in a land administration system. Therefore, only a subset of LADM is implemented. In

practice, this means that PaS can handle all those LADM concepts which deal with the evidence of land rights and thus enables a legally secure registration of rights by a land administration system. The following concepts of LADM are supported in PaS as shown in Table 1 below:

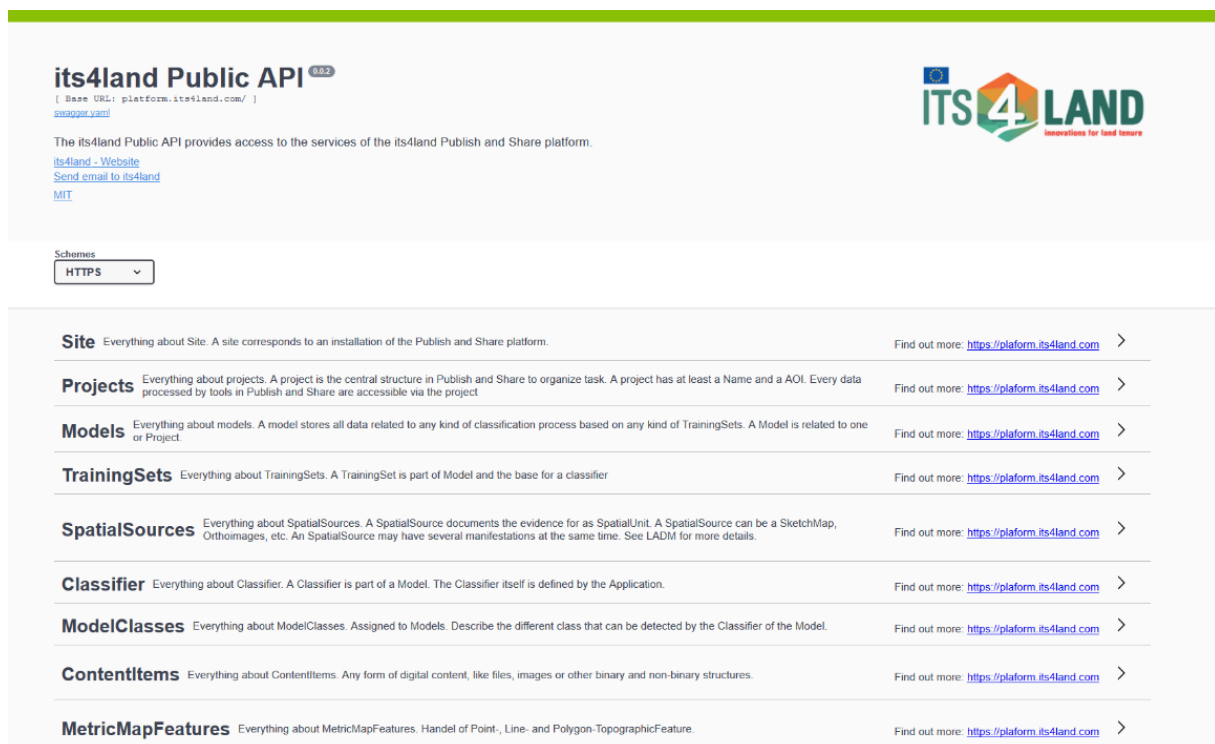
**Table 1.** Concepts from LADM supported by PaS.

LADM Concept	Usage in PaS
LA_SpatialUnit	<p>LA_SpatialUnit is the spatial reference in an LADM-based Land Administration System (LAS). It is used in PaS because it is the spatial reference for any kind of tenure registration. The interpretation of LA_SpatialUnit provided by PaS is subject of the context, including the legal framework in which PaS is used.</p> <p>Example 1: A SpatialUnit is a parcel that was created by the <i>Boundary Delineator</i> tool.</p> <p>Example 2: The <i>SmartSkeMa</i> tool produces spatially demarcated interest in land, which is treated as LA_SpatialUnit.</p>
LA_Level	<p>LA_Level can be used to group LA_SpatialUnits with a geometric or thematic coherence.</p> <p>Example: Distinguish SpatialUnits, which represent different types of community land, such as seasonal pastures.</p>
LA_BoundaryFaceString	<p>LA_BoundaryFaceString forms the outside of LA_SpatialUnit in a 2D geometric representation. It represents a general or fixed boundary. According to the principles of Fit-For-Purpose it is treated in PaS as a general boundary. A land administration system can use boundary face strings to create SpatialUnits as needed in the specific implementation.</p> <p>Example: The <i>Boundary Delineator</i> tool produces general boundaries, which are managed as BoundaryFaceStrings in PaS.</p>
LA_SpatialSource	<p>LA_SpatialSource documents the evidence of a spatial unit or a boundary face string. It can either be an input or output of a step in the workflow. A LA_SpatialSource can be any kind of document, such as orthomosaics, images, surveying sketches PaS does not restrict it to a specific type. How a SpatialSource is interpreted forms part of the use of PaS, in a specific project or implementation.</p> <p>Example 1: The SketchMaps used in <i>SmartSkeMa</i> are treated as SpatialSources</p> <p>Example 2: Orthoimages produced by the <i>UAV Ortho Generator</i> are treated as LA_SpatialSource as well. They are used by the <i>Boundary Delineator</i> a starting point to delineate boundaries.</p>
LA_AdministrativeSource	<p>LA_AdminSource documents the evidence of an interest in land. This includes rights, restrictions, responsibilities, and the involved parties. The documents can be any kind of document and files—from a scanned contract to a recorded narrative description of alternative concepts of land rights. According to Fit-for-Purpose principles, this addresses inclusive and participatory dimensions since it allows a formalized documentation of evidence of interests in land in a wide range of ways.</p> <p>The interpretation of a LA_AdminSource Document is part of the use of PaS, in a specific project. This depends highly on the legal framework of the country where the project is conducted. The legally valid registration itself is done in a LAS.</p> <p>Example: <i>SmartSkeMa</i> captures information about land rights and land usage based on community-related ontologies. The LA_AdminSources information is stored in a structured form in PaS. Furthermore, it is linked LA_SpatialUnits which are created by <i>SmartSkeMa</i> as well.</p>

The PaS platform offers developers and system integrators a Public API on top of which custom applications can be built or platform features integrated into existing land administration systems. The API provides an implementation for LADM concepts such as spatial sources and spatial units, among others, such that they can be used in a pro-

grammatical fashion in an information system. Linking different concepts, as required by the implemented workflow, can be performed by the API. A parcel can be linked to an orthoimage or a Sketch as their SpatialSource. It can also be linked to a file that documents the ownership of that parcel. During the legal registration in a LAS, the user of the LAS can access this information and relationships to prove the evidence easily.

The API itself is a REST API [41] and is served over HTTP(S). Implementing a REST API makes integration on any platform or programming language seamless. Figure 2 shows the main user interface of the online documentation of the Public API (Public API is used here to differentiate from an internal private API used to extend the platform itself). The document acts as a reference for developers to interact with the platform to perform tasks such as creating instances of concepts and adding and querying information to the instances. In addition to this, the platform website (<https://platform.its4land.com>, accessed on 24 May 2021) offers additional documentation and guides for developers, integrators and other users to familiarize themselves with its concepts and usage.



**Figure 2.** The main user interface of the online documentation of the Public API.

The Public API lends itself to multiple usage models discussed previously. These include an end-user who interacts using only a GUI client, a developer wishing to extend their legacy land administration system with features of PaS, or wanting to extend and customize the platform itself. The API is designed to achieve these workflows by following the OpenAPI 2.0 (<https://spec.openapis.org/oas/v2.0.html>, accessed on 24 May 2021) standard for specification, which allows the generation of interactive documentation that includes examples.

The platform's Data Dissemination Interface (DDI) provides an alternative means of accessing spatial data stored in PaS. Compared to the Public API, the DDI allows limited read-only access to data via OGC services such as WMS/WFS. The DDI is useful to access LADM spatial concepts such as spatial units or boundary face strings. DDI also provides high-performance access to orthoimages and other raster data stored in PaS via WMS services. The main advantage of the DDI is the ease of use. Nearly every popular GIS Tool can use OGC services out of the box. This allows lightweight data access by workflows

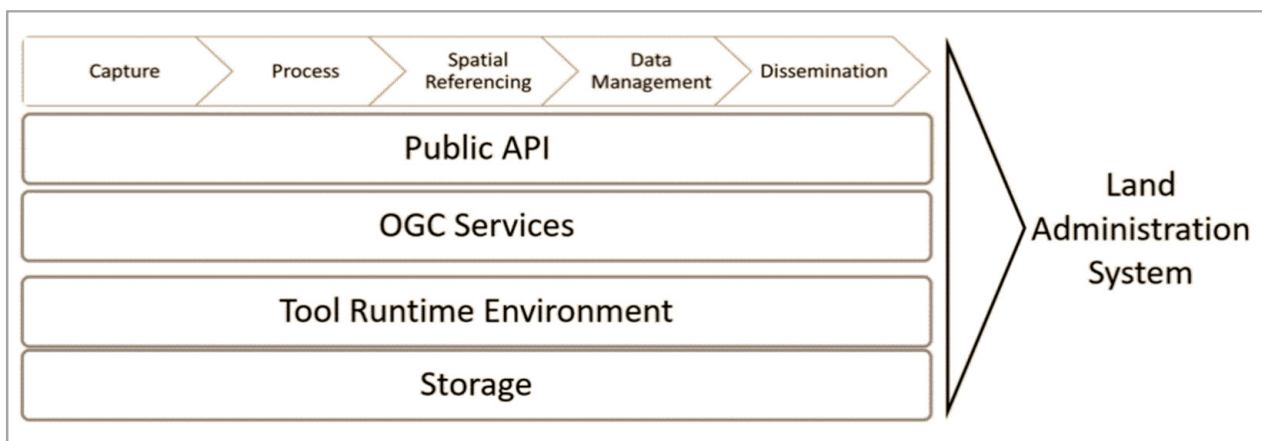
developed by the application or integration usage model. The Public API requires more effort on the client-side to handle requests and responses. However, on the other hand, the Public API allows better control, such as advanced filtering capabilities compared to the WFS interface. If data should be manipulated, the use of the Public API is required. Table 2 provides an overview of the available spatial data classes in PaS and their access services in DDI.

**Table 2.** Spatial data classes in PaS (X indicates support).

Data	WMS	WFS	Remarks
Spatial Unit	X	X	Only 2D polygon profile
Boundary Face String	X	X	
Metric Map Feature	X	X	
Orthomosaic	X		
Other Raster Data	X		
Other Vector Data	X	X	

#### 2.4.1. Tool-Based Workflow

Tools and services built using features provided by PaS enable innovative workflows, which can be integrated into a land administration system. As depicted in Figure 3, the components provided by the platform support a workflow from capture to dissemination of data, including the intermediate steps, the output of which is ready for consumption by a land administration system.



**Figure 3.** Abstract workflow of PaS.

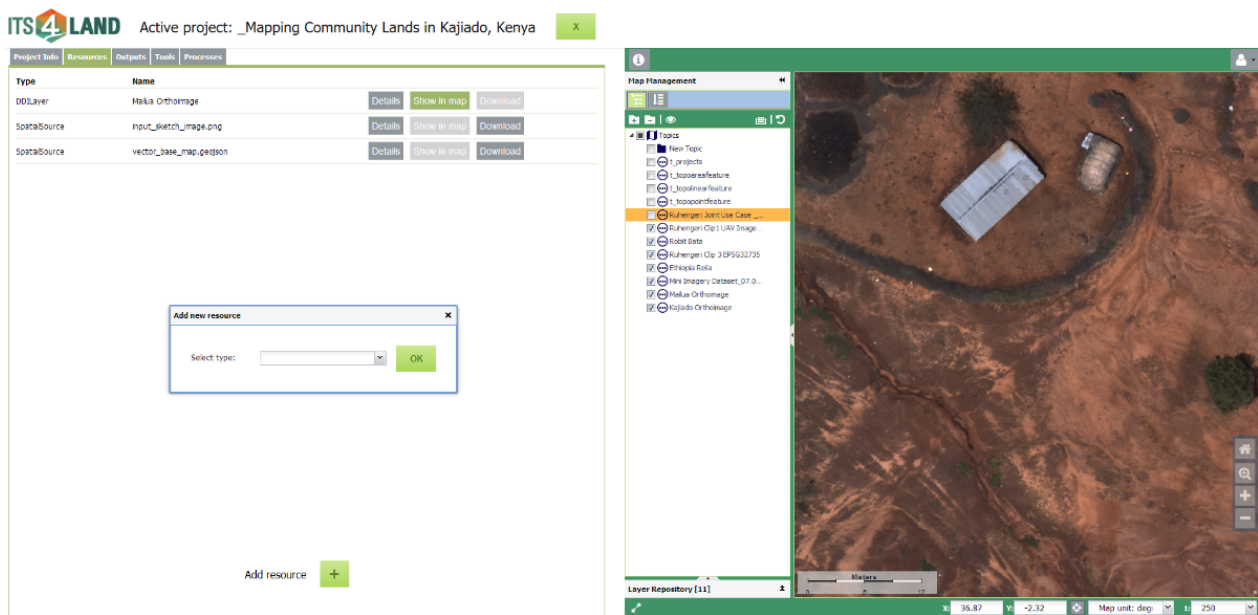
To add a tool, a developer creates an application in a programming language of their choice and uses the REST API to communicate with PaS. Tools may be made available and run on the platform itself. In this case, the tool is packaged using Docker (<https://www.docker.com/>, accessed on 24 May 2021), added to the PaS server and registered on the platform by the administrator. The its4land tools—UAV Orthogenerator and SmartSkeMa were made available this way. The alternative is for the tool to run outside the PaS environment, which was the model used by the Boundary Delineator tool, since it was a QGIS plugin. In both cases, the PaS API provides various endpoints to read and write data. Tools available and registered in the PaS environment may be started/stopped and their execution status queried via the tools endpoint. A PaS-based workflow consists of executing tools at various stages, often using the output of one tool as the input to another.

The its4land project demonstrated how innovative tools could be orchestrated to provide a coherent workflow to capture and process spatial information from non-traditional sources. This workflow used all the developed tools—UAV Ortho Generator, SmartSkeMa,

and the Boundary Delineator. Likewise, a client web application used the public platform API to provide a user interface to carry out different steps in the workflow.

A typical workflow consists of the following steps, all of which are performed via the API:

1. Create a project context by specifying the project metadata—name, description bounding box, tag, external links.
2. Add resources to the project (Figure 4). Resources can be of the type Spatial Source or DDI Layers (served via OGC). Additionally, tool-specific resources such as validation sets required by the Boundary Delineator tool can also be added. The tool developers specify what kind of resources are supported and what metadata are required for execution. Figure 4 shows this being accomplished via the client web application.
3. Once resources have been added, tools can be started within the context of the project by providing the required parameters. The tools can access the requisite resources within the project context, process them and add the output back to the project. It is not a requirement for all tools to run on the cloud platform. For instance, the Boundary Delineator tool was developed as a QGIS plugin and runs locally on the user's workstation. The input and output data for such tools, however, are optionally stored on the platform when used in conjunction with complementary tools.
4. Different its4land tools produce different outputs. For e.g., SmartSkeMa produces spatial units, while the Boundary Delineator produces BoundaryFaceString—both concepts from LADM. Other tools such as the UAV Ortho Generator produces an orthomosaic (DDI Layers), which are used as inputs for the next tool.



**Figure 4.** Client Web Application—Adding Resources.

The UAV Ortho Generator tool is based on and allows the creation of orthomosaics from imagery captured by unmanned aerial vehicles (UAVs). ODM is open source and freely available. However, in most projects, the creation of orthomosaics involves extensive image processing. Depending on the workload, the limited processing and storage capacities of PCs and mobile devices can prove insufficient. Offloading such workload to the cloud, where processing can be scaled up on-demand, is ideal. The UAV Ortho Generator of the PaS platform provides this solution and allows the processing of large datasets even though local processing capacities are limited. Upon starting the tool, the status of the execution can be queried via the API. Once the orthomosaic is generated, it is added as a resource within the project context. An internally carried out step here involves optimizing the resulting orthomosaic in the Cloud Optimized GeoTIFF (COG) format for cloud-based





2. PaS can host the necessary workflows for these tasks and provide the results to the LAS for formal registration.
3. Forming new interests in the cadaster (such as subdivision or merging)—To apply changes to the cadaster, information must be gathered in advance, which documents the evidence of the changes. These are documents that describe the target situation in the cadaster, but could be also the target situation itself, which is registered afterwards by the LAS.
4. Determining boundaries—Determining new boundaries in a cadaster requires a complex workflow and several documents to confirm the correctness of the new boundaries (like survey sketches or orthophotos). This workflow can be implemented on PaS and the results can be provided as a boundary face string to the LAS, which creates parcels according to regulatory standards in the LAS.

#### 2.4.2. Example Workflow

To better illustrate how PaS facilitates Land Administration workflows, Figure 6 offers a glimpse of how it was applied to a proof-of-concept scenario in Ruhengeri, Rwanda. In this scenario, an orthophoto of the study area was created using data collected from UAVs. The orthophoto was used to create precise geometries from visible boundaries using the Boundary Delineator. SmartSkeMa made use of hand-drawn maps collected via participatory mapping. This resulted in less precise geometries, but it allowed recording of information on the right restrictions and responsibilities (RRR)S formed the glue, allowing both tools and users access to the data, which was its design purpose.

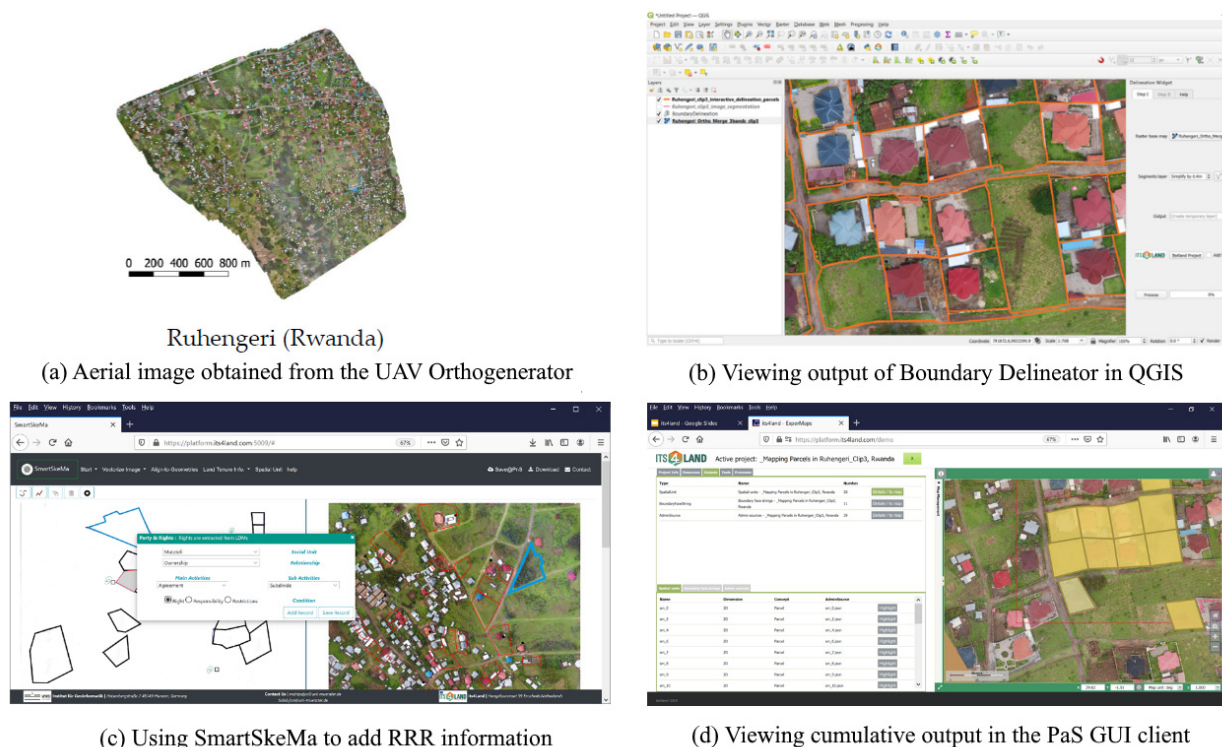


Figure 6. Example workflow using PaS and tool in Ruhengeri, Rwanda.

Figure 6a, depicts a georeferenced aerial orthophoto image of a study area in an urban environment. To generate this orthophoto image, the raw aerial photograph dataset was uploaded to PaS and the UAV Orthogenerator tool was started by setting a few required parameters. Once the tool completed the image processing procedure, the resulting orthophoto image was made available via WMS or directly in a GeoTIFF raster format. The latter was used by the Boundary Delineator in QGIS (Figure 6b) to demarcate visible boundaries. The resulting BoundaryFaceStrings are saved in PaS. SmartSkeMa (Figure 6c)

provided a means to record non-visible RRR information and save the resulting spatial units back to PaS. Storage and exchange of data between the tools was made possible via the PaS API. A demo GUI client (Figure 6d) enabled access to the data uploaded to the platform via a modern web browser, for visualization and editing. Similar scenarios for chosen areas in Kenya and Ethiopia also demonstrated this integrated approach.

In summary, the its4land project developed a suite of independent, innovative tools for undertaking specific land administration activities, but, via PaS, also provided an open platform to enable the integration of outputs from those independent tools, with a view to enabling mixing and matching of the tools, for a given project context. Until now, while the individual geospatial tool innovations have been formally evaluated, they have not been assessed together against FFP elements or criteria. Moreover, evaluation of PaS as a standalone platform, in terms of usability and functionality, let alone its ability to enable integration of outputs from other tools, and FFP for that matter, has yet to be undertaken. Therefore, there exists good motivation to undertake such an evaluation. The following section explains the methods for enabling this evaluation.

### 3. Methods

In this section, the methods for assessment of the individual tools and the integrative platform (PaS), with respect to FFP elements, are explained. In this regard, the overarching research paradigm can be considered to be pragmatist, i.e., commencing from the starting point that there many means to respond to a particular set of real-world requirements and basing the solution assessment on the integration of concepts and methods from a range of applied sciences. In this case, those applied sciences are the geospatial sciences, information systems, and computer sciences. More specifically, the methods in this paper gain some inspiration from action-research and reflexivity-based methodologies [43], although they cannot be said to be complete or formal applications of those approaches.

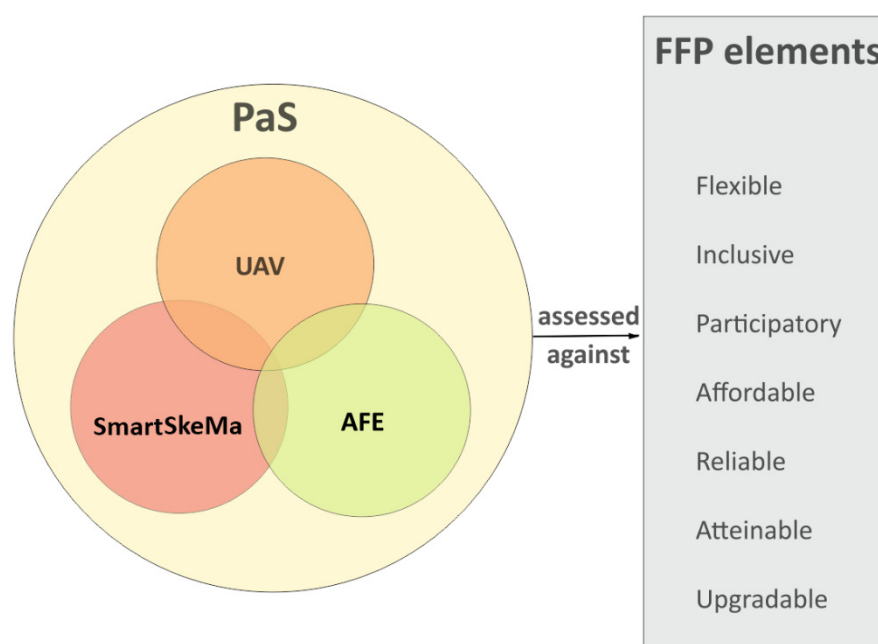
First, the individual data collection and analysis tools—SmartSkeMa, UAVs, Boundary Delineator—were tested during their development and demonstrated across Eastern Africa. Fieldwork, workshops, semi-structured interviews, and focus group discussions were completed for all tools in Kenya in 2017 and 2018, where 58 land administration stakeholders from local government institutions, non-governmental organizations, private companies, and national institutions participated [22]. Two workshops were organized; one at the local government in Kajiado and one at the Regional Centre for Mapping of Resources for Development (RCMRD) in Nairobi. Both followed the same structure: presentation by the facilitators, splitting the participants into groups for detailed activities, demonstrations, and discussions on the individual tools. Independently, SmartSkeMa testing was done in Ethiopia in 2017 with 20 local stakeholders. To collect data for analyzing UAV workflows, three different UAVs (Inspire 2 DJI, e FireFLY6, and DT18) were tested and demonstrated in Rwanda in 2017 [19]. At the same location, the previously collected UAV-based orthomap was used to test a participatory mapping approach along with presentations about the results [44]. In addition, UAV data collection and workshops were carried out in Zanzibar in 2019. Overall, 33 people from local and national government participated during those workshops (16 in Zanzibar and 17 in Rwanda) [45].

Second, the overarching PaS platform, the latest development of its4land was assessed. It was demonstrated during Rwanda AfricaGIS in December 2019. Furthermore, a workshop with 4 experts from ESRI Rwanda was organized to test the functionalities of the platform and to obtain their feedback.

Third, and for the specific aims of this paper, i.e., the assessment of the individual tools and the platform against the FFP elements reported, in addition to the information obtained during the above-mentioned events, feedback from 15 key informants and experts was gathered via an online survey. The background of the selected experts is shown in Appendix A. From them, 3 experts were involved in the development and testing of the tools, and 4 were directly involved in the testing and demonstration of PaS during Africa GIS 2019 in Rwanda. The remaining 8 experts were well familiar with the functionalities

of the tools and the platform. The selection of the participants was intentionally made having in mind their familiarity with these particular tools and platform since in this way, more critical views and feedback is obtained. Given the close (and sometimes direct) links between the participants in this evaluation work and the tool/platform development, the potential for bias needs to be and is hereby acknowledged.

The experts were asked to fill a survey rating the platform and the tools with respect to the seven FFP elements (Figure 7). Provision for qualitative feedback was also provided.



**Figure 7.** Assessment method.

A clarification on how to understand these elements for the specific context of the tools was initially provided to the experts (Annex2). Based on the results from the survey, answers to the following questions could therefore be ascertained, each in the context of FFP:

- What value does PaS bring (in terms of FFP)?
- How does the PaS improve the performance of the other its4land tools (with respect to FFP)?
- When do the individual tools perform better on their own?
- What can be improved in the future (in terms of FFP support)?

After obtaining the results, the authors that were involved in the development of the tools and the platform did the initial result screening and analysis. The answers which differ significantly between the participants have been analyzed, and an explanation of the reasoning is provided. For this task, the level of familiarity of the participants with the concrete tool was taken into account. Therefore, more trust was ascribed the values given by the expert than voted being more familiar. Some participants wrote extensive comments to explain their answers which helped us with the assessment. From one side, the low number of participants can be seen as a limitation of this research. However, if there were more participants without a deep understanding of the tools, the obtained feedback would have been global and not so critical. Therefore, even with the limited number of participants, the answers from the survey provide enough information for the analysis.

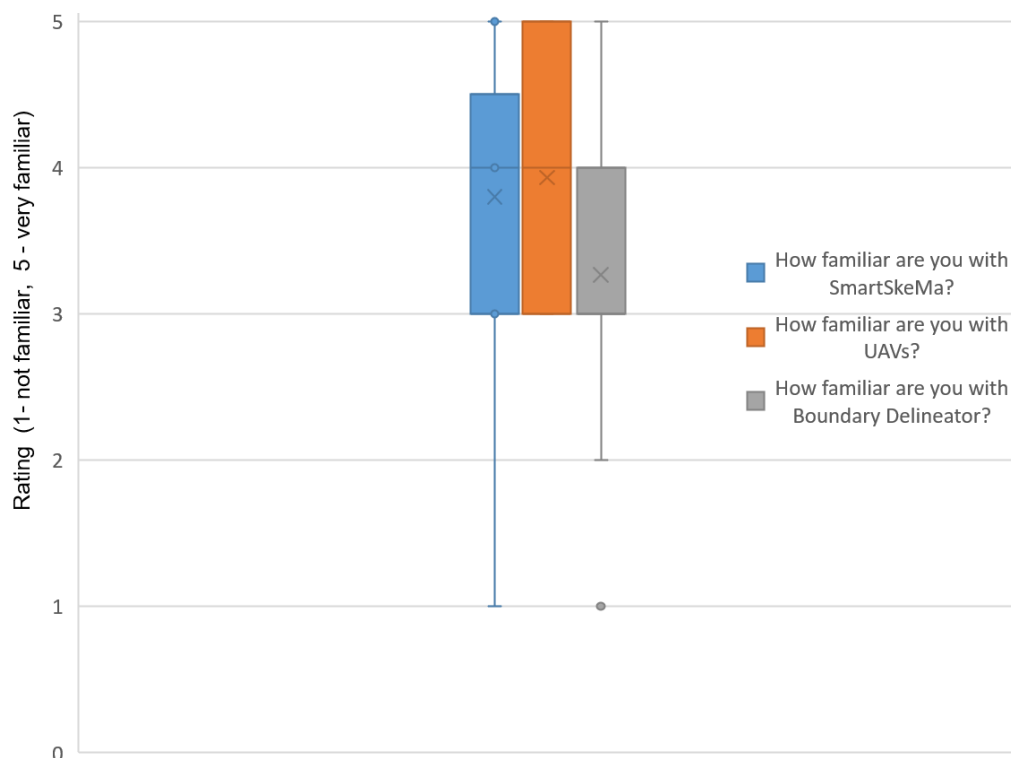
#### 4. Results

In this section, the results from the assessment of the platform and the individual tools with respect to FFP elements are presented. The boxplot method for graphical representation grouping the numerical data through their quartiles is selected. The box

shows the interquartile range (IQR) containing 50% of the scores between the first (Q1) and the third quartile (Q3). The middle line of the box represents the median and the mean value is denoted with a cross (x). The whiskers display the values 1.5 times below Q1 and 1.5 times above Q3, respectively. Scores falling outside the whiskers are considered outliers. The longer the box the more scattered the data. The shorter the box the less scattered is the data.

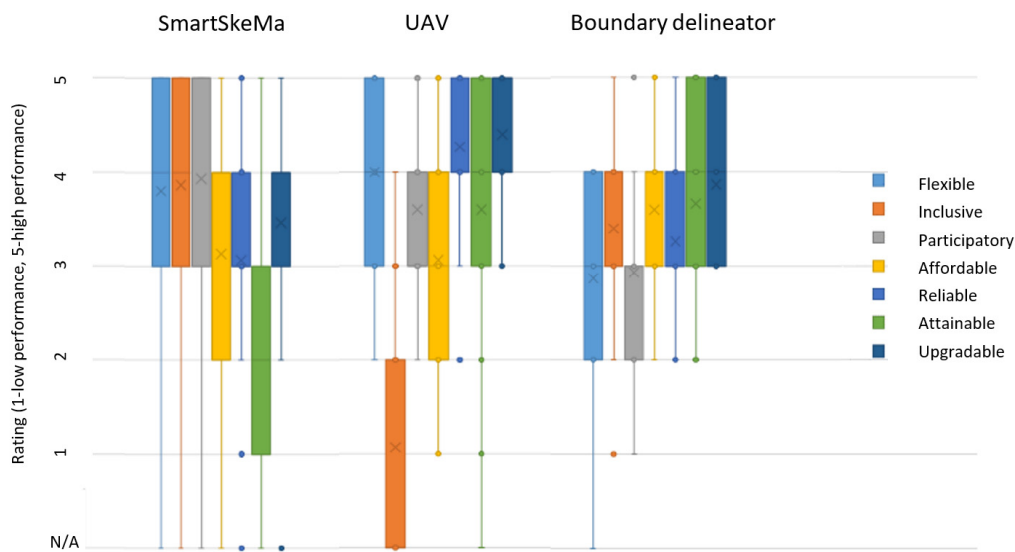
#### 4.1. Evaluation Results of the Individual Geospatial Tools (SmartSkeMa, UAVs, Boundary Delineator)

The results of the tools are combined in one chart to compare them easier and to split them from the one for PaS. Out of the 15 participants in the survey, seven persons reported being somewhat familiar with SmartSkeMa, four mentioned that they were very familiar, three respondents were ambivalent, while one person was not at all familiar with it (Figure 8). The one unfamiliar respondent also chose the not applicable option for all FFP elements and was not included in the analysis.



**Figure 8.** Familiarity of the participants with the tools and the platform.

SmartSkeMa was rated high on the flexibility, inclusivity, participatory nature, and upgradability elements of the FFP (see Figure 9). These ratings agree with the design principles behind SmartSkeMa's development. The fact that interactions with SmartSkeMa are based on physical interaction via sketching makes it a very participatory tool. This explains the high rating on the participatory element (8 out of 14 participants with score of 5 and 2 with score of 4 and 5 with score of 3). Not surprisingly, most participants could not decide whether the tool met the FFP reliability criteria. One participant noted that SmartSkeMa "SmartSkeMa is not suited for authoritative data, but for [up-to-date] data [it is] very usable." Another participant observed that the tool might not meet "legal precision and accuracy requirements". One can interpret these data as indicating that the tool has some reliability with respect to the production of up-to-date data but is not reliable for the production of authoritative data.



**Figure 9.** Assessment of the tools against the FFP elements.

The elements of affordability and attainability received the worst ratings (7 of the participants rated reliability with a score of 3, meaning they did not know whether SmartSkeMa meets the reliability criteria for FFP). Affordability was the worst-rated element, with 6 participants responding that it did not meet the FFP criteria for affordability. The reason for this rating is not clear at present, but one possible explanation is that participants considered it a human resource-intensive approach.

In contrast to the other tools, all respondents showed a medium to high familiarity with UAVs (see Figure 9) as a data collection technology for land administration. This is not surprising given that UAVs are increasingly applied to various surveying and mapping tasks during recent years. As indicated in Figure 9, UAVs score notably high in terms of flexibility, reliability, attainability, and upgradability. The availability of different UAV platforms and sensor combinations, and highly customizable flight plans, and various means of ground-truthing, cater to a high level of flexibility. Furthermore, it appears that the high resolution of generated orthophotos is perceived as reliable and authoritative data, which is easy to upgrade with an increased temporal or spatial resolution. The participatory and affordable elements were rated with medium performance. Particularly affordability stands out as the primary concern shared by half of the respondents. It reflects the high costs typically involved in UAV data collection processes, including the purchase of equipment, ground-truthing measurements, import fees, charges for flight permissions, etc. Out of the eight elements, “inclusive” was the only one rated not applicable for UAV workflows: UAV data can only be used to create base-maps and does not provide further information on existing people-to-land relationships.

For the boundary delineation tool, 15 participants provided input to our study. As shown in Figure 9, most participants (6) have medium experience with the tool. Likewise, Figure 9 shows how the participants rated the degree to which the tool fulfills each of the FFP criteria. The tool scores high (5) in terms of being attainable and upgradable. This can be explained by the fact that the tool is open source and that it can be further developed. The tool scores low (2) to medium (3) in terms of being flexible, inclusive, participatory, affordable, and reliable. This can be explained by the fact that the tool can be used to delineate visible boundaries only. In addition to its dependency on visible boundaries, the tool requires trained GIS staff to be implemented as well as image data as an input to locate the visible boundaries.

#### 4.2. Evaluation Results of PaS

Most experts who participated in the assessment rated themselves as having a high degree of familiarity (7 nos.), with PaS as indicated in Figure 10. When it came to judging

the platform with respect to the FFP elements (Figure 10), the element of upgradability was rated the highest, followed by flexibility and attainability. This can be attributed to PaS’s ability to support different tools and features via the API, use of OGC services and LADM. Experts judged the proof-of-concept connectivity between the tools demonstrated here at the R&D level as having the potential for upgrading/extending to respond to future needs (see Upgradable in Appendix B-1). This is where it could be inferred that PaS’s ability enables it to connect different tools to make possible more complex land administration workflows. Complexity here refers to combining usage of tools as opposed to using them singularly, for example, the combination of UAVs and use of SmartSkeMa, or UAVs combined with automatic boundary detection, or perhaps some other combination. The inclusivity and affordability elements garnered low-medium ratings overall. This indicates not all participants are convinced PaS can store different types of land tenure in an affordable manner.

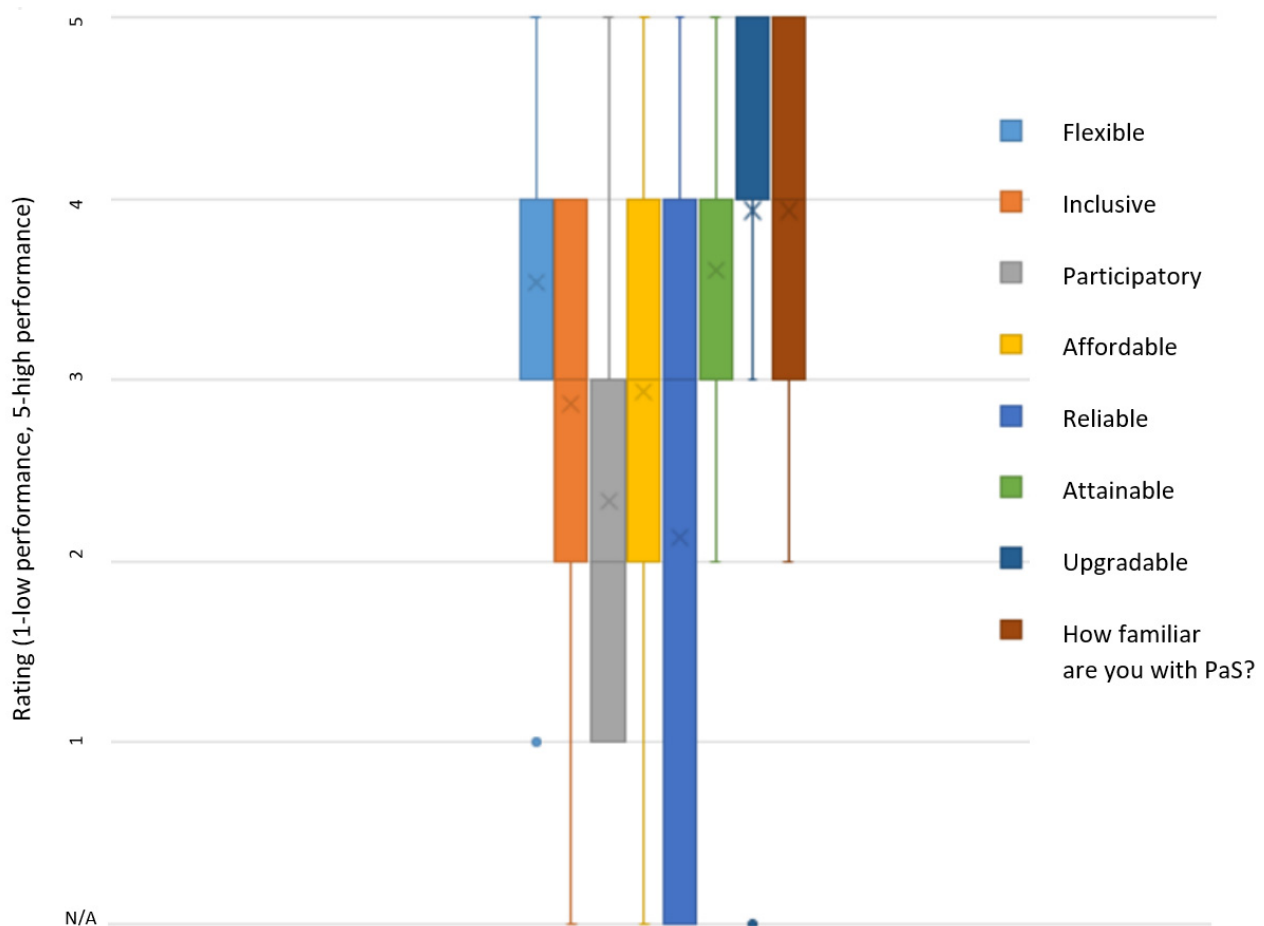


Figure 10. Assessment of PaS against the FFP elements and familiarity with the platform.

PaS is not meant for data capture and cannot offer guarantees regarding the authoritativeness and reliability of data, which are sourced elsewhere. The survey made this point clear, and this could explain the reason for the low ranking of reliability. It is also possible that the infrastructure and expertise needed to operate the platform has affected the reliability perception.

The participatory element fared poorly. Given the nature of PaS this is difficult to assess since the participatory element is more of a procedural dimension in FFP and refers to how different groups participate and contribute to the registration of land and rights. The development and use of the platform is not participatory, in a manner that someone interested in land can use it directly. Rather, it can be used to create tools and applications which allow for participation.

As per the comments of one of the participants, the nature of PaS as a development platform for LADM-based applications means every FFP goal can be achieved by an application that uses it. Some criticism was also leveled at the platform requiring high technical expertise to operate, its dependency on a cloud service provider, and the fact that testing its workability by the wider public is restricted due to its experimental nature. Future work in this direction will benefit by addressing these concerns.

## 5. Discussion

This section is organized as follows. First, an overall assessment of the suite of its4land tools, including (and with a specific emphasis on) PaS, against FFPLA elements is provided, based on the results presented. Second, the interactions between PaS and the other tools, in terms of any further strengths, weaknesses, opportunities, and threats, are provided. Third, areas for further developments based on the results are presented.

### 5.1. Overall FFPLA Assessment

Overall, the its4land suite of tools and the associated PaS platform appear to align well with the elements of FFPLA, at least according to the experts surveyed, and albeit with some variation between tools with regards to specific FFPLA elements. This is perhaps to be expected, given the broad definitions ascribed to the FFPLA elements and the potential for different interpretations among survey participants. Interpretation of the elements is also challenged by the fact that the elements also describe the social and legal context for the implementation of a LAS, but only the technical aspects are taken into consideration here. In this regard, it is perhaps most interesting to look at the extremes in responses, and here, UAVs scoring low on “inclusiveness”, SmartSkeMa scoring low on “attainability”, and the Boundary Delineator scoring lower on “participatory”, speak to the tools still requiring a high level of geospatial technical insights to understand and use, and by association, still needing a layer of simplification and increased levels of usability if the aim is for lay-people to use those tools themselves.

In contrast to the other tools developed in the its4land project, the PaS platform is not meant as a tool for an in-field surveyor or community mapper. While it was also seen to adhere or align to many of the FFPLA elements, at least in terms of the experts surveyed, it is interesting that overall it scored lower on most of the FFPLA elements—tending to score near “2” at the lower quartile, whereas the other tools tended to bottom out at “3”. Looking at the more extreme results, PaS scores lower on reliability, inclusiveness, affordability, and participation. The elements on inclusiveness and participation are perhaps best explained via potential differences in interpretation by respondents, if not practicalities of implementation: while the other tools provide a direct and self-contained benefit for an end-user in the area of land administration for specific tasks, in practice, PaS would have a degree of separation from users in the field, or even local land officers, in that PaS is more for developers and system integrators, and actors who create a land administration workflows. For these kinds of users, PaS can be beneficial. That said, it is understandable that PaS could be misinterpreted or understood as “out of the hands” of land administration practitioners, let alone communities, and therefore less “participatory” or “inclusive” (noting anyway that “inclusiveness” relates to types of tenure included in a system, not the participants doing the mapping).

Perhaps of more interest or concern is that PaS scored lower on reliability and affordability. The reliability perception could be to do with the expert experiences with PaS, but is more likely to do with the fact that it requires a level of IT and internet infrastructure maturity to function. In the locations where PaS is intended for use, these infrastructures are often not reliable, particularly outside major urban centers, although it should be noted that this situation, particularly via mobile communications networks, is steadily improving. The affordability element links to this: PaS application does and would require mature levels of IT investment and the associated skill sets needed to maintain them. This not



only applies to the land administration function within a jurisdiction but all government services generally.

These potential negatives aside, via those surveyed, it can be seen that PaS is agreed to provide a targeted and widely accepted development model and a platform concept for the specific needs of the land administration sector. There is currently no platform available on the market that addresses these specific needs and combines the land administration concepts with a state-of-the-art API.

Following the platform approach, the utility of PaS highly depends on the availability of tools, which provide high-level building blocks for land administration workflows. Although the tools could operate alone, the combination of the tools allowed more integrated workflows.

### *5.2. PaS-Tool Interactions FFPLA Assessments*

Attention now turns to consider how PaS can integrate and interoperate with the other tools, and specifically, what added value these combinations might bring—in terms of enabling what we characterize as complex land administration workflows.

First, SmartSkeMa was designed to be used independently as a data collection tool. However, as with any other data collection, to make use of its outputs, it must be used in conjunction with other tools. Deployment of SmartSkeMa within PaS showed that several of the poorly rated FFP criteria could be realized when SmartSkeMa is combined with the other its4land tools. On the upgradability question, one participant in the survey mentioned that SmartSkeMa needs to be upgraded “in such a way that it should work as a standalone system” by supporting independent database access capabilities and the ability for cloud deployment. This is precisely where PaS can play a key role in a project based on its4land tools. It can also be argued that PaS can allow SmartSkeMa data to be used together with authoritative data, especially for planning purposes. In this case, the reliability aspect is addressed by reference to the authoritative data and by the fact SmartSkeMa tenure data are likely to be more up to date than official data collected at longer intervals. This would be achieved without losing most of the other FFP attributes of SmartSkeMa itself.

Evidently, there are scenarios where SmartSkeMa performs better or at least not worse when used without the PaS platform. For example, PaS does not address the affordability concerns rated poorly by the survey participants. PaS can further negatively affect the attainability of SmartSkeMa by requiring an internet connection and the upload of base map data to the platform. This is a double-edged sword—on the one hand, PaS allows access to base data produced by other teams and tools while, on the other hand, constraining the number of situations in which SmartSkeMa can be used.

Second, On UAVs, the battery endurance and the productivity of UAVs have increased, leading to larger areas that can be mapped. Consequently, more significant amounts of data are collected, and more substantial computations are needed to process these images, which consumer-grade laptops and PCs can hardly accomplish. In this aspect, the functionalities of the PaS platform are highly beneficial for UAV image processing overcoming the bottleneck of low computational power. In particular, cloud computing allows the speeding up of image processing, if needed. Furthermore, the last mile in terms of dissemination, visualization, and data sharing of large UAV-based orthophotos can be reached by the PaS platform using embedded WMS services and web-based data visualization. The use of the PaS platform and its UAV Ortho Generator tool would significantly improve the affordability and attainability of UAV-based data acquisition for two reasons. First, less money would need to be spent on expensive image processing software. Second, less technical expertise would be required by local staff implementing the UAVs as a data acquisition tool.

Third, the integration of the boundary delineation tool into the PaS platform is not mandatory, but beneficial. Since all the source code is publicly available (See: <https://github.com/its4land/delineation-tool>, accessed on 24 May 2021), it can be used on its

own. However, the tool requires image data as input that can be processed and stored on the PaS platform. Such image data can come from UAVs and thus be combined with another tool's output via the platform. Furthermore, the output of the tool can be stored and viewed as boundary facestrings on the platform. These boundaries can then be used in the SmartSkeMa process to visually compare hand-drawn and visible boundaries from both tools. The tool could be improved via the platform when especially its first part (image segmentation) would be done online on UAV images. This result could then be used in the QGIS plugin Boundary Delineation (<https://plugins.qgis.org/plugins/BoundaryDelineation/>, accessed on 24 May 2021), which represents the second mandatory part of the tool. At the time of writing, the image segmentation requires extensive IT knowledge and is less user-friendly than the QGIS plugin. If the image segmentation could be done on the platform, less processing power would be required from the user, and the entire tool experience would be more user-friendly.

### 5.3. Opportunities for Further PaS Development

Looking ahead and taking into account the inputs from the survey respondents, it appears that the three complementary tools developed in the its4land project show the potential for further development and improvement in several ways. These include: adding more tools to the platform; adding more concepts from the LADM model, such as the LA\_RRR concept; adding more spatial profiles (like textual or survey Sketch-based) to the LA\_SpatialUnit API; developing new business models, such as an online app store system for tools; using tools such as Terraform (<https://www.terraform.io/>, accessed on 24 May 2021) and Chef (<https://www.chef.io/>, accessed on 24 May 2021) to make PaS independent of a specific cloud platform; this would include the possibility to operate PaS also on a private cloud; bundle the hyper-converged infrastructure of PaS with standard hardware to a self-contained system that can be operated in the field without the need for permanent internet connection. This will address the affordability concerns.

## 6. Conclusions

This paper aimed to contribute to the broad challenge of mapping unrecorded land rights across sub-Saharan Africa. It provided an update on the results of the "its4land" project, a European Commission Horizon 2020 project aimed at developing, adapting, and testing innovative geospatial tools for the purposes of enabling alternate approach must land rights mapping in that region. Specifically, the project developed (1) software that underpinned by the smart Sketch maps concept, called SmartSkeMa; (2) a workflow for applying unmanned aerial vehicles (UAV); and (3) a semi-automatic feature extraction (AFE) tool. Additionally, the consortium developed (4) a platform called Publish and Share (PaS), enabling integration of all the outputs of tools and that could share and publish land information through a geocloud web service approach. This particular paper aimed at assessing these tools against FFPLA elements for the tools and platform individually, but also taking more holistic viewpoints.

Although the tools and platform development processes had previously been undertaken in Rwanda, Kenya, Ethiopia, and Zanzibar, this paper sought to use key informants and experts, including those who had taken part in the tool development, to obtain a more reflexive and post-project perspective. In this regard, it provides an alternate perspective on the its4land results and constitutes a further and novel contribution.

Overall, the results show that individually, each of the tools can be said to adhere or deliver upon FFPLA elements, albeit with areas of improvement available in all cases. Each of the tools can function and deliver outputs independently and reliably. That said, each is seen to have its own challenges or weaknesses in the regard, usually linked to the level of technical maturity of the technology generally, the level of technical acumen needed to use or maintain the use of the tool, and/or the level of cost involved. Interestingly, each tool and the platform is also seen to have its own strengths and weaknesses: it is not that there are FFPLA elements that scored high or low uniformly across all tools.

On PaS, it was shown to be complementary, if not underpinning, providing enhancements but also potentially enabling the development of more complex land administration workflows by combining usage of tools and data—that could be tailored to the specific needs of given country contexts. The viability, in terms of cost-benefit needs further validation though through practice and scaled implementation. That said, it is important to emphasize that there is currently no platform available on the market that addresses the specific needs and combines the land administration concepts with a state-of-the-art API that PaS enables.

In terms of further work, aside from examining further the limitations against specific FFPLA elements for each of the tools and the platform, now that PaS is established as an integrative and interoperable platform, there lies the potential to add further tools and extensions and to consider ways of scaling its use through business model considerations and larger-scale piloted usage.

**Author Contributions:** Conceptualization, M.K., S.C., M.C., C.S., M.I.H., C.T., R.B., methodology, M.K., S.C., M.C., C.S., M.I.H., C.T., R.B., formal analysis, M.K., S.C., M.C., C.S., M.I.H., C.T., R.B., writing—original draft preparation M.K., S.C., M.C., C.S., M.I.H., C.T., R.B. final version review M.K., S.C., M.C., C.S., M.I.H., C.T., R.B., J.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** The research described in this paper was funded by the research project “its4land,” which is part of the Horizon 2020 program of the European Union, project number 687828. Funding of the publication costs for this article has kindly been provided by the School of Land Administration Studies, University of Twente, in combination with Kadaster International, the Netherlands.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** Its4land team would like to also express their acknowledgments to their colleagues for their support during the fieldworks and workshops and the experts that were part of the survey.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

N	Background of the Experts
1	Photogrammetry and Remote Sensing, Cadastre
2	Spatial Knowledge Representation
2	Geography, UAV
4	Geo-information, automatic feature extraction from images
5	Land administration and Management
6	Land administration and Management
7	Land administration and Management
8	Geoinformatics
9	Spatial Knowledge Representation
10	Software engineer
11	Software engineer
12	GIS and geo-data
13	Geo-consulting
14	GIS, Geo-information, land administration
15	GIS, software developer

## Appendix B

1. Rate the PaS according to the FFP elements. In the context of PaS, they mean the following:

Flexible: To what extent can PaS be used to store and view information about different uses and land occupations?

1(– –) Cannot store or view such information

5(+++) Supports storing/viewing information about all uses and occupations of land.

Inclusive: To what extent can PaS be used to store and view information about different land tenure types?

1(– –) Cannot store or view land tenure information

5(+++) Supports storing and viewing all types of land tenure information

Participatory: To what extent does PaS support community engagement and participation in storing and distributing land administration data?

1(– –) Not designed for community engagement and participation

5(+++) Fully supports community engagement and participation

Affordable: Is PaS affordable as a platform to build land administration systems for government and society?

1(– –) Not affordable

5(+++) Very affordable

Reliable: Is the data provided by PaS authoritative and reliable?

\*(note that PaS is not meant for data capture)

1(– –) Not authoritative or reliable

5(+++) Highly authoritative or reliable

N/A: PaS does not provide reliable data on its own

Attainable: Can PaS support creating land administration systems with new and innovative methods to capture land use and tenure?

1(– –) Impossible in a short time with available resources

5(+++) Highly achievable in a short time with available resources

Upgradable: Can PaS be upgraded and improved to respond to social and legal needs as well as economic opportunities?

1(– –) It is not upgradable

5(+++) It is highly upgradable

2. Rate the SmartSkeMa according to the FFP elements. In the context of SmartSkeMa they mean the following:

Flexible: To what extent can SmartSkeMa be used to capture information about different uses and occupations of land?

1(– –) SmartSkeMa can capture information about ONLY ONE use or occupation of land

5(+++) SmartSkeMa can capture information about ALL uses and occupations of land

Inclusive: To what extent can SmartSkeMa be used to capture different types of land tenure?

1(– –) SmartSkeMa can capture ONLY ONE type of land tenure

5(+++) SmartSkeMa can capture ALL types of land tenure

Participatory: To what extent does/can SmartSkeMa support community engagement and participation in the data capture process?

1(– –) SmartSkeMa does/can NOT support community engagement/participation

5(+++) SmartSkeMa does/can fully support community engagement/participation

Affordable: How do you rate the affordability of SmartSkeMa as a land tenure data capture tool from the perspective of the government or civil society organizations?

1(– –) SmartSkeMa is NOT affordable for the government and civil society

5(+++) SmartSkeMa is affordable for the government and civil society

Reliable: To what extent can SmartSkeMa be used to generate data that is authoritative and up to date?

1(– –) SmartSkeMa CANNOT be used to produce authoritative and up-to-date data

5(+++) SmartSkeMa CAN be used to produce authoritative and up-to-date data

Attainable: To what extent can SmartSkeMa be set up and put into operation within a short time-frame and with limited resources?

- 1(– –) SmartSkeMa CANNOT be quickly set up and put into operation  
 5(+++) SmartSkeMa CAN be quickly set up and put into operation  
 Upgradable: To what extent can SmartSkeMa be upgraded and improved to respond to social and legal needs as well as economic opportunities?  
 1(– –) SmartSkeMa CANNOT be upgraded  
 5(+++) SmartSkeMa CAN be upgraded
3. Rate the UAVs according to the FFP elements. In the context of UAV, they mean the following:
- Flexible: To what extent can UAV be used to capture images of different uses and occupations of land?  
 1(– –) UAV data can capture only one use or occupation of land  
 5(+++) UAV data can capture all uses and occupations of land  
 Inclusive: N/A for UAVs—UAV cannot collect land tenure data  
 Participatory: To what extent support UAVs community engagement and participation in the data capture process?  
 1(– –) UAV do not support community engagement  
 5(+++) UAV fully support community engagement  
 Affordable: To what extent can UAVs be afforded by the government and society as a collection tool for aerial images?  
 1(– –) UAV are not affordable for the government and society  
 5(+++) UAVs are affordable for the government and society  
 Reliable: To what extent provide UAV imagery authoritative and reliable base data?  
 1(– –) UAV imagery are not authoritative and reliable  
 5(+++) UAV imagery are authoritative and reliable  
 Attainable: To what extent can UAVs be used to collect aerial base data in a short time with limited resources?  
 1(– –) UAV do not allow for quick data collection of aerial imagery  
 5(+++) UAV allow for quick data collection of aerial imagery  
 Upgradable: To what extent can UAVs be used to provide upgraded and improved base data to respond to social and legal needs as well as economic opportunities?  
 1(– –) UAVs cannot be used to upgrade existing data  
 5(+++) UAVs can be used to upgrade existing data
4. Rate the AFE according to the FFP elements. In the context of AFE they mean the following:
- Flexible: To what extent can AFE be used to capture different uses and occupations of land?  
 1(– –) AFE can capture only one use or occupation of land  
 5(+++) AFE can capture all uses and occupations of land  
 Inclusive: To what extent can AFE be used to capture different types of land tenure  
 1(– –) AFE can capture only one type of land tenure  
 5(+++) AFE can capture all types of land tenure  
 Participatory: To what extent can AFE be used participatory by engaging the community?  
 1(– –) AFE cannot be used in a participatory manner  
 5(+++): AFE can fully be used in a participatory manner  
 Affordable: To what extent is AFE affordable for the government and society  
 1(– –) AFE is not affordable for the government and society  
 5(+++) AFE is freely affordable for the government and society  
 Reliable: To what extent are the boundaries delineated with AFE reliable?  
 1(– –) AFE cannot capture reliable boundary information  
 5(+++) AFE can capture reliable boundary information  
 Attainable: To what extent is a system for boundary capture based on AFE attainable in a short time with limited resources?  
 1(– –) AFE does not allow quick boundary delineation in any system

5(+++) AFE allows quick boundary delineation in any system  
 Upgradable: To what extent can AFE be upgraded and improved to respond to social and legal needs as well as economic opportunities?  
 1(– –) AFE cannot be upgraded  
 5(+++) AFE can be upgraded

## References

- Nations, U. Home | Sustainable Development. Available online: <https://sdgs.un.org/> (accessed on 25 May 2021).
- Why Secure Land Rights Matter. Available online: <https://www.worldbank.org/en/news/feature/2017/03/24/why-secure-land-rights-matter> (accessed on 15 March 2021).
- Lakner, C.; Mahler, D.G.; Negre, M.; Prydz, E.B. *How Much Does Reducing Inequality Matter for Global Poverty?* The World Bank: Washington, DC, USA, 2019.
- Bennett, R.M.; Alemie, B.K. Fit-For-Purpose land administration: Lessons from urban and rural ethiopia. *Surv. Rev.* **2016**, *48*, 11–20. [CrossRef]
- Koeva, M.N.; Crommelinck, S.; Stöcker, C.; Crompvoets, J. Its4land—Challenges and opportunities in developing innovative geospatial tools for fit-for-purpose land rights mapping. In Proceedings of the FIG Congress 2018, Istanbul, Turkey, 6–11 May 2018; International Federation of Surveyors (FIG): Copenhagen, Denmark, 2018; pp. 1–17.
- Zevenbergen, J.; Augustinus, C.; Antonio, D.; Bennett, R. Pro-Poor land administration: Principles for recording the land rights of the underrepresented. *Land Use Policy* **2013**, *31*, 595–604. [CrossRef]
- Lemmen, C.; van Oosterom, P.; Bennett, R. The land administration domain model. *Land Use Policy* **2015**, *49*, 535–545. [CrossRef]
- International Organization for Standardization (ISO). Geographic information—Land Administration Domain Model (LADM). Available online: <https://www.iso.org/standard/51206.html> (accessed on 12 July 2018).
- Ho, S.; Pattyn, V.; Broucker, B.; Crompvoets, J. Needs assessment in land administration: The potential of the nominal group technique. *Land* **2018**, *7*, 87. [CrossRef]
- Rahmatizadeh, S.; Rajabifard, A.; Kalantari, M.; Ho, S. A framework for selecting a fit-for-purpose data collection method in land administration. *Land Use Policy* **2018**, *70*, 162–171. [CrossRef]
- De Vries, W.; Bennett, R.; Zevenbergen, J. Toward responsible land administration. In *Advances in Responsible Land Administration*; CRC Press: Boca Raton, FL, USA, 2015; pp. 3–14.
- Zevenbergen, J.; De Vries, W.; Bennett, R. *Advances in Responsible Land Administration*; CRC Press: Padstow, UK, 2015; ISBN 9781498719599.
- Enemark, S.; McLaren, R.; Lemmen, C.; Antonio, D.; Gitau, J. *Guiding Principles for Building Fit-For-Purpose Land Administration Systems in Developing Countries*; UN-Habitat: Nairobi, Kenya, 2016.
- Enemark, S.; Bell, C.K.; Lemmen, C.; McLaren, R. *Fit-For-Purpose Land Administration*; International Federation of Surveyors (FIG): Copenhagen, Denmark, 2014; ISBN 9788792853103.
- Koeva, M.; Stöcker, C.; Crommelinck, S.; Chipofya, M.; Kundert, K.; Schwering, A.; Sahib, J.; Zein, T.; Timm, C.; Humayun, M.; et al. Innovative geospatial solutions for land tenure mapping. *Rwanda J. Eng. Sci. Technol. Environ.* **2020**, *3*, 34–49. [CrossRef]
- Koeva, M.; Stöcker, C.; Crommelinck, S.; Ho, S.; Chipofya, M.; Sahib, J.; Bennett, R.; Zevenbergen, J.; Vosselman, G.; Lemmen, C.; et al. Innovative remote sensing methodologies for Kenyan land tenure mapping. *Remote Sens.* **2020**, *12*, 273. [CrossRef]
- Stöcker, C.; Nex, F.; Koeva, M.; Gerke, M. Uav-Based cadastral mapping: An assessment of the impact of flight parameters and ground truth measurements on the absolute accuracy of derived orthoimages. *ISPRS Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *42*, 613–617. [CrossRef]
- Koeva, M.; Bennett, R.; Gerke, M.; Crommelinck, S.; Stöcker, C.; Crompvoets, J.; Ho, S.; Schwering, A.; Chipofya, M.; Schultz, C.; et al. Towards innovative geospatial tools for fit-for-purpose land rights mapping. *ISPRS Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *42*, 37–43. [CrossRef]
- Stöcker, C.; Ho, S.; Koeva, M.N.; Nkerabigwi, P.; Schmidt, C.; Zevenbergen, J.A.; Bennett, R. Towards UAV-based land tenure data acquisition in Rwanda. In Proceedings of the FIG Congress 2018, Istanbul, Turkey, 6–11 May 2018; International Federation of Surveyors (FIG): Copenhagen, Denmark, 2018.
- Schwering, A.; Wang, J.; Chipofya, M.; Jan, S.; Li, R.; Broelemann, K. SketchMapia: Qualitative Representations for the alignment of sketch and metric maps. *Spat. Cogn. Comput.* **2014**, *14*, 220–254. [CrossRef]
- Chipofya, M.; Jan, S.; Schultz, C.; Schwering, A. Towards smart sketch maps for community-driven land tenure recording activities. In Proceedings of the 20th Conference on Geo Information Science AGILE, Wageningen, The Netherlands, 9–12 May 2017.
- Casiano Flores, C.; Tan, E.; Buntinx, I.; Crompvoets, J.; Stöcker, C.; Zevenbergen, J. Governance assessment of the UAVs implementation in Rwanda under the fit-for-purpose land administration approach. *Land Use Policy* **2020**, *99*. [CrossRef]
- Drone Mapping Software—OpenDroneMap. Available online: <https://www.opendronemap.org/> (accessed on 14 April 2021).
- Crommelinck, S.; Bennett, R.; Gerke, M.; Koeva, M.N.; Yang, M.Y.; Vosselman, G. SLIC superpixels for object delineation from UAV data. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *9*–16. [CrossRef]
- Crommelinck, S. Delineation-Tool GitHub. Available online: <https://github.com/its4land/delineation-tool> (accessed on 13 May 2019).

26. Crommelinck, S.; Yang, M.Y.; Koeva, M.N.; Vosselman, G. Towards automated cadastral boundary delineation from UAV data. *arXiv* **2018**, arXiv:1709.01813.
27. Crommelinck, S.; Koeva, M.; Yang, M.Y.; Vosselman, G. Robust object extraction from remote sensing data. *arXiv* **2019**, arXiv:1904.12586.
28. Crommelinck, S.; Bennett, R.; Gerke, M.; Nex, F.; Yang, M.Y.; Vosselman, G. Review of automatic feature extraction from high-resolution optical sensor data for UAV-based cadastral mapping. *Remote Sens.* **2016**, *8*, 689. [[CrossRef](#)]
29. Crommelinck, S.; Höfle, B.; Koeva, M.N.; Yang, M.Y.; Vosselman, G. Interactive cadastral boundary delineation from UAV images. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2018**, *4*, 81–88. [[CrossRef](#)]
30. Xia, X.; Koeva, M.; Persello, C. Extracting cadastral boundaries from UAV images using fully convolutional networks. In Proceedings of the IGARSS 2019 IEEE International Geoscience and Remote Sensing Symposium, Yokohama, Japan, 28 July–2 August 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 2455–2458.
31. Xia, X.; Persello, C.; Koeva, M. Deep fully convolutional networks for cadastral boundary detection from UAV images. *Remote Sens.* **2019**, *11*, 1725. [[CrossRef](#)]
32. United Nations Economic Commission for Europe (UNECE). *Land Administration Guidelines. With Special Reference to Countries in Transition*; United Nations Economic Commission for Europe: New York, NY, USA, 1996.
33. Enemark, S. The Land Management Paradigm for Institutional Development. In Proceedings of the Expert Group Meeting on Incorporating Sustainable Development Objectives into ICT Enabled Land Administration Systems, Centre for Spatial Data Infrastructures and Land Administration the Land Management Paradigm for Institutional Development, Melbourne, Australia, 9–11 November 2005.
34. Stöcker, C.; Bennett, R.; Nex, F.; Gerke, M.; Zevenbergen, J. Review of the current state of UAV regulations. *Remote Sens.* **2017**, *9*, 459. [[CrossRef](#)]
35. Stocker, C.; Koeva, M.; Bennett, R.; Zevenbergen, J. Evaluation of UAV-based technology to capture land rights in Kenya: Displaying stakeholder perspectives through interactive gaming. In Proceedings of the 2019 Annual World Bank Conference on Land and Poverty, “Catalyzing Innovation”, Washington, DC, USA, 25–29 March 2019.
36. Koeva, M.; Muneza, M.; Gevaert, C.; Gerke, M.; Nex, F. Using UAVs for map creation and updating. *Surv. Rev.* **2018**, *50*, 312–325. [[CrossRef](#)]
37. Stöcker, C.; Nex, F.C.; Koeva, M.N.; Gerke, M. Quality assessment of combined IMU/GNSS data for direct georeferencing in the context of UAV-based mapping. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, 355–361. [[CrossRef](#)]
38. Crommelinck, S.; Koeva, M.; Yang, M.; Vosselman, G. Application of deep learning for delineation of visible cadastral boundaries from remote sensing imagery. *Remote Sens.* **2019**, *11*, 2505. [[CrossRef](#)]
39. Crommelinck, S.; Bennett, R.; Gerke, M.; Yang, M.; Vosselman, G. Contour detection for UAV-based cadastral mapping. *Remote Sens.* **2017**, *9*, 171. [[CrossRef](#)]
40. Crommelinck, S.; Höfle, B.; Koeva, M.N.; Yang, M.Y.; Vosselman, G. Interactive cadastral boundary delineation from UAV images. In Proceedings of the ISPRS TC II Mid-Term Symposium “Towards Photogrammetry 2020”, Riva del Garda, Italy, 4–7 June 2018; Volume 4, pp. 81–88.
41. Fielding, R.T. *Architectural Styles and the Design of Network-Based Software Architectures*; University of California: Irvine, CA, USA, 2000; Volume 54.
42. Williamson, I.; Enemark, S.; Wallace, J.; Rajabifard, A. *Land Administration for Sustainable Development*; ESRI Press Academic: Redlands, CA, USA, 2010; p. 487.
43. Unger, E.M.; Bennett, R.; Lemmen, C.; de Zeeuw, K.; Zevenbergen, J.; Teo, C.H.; Cromptvoets, J. Global policy transfer for land administration and disaster risk management. *Land Use Policy* **2020**, *99*. [[CrossRef](#)]
44. Stöcker, C.; Ho, S.; Nkerabigwi, P.; Schmidt, C.; Koeva, M.; Bennett, R.; Zevenbergen, J. Unmanned aerial system imagery, land data and user needs: A socio-technical assessment in Rwanda. *Remote Sens.* **2019**, *11*, 1035. [[CrossRef](#)]
45. Stöcker, C.; Nex, F.; Koeva, M.; Gerke, M. High-Quality UAV-based orthophotos for cadastral mapping: Guidance for optimal flight configurations. *Remote Sens.* **2020**, *12*, 3625. [[CrossRef](#)]