Global Donor Platform
for Rural Development

SCOPING STUDY ON OPEN DATA, INNOVATIVE TECHNOLOGY-BASED SOLUTIONS FOR BETTER LAND GOVERNANCE

FINAL REPORT

Memoris
INGENIERIE GEOGRAPHIQUE

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Contents

Acronyms

A	
APK	*Android Application Package*
API	*Application Program Interface*
AppLab	*Application Laboratory*
B	
BYOD	*Bring Your Own Device*
C	
CAPEX	*Capital Expenditure*
CCRO	*Certificates of Customary Rights of Occupancy*
CKW	*Community Knowledge Workers*
CORS	*Continuously Operating Reference Station*
D	
DeSINLISI	*Design, Supply, Installation and Implementation of National LIS Infrastructure*
DFID	*Department for International Development*
E	
EE	EarthExplorer
EGNOS	European Geostationary Navigation Overlay Service
EROS	*Earth Resource Observations and Science*
ESA	*European Space Agency*
EULA	*End User License Agreement*
F	
FAA	*United States Federal Aviation Administration*
FAO	*Food and Agriculture Organization*
FIG	*Fédération Internationale des Géomètres*
FLOSS	*Free and open-source software*
FTP	*File Transfer Protocol*
FTTH	*Fiber to the Home*
G	
GAGAN	GPS Aided Geo Augmented Navigation
GELIS	*Ghana Enterprise LandInformation System*
GCP	*Ground Control Points*
GDBMS	*Geospatial database management systems*
GDPRD	*Global Donor Platform for Rural Development*
GDWGL	*Global Donor Working Group on Land*
GIGA	*German Institute of Global and Area Studies*
GIS	*Geographic Information System*
GIZ	*Gesellschaft für Internationale Zusammenarbeit*
GloVis	Global Visualization portal

GLONASS	*GLObal NAvigation Satellite System in russian*
GNSS	*Global Navigation Satellite System*
GPRS	*General Packet Radio Service*
GPS	*Global Positioning System High*
GSM	*Global System for Mobile Communications*
GSMA	*Global System for Mobile Communications Association*
	H
HTS	*High Throughput Satellites*
	I
IAG	*International Association of Geodesy*
IGAC	*Instituto Geografico Agustin Codazzi*
IGS	*International GNSS Service*
ILC	*International Land Coalition*
IMU	*Inertial Measurement Units*
ISO	*Integrated Sensor Orientation*
IT	*Information Technology*
	J
JCAB	*Japan's Ministry of Land, Infrastructure and Transport Japan Civil Aviation Bureau*
JSON	*JavaScript Object Notation*
	L
LADM	*Land Administration Domain Model*
LAS	*Land Administration System*
LDPI	*Land Deals Politics Initiative*
LADM	*Land Administration Domain Mode*
LARISITA	*mobile land service in Indonesia*
LGAF	*Land Governance Assessment Framework*
LTA	*Long Term Archive*
LTE	*Long-Term Evolution*
LTERA	*Land Titling and Economic Restructuring in Afghanistan*
LTRSS	*Land Tenure Regularization Support System*
	M
MAST	*Mobile Application to Secure Tenure*
MSAS	*The Multi-functional Satellite Augmentation System*
	N
NGO	*Non Governmental Organization*
NICT	*New Information Communication technology*
	O
OGC	*Open Geospatial Consortium*
OPEX	*Operating Expenditure*
OS	*Open Source*

	P	
PHP	*Hypertext Preprocessor*	
PIN	*Personal identification numbers*	
PPP	*Precise Point Positioning / Public Private Partnership*	
	R	
REILA	*Responsible and Innovative Land Administration*	
RICS	*Royal Institution of Chartered Surveyors*	
RINEX	Receiver Independent Exchange	
RTCM	*Real-Time Correction Messages*	
RTK	*Real Time Kinematic*	
RTS	*Real Time Service*	
RTU	*Remote Terminal Unit*	
	S	
SBAS	*Satellite-Based Augmentation Services*	
SOLA	*Solutions for Open Source Software*	
STDM	*Social Tenure Domain Model*	
	U	
UAS	*Unmanned Aerial systems*	
UHF	*Ultra high frequency*	
UNCTAD	*United Nation Conference on Trade & Development*	
USAID	*United States Agency for International Development*	
USGS	*U.S. Geological Survey's*	
	V	
VGGT	*Voluntary Guidelines on the Responsible Governance of Tenure*	
VHF	*Very High Frequency*	
VSAT	*Very Small Aperture Terminal*	
	W	
WAAS	*Wide Area Augmentation System*	
WIMAX	*Worldwide Interoperability for Microwave Access*	
WMS	Web Map Service	

Chapter 1 – Introduction

"More indigenous territory has been claimed by maps than by guns".- Bernard Nietschmann

The Global Donor Platform for Rural Development (GDPRD) is a network of 38 bilateral and multilateral donors, international financing institutions, intergovernmental organisations and development agencies. Members share a common vision that agriculture, rural development and food security are central to poverty reduction, and a conviction that sustainable and efficient development requires a coordinated global approach. The Platform provides a forum to exchange knowledge, build consensus and formulate joint approaches around critical or emerging issues.

The Global Donor Working Group on Land (GDWGL) was established in the summer of 2013 hosted by the Donor Platform. Its purpose is to improve land governance transparency and enhance the coordination of efforts undertaken by its bilateral and multilateral donor members with each other and with key external government, non-governmental and private sector stakeholders at the global, regional, and national level. The objectives are to advance information sharing, lesson learning and coordination at the international level, highlight existing challenges around land governance, and to agree on joint actions wherever this may be suitable. One of these challenges pertain to the role played by technologies in mapping, clarifying and pre-registering, sometimes even formally registering land tenure and other property rights, in increasing the transparency and accountability around land acquisitions, and in monitoring progress on land governance reforms.

"Between 2001 and 2010, 140 earth objects satellites from 26 countries were deployed on orbit. This number is expected to increase to 298 satellites from 43 countries by 2020. Private industry is building and operating a growing number of these satellites. The installed base of Global Navigation Satellite System devices is just over a billion and is expected to rise to 7 billion by 2022 – almost one for every person on the planet."
Bringing Space Down to Earth (2014), World Economic Forum Global Agenda Council on Space Security, http://www3.weforum.org/docs/AM14/WEF_AM14_GAC_BringingSpaceEarth_BookPreview.pdf

The current scenario is characterized by a plethora of often "projectized" pilot mapping exercises or other tech-based activities, with many not operating with open data and open source approaches, and with software applications that are not interoperable. This means that while most aim to improve transparency and accountability, and thereby the protection of land tenure rights, the total is not larger than the sum of its parts. On the contrary, many find the multitude of efforts confusing and would hope for a more joined-up approach that delivered a better picture across a larger area instead of many small and disparate pieces to a larger unknown puzzle. These "projectized" approaches are also not sustainable. Most projects have no plan for how the communities can continue to utilize these technologies, after the project ends.

Where private sector players are competing for market share or new market niches in what is perceived as lucrative future market opportunity, open source-open data approaches may be an excellent process for the market to deliver innovation at value for money. However, where donors fund projects aiming to make poor people's land tenure rights more secure, a better understanding of the landscape and recommendations for coordinated, aligned or joined-up approaches would be helpful to reach more poor people and driver better impact for public funding. Many approaches are currently neither open data, nor open source, and donors need to better understand what is most useful in a given context to maximize impact, value for money and joined-up approaches.

These observations have the Global Donor Working Group on Land (GDWGL) to commission a series of scoping studies, one of which aims to identify and discuss the extent to which innovative technological approaches can induce behavioral changes across the spectrum of land governance stakeholders - notably in rural areas – that can positively contribute to improve land governance. To reach that target, the study conducted an in-depth desk review of land governance initiatives implemented in the past five to ten years as well as a wide range of interviews, based on semi-open questionnaires, skype conference, as well as face to face interactions during the FIG Commission 7 and 3 seminar in Malta from 16 to 20th November 2015.

All the interviewees have warmly welcomed this study and embraced it as an opportunity to provide their views on existing and promising open technologies towards better rural land governance. Nevertheless, due to time schedule constraints, interviews and feedback from the donor community have been more limited than initially expected. One can regret not having enough time to meet and exchange with land administrations executives from emerging countries, to get their ideas, expectations and feedback. This study definitely deserves more time to draw up the big picture.

In the course of our investigations we also felt it was necessary to readjust the scope of the study and include a review of “enabling technologies”. Although these technologies – in particular related to internet connectivity – may not have been originally been designed and tested in support of land governance projects, have the potential to profoundly and positively change the outcomes of rural land governance projects in the future.

The present report precisely reviews the state of technologies that have emerged in the past five to ten years in land governance projects, discusses their trends and highlights some recommendations for coordinated efforts by the donor community.

Chapter 2 – An overview of technologies for rural land governance

Land governance is the process by which decisions are made regarding the access to and use of land, the manner in which those decisions are implemented and the way that conflicting interests in land are reconciled (UN-HABITAT, 2008). For more than two decades, the donor community has been assisting emerging countries in improving this process notably through activities that aims to:

a) fairly and equitably compensate land holders for land loss associated with land acquisition projects
b) modernize land rights administration system
c) survey and regularize informal land rights
d) arbitrate land-related disputes

Such activities require that land parcels be surveyed and assessed, associated rights be identified and ascertained, decisions be made, formalized, and publicized. Technologies have been key to achieving these objectives faster, more accurately, more transparently, more securely and more cost-effectively. These technologies can be divided into 6 broad categories:

- **Connectivity technologies**, that aim to remotely exchange land-related information between devices/computers and remotely execute processing instructions in a real-time manner, through data cables or radio-frequency signals. Connectivity thus removing the need for back-to-office reporting and data entry, and enabling instant processing of land related information.

- **Ground positioning technologies** that aim to determine the geographical coordinates of land parcel boundaries and other features that are relevant to land rights, through field survey measurements of the required accuracy

- **Remote sensing technologies** that aim to obtain exhaustive raster images of the ground surface from a spaceborne or airborne sensor, from which such information as location, shape and size of land parcels and any other relevant features can be extracted through visual or computer-aided interpretation.

- **Data capture technologies** that aim to gather land-related data - by hand or by automatic device – in a form that can be later on used for further processing.

- **Data storage and security technologies** that aim to protect records from accidental or malicious alteration or destruction.

- **Land administration workflow technologies** that facilitate the step-by-step execution of land-related administration processes with the view to deliver land related services including, but not limited to land registration, land transfer, land subdivision, or land mortgaging.

Each of these technologies are providing complementary technological “blocks” or “bricks” upon which land governance projects are being built or can potentially be built in the future. It must be emphasized that these technologies are not being developed specifically for the purpose of land governance. They are to be considered as “enabling technologies” that yield benefit for a wide range of applicative fields that includes land governance.

It is worth mentioning that there has been real innovation in the above mentioned enabling technologies. By way of illustration, such technological innovations include Maps API, Direct Geo-referencing, and multisource data fusion offer very promising opportunities to land governance projects across the world. There has also been genuinely innovative approaches to bridge the digital divide in rural areas: Grameen’s CKW initiative, Google’s Loon project and Ushahidi’s BRCK are among those. However, if we look a closer and objective look at it, there has been little breakthrough innovations in the specific fields of rural land governance, with the notable exception of smartphone-based applications dedicated to rural land government land.

Therefore, with a view to be exhaustive, and relevant to the donor community, the review of technologies supporting rural land governance shall consider both technologies that have been in use or experimented in the framework of land governance projects, as well as enabling technologies that have been designed to bridge the digital divide in remote rural areas, but have yet to be experimented in the field rural land governance.

The table below provides an overview of such technologies together with a review of their respective pros and cons in terms of coverage, speed, cost, or any other relevant criteria that were identified or reported during the scoping study. Following chapters do not provide an in-depth review of each of the technologies listed – such a review exceeds the scope of the present study – but rather focuses on those technologies that appear particularly promising and may deserve attention and support.

Table 1. Overview of technologies applicable to rural land governance

Technological blocks	Application to rural land governance	Pros	Cons
Connectivity technologies			
Mobile connectivity	• Remote exchange, storage and processing of land-related information - including imagery – between devices and computers	• Mobile technology is pervasive and spreading rapidly everywhere, even in rural areas • Telecommunications companies are continuously investing in extending mobile coverage to off-grid areas. • Cost of mobile broadband subscription keeps decreasing (below 10 US$ per month)	• Although rural connectivity is growing, a significant percentage of remote rural areas are still off-grid
VSAT	• Remote exchange, storage and processing of land-related information - including imagery – between devices and computers within off-grid areas	• Can provide broadband connectivity to off-grid remote areas	• Require costly specialized telecommunication equipment and connectivity service subscription in the range of 800 to 1000 US$ per month
L-band connectivity	• Remote exchange, storage and processing of land-related information – excluding imagery – between devices and computers • Provision of Real-Time Correction Messages (RTCM) for increasing the accuracy of GNSS-based coordinates in off-grid areas	• Provide satellite-based internet connectivity with a worldwide coverage • Cost of L-band messaging terminal is moderate (less than 500 US$) • Unlike VSAT, L-band connectivity services are "pay-per-use" based.	• Connectivity is limited to messaging format, L-band cannot carry streaming or large volumes of data
Small cells	• Remote exchange, storage and processing of land-related information - including imagery – between devices and computers within the fringes of internet coverage areas.	• Extends internet connectivity in rural and periurban fringe areas through the use of inexpensive antennas.	• Small cells technology are adapted to extend connectivity or bridge the last mile at the fringe of mobile coverage areas. Small cells do not solve connectivity issues in areas that are off-grid • The coverage of small cells is limited to a few kilometers
Loon project	• Remote exchange, storage and processing of land-related	• Intends to provide mobile and internet connectivity to remote	• Helium-filled balloons have a short life cycle (about 100 days) and need

Technological blocks	Application to rural land governance	Pros	Cons
	information - including imagery – between devices and computers within off-grid areas	areas where optics fiber and macro-cell towers cannot be competitively deployed • Loon project is deemed to bring internet subscription costs to less than 5 US$ per month	frequent replacements
Ground positioning technologies			
Local geodetic networks	• Provision of a geographic reference system (GRS) for land and property surveys	• May be used with inexpensive survey instrumentation • Facilitate inclusion of senior community citizens in land and property surveys	• Is costly for the National Survey Authorities to set up and maintain. In some counties, local geodetic networks have not been maintained for decades and records are lost.
Conventional land survey	• Provision of coordinates of land features with the required accuracy	• appropriate for securing property boundaries wherever fixed boundaries is required by legislation • High spatial accuracy (few centimeters)	• Time consuming • Require advanced survey and mapping skills • Survey cost per parcel can be considerable
Standalone Global Navigation Satellite System (GNSS)	• Provision of coordinates of land features with the required accuracy	• Standalone/recreation-grade GNSS equipment is inexpensive (100 US$) • Does not require advanced knowledge in GNSS surveying	• The geographic position of land features is inaccurate (within few meters) and may not be suitable for all land governance application
Post-processed differential Global Navigation Satellite System (GNSS)	• Provision of coordinates of land features with the required accuracy	• Cost of equipment is moderate (1,000 US$) • Data correction services are available online and free-of-charge (e.g. IGS) • Does not require advanced knowledge in GNSS surveying	• The accurate position of land features is not determined real time but require post-processing in office
Real Time Kinematics (RTK) Global Navigation Satellite System (GNSS)	• Provision of coordinates of land features with the required accuracy	• Geographic position of land features is accurately determined in a real time manner	• Cost of equipment is considerable (4,000 to 8,000 US$) • Requires advanced knowledge in GNSS surveying

Technological blocks	Application to rural land governance	Pros	Cons
Augmented Global Navigation Satellite System (GNSS)	• Provision of coordinates of land features with the required accuracy	• Geographic position of land features is accurately determined in a real time manner through a subscription to GNSS augmentation service provider • Does not require advanced knowledge in GNSS surveying	• Cost of equipment is moderate but GNSS augmentation subscription services can be significant (5,000 US$ per annum)
Remote sensing technologies			
Satellite imagery	• Provide regularly updated information about land cover and land use patterns	• Ground resolution, ranging from 50 cm to a few meters is suitable for most land governance applications • Medium resolution images (10 to 30 meters) are available for free • Satellite imagery is relatively inexpensive for small to medium size areas (typically from 20 to 40 US$ per km2)	• Use of data is restricted by an End-User License Agreement • Requires GIS capabilities to visualize and manipulate the imagery • Quality of images may be impacted by bad weather • Size of imagery files are huge (4 to 8 Gbytes) and either requires broadband internet connectivity to download or DVD delivered through regular mail
Maps API	• Provide regularly updated information about land cover and land use patterns without the need for any GIS software	• Allow the dynamic display on satellite images on laptop/smartphone/tablet screen without the need to download the full imagery. • Does not require any GIS skills • Maps API tend to be developed using Open Source platforms which offer large possibilities of customization	• Maps API does not store full imagery, therefore some areas may not be available to the application in case the device is offline
Nanosatellites	• Provide regularly updated information about land cover and land use patterns	• Intends to provide daily to weekly updates of high resolution satellite imagery at a competitive price	• Experimental technologies which is not yet proven
Aerial imagery	• Provide highly accurate information about land cover and land use patterns	• Very high resolution (few centimeters) • Cost-effective for large areas	• Requires GIS capabilities to visualize and manipulate the imagery • Quality may be impacted by bad

Technological blocks	Application to rural land governance	Pros	Cons
		• Imagery is not copyrighted. Data are owned by the project sponsors and can be distributed and reused at will by the project sponsors.	weather • Cost-ineffective for small areas due to high mobilization/demobilization costs • Aerial Imagery acquired from aircraft are not immediately usable and require post-processing (referred to as aerial triangulation) before it can be made usable to land governance projects
Direct georeferencing	• Provide real-time highly accurate information about land cover and land use patterns	• As opposed to conventional aerial imagery that requires post-processed aerial triangulation, direct georeferencing allows the real time acquisition of geometrically corrected images directly from the airborne sensors	• Not all embarked aerial camera system offers direct geo-referencing capabilities. The market seems limited to a few advanced camera systems.
Drone imagery	• Provide highly accurate information about land cover and land use patterns	• Very high resolution (few centimeters) • Quality of data Is insensitive to weather as drones fly below the cloud cover • Use of drones reportedly ensures a higher degree of community participation	• Requires GIS capabilities to visualize and manipulate the imagery • Requires in-house geometric processing capabilities • Cost-ineffective for large areas due to the low autonomy
Multisource data fusion	• Fast detection of land cover and land use changes	• Transform images acquired by different sensors and/or at different time in the same coordinate system within a limited processing time	• Still experimental
Data capture technologies			
Paper-based field data collection	• Collect field data about land rights and right holders	• Easy and fast to deploy at site	• Time-consuming as it requires back-office data entry • Prone to errors during data re-entry
Heads-up digitization of parcel boundaries	• Fast delineation of land parcel boundaries from remotely sensed	• Appropriate in legislations that recognize general boundaries	• May not be suitable for securing property boundaries wherever fixed

Technological blocks	Application to rural land governance	Pros	Cons
	data	• Suitable for fast assessment of parcel size • Field survey and related costs are limited to ground truth sampling	boundaries is required by legislation • Spatial accuracy depends on the geometric quality of remote sensing data used • Requires GIS capabilities
Smartphone and tablets	• Collect field data about land rights and right holders • Fast delineation of land parcel boundaries from remotely sensed data	• Smartphone and tablets are versatile all-in-one data capture devices combining GPS, camera, and text data entry capabilities directly in a digital format, thus reducing the need for back-to-office data re-entry • Smartphone and tablets are pervasive and can be found wherever there is mobile connectivity.	• Smartphone and tablets are usually held by the wealthiest rather than the poorest of the poor
Digital pen	• Collect data about land rights and right holders • Fast delineation of land parcel boundaries from remotely sensed data	• *Modus operandi* of digital pens is comparable to conventional pens, making this technology accessible to every literate community members • Information is directly converted and stored in a digital format • Information can be text-based or graphics-based (e.g. property boundaries) • Is adapted for land governance projects that only require parcels to be depicted in simple terms (for example, rapid assessment prior to land acquisition)	• Digital pen require special dotted watermark paper • Information about land parcel boundaries is generally sketchy and qualitative, and not suitable for land governance projects requiring some accuracy
Transaction and data security technologies			
Regular ID documentation	• Authentication of parties to a transaction	• Paper ID documents are commonly found in every country, even in remote rural areas	• Paper IDs are easy to forge
Biometric authentication	• Authentication of parties to a	• Biometrics authenticate parties to a	• Biometric authentication is not 100%

Technological blocks	Application to rural land governance	Pros	Cons
	transaction	land transaction in a far better way than regular ID documentation, thus reducing the risk of fraudulent transaction. Two or more biometric authentication method (e.g. face and voice recognition, keystroke, fingerprint) can be combined to increase security	reliable. Biometric authentication is affected by false positives and false negatives alike.
Security printing	• Authentication of land records	• Land records printed on security paper are difficult to counterfeit	• Requires expensive state-of-the-art printing capabilities for the issuing authorities • There are logistical issues related to supply security paper to remote areas • Does not protect against abuse of power from land officials
Cryptographic signature	• Authentication of land records by the authorized authority	• Cryptographic signature provides evidence that the land transaction / title to land has been digitally approved the chief land registrar and is therefore a legitimate entry in the land registry	• Does not protect against abuse of power from land officials
Cryptographic block chain	• Protection of land records against accidental or malicious alteration	• Titles to land are recorded in an immutable way guaranteed by a globally distributed network of nodes working collectively but anonymously. • Block chain does not require a trusted central authority to store and secure land records	• Requires that a large community of participating nodes be established and collectively contribute to secure the land registry
Cloud-based storage	• Secured storage of land records	• Purchase of server equipment is not needed • Cost of cloud-based storage is considerably less than the cost of purchasing server equipment • Cloud-based storage offer	• Requires an internet connection even intermittent

Technological blocks	Application to rural land governance	Pros	Cons
		possibilities to work offline and synchronize data as soon as an internet connection is available • Cloud-server are managed by high tech companies worldwide and are less prone to failure than self-managed servers	
Land administration workflow technologies			
Paper-based recording of rights	• Recording of rights about land parcels	• Easy and inexpensive to implement	• Prone to errors and falsification • Exposed to hazard and degradation
Land Administration Domain Model (LADM)	• Recording of rights about land parcels	• LADM is a land rights modelling standard widely adopted by most land rights management software	• Is not adapted for land tenure systems that are characterized by less-than formal customary rights
Social Tenure Domain Model (STDM)	• Recording of rights about land parcels	• Provides a framework for recording formal as well as less-than-formal land tenure rights	• Only few land rights management software are currently implementing STDM modelling standards (e.g. SOLA, STDM)
Point Cadastre	• Recording of rights about land parcels	• Easy and inexpensive to implement using mainstream GIS system (either Open source or COTS). • Adapted for land governance projects that do not require recording spatial information about land parcel boundaries.	• Is not adapted for land tenure systems or land governance projects that require recording spatial information about property boundaries and /or areas where land parcel boundaries are challenged
Land rights registration software	• Recording of rights about land parcels	• Automatize the workflow of managing rights from identification, verification to registration • Automatize the generation of records at each step of the land right management workflow (e.g. lodgment receipt, payment receipt, titles)	• Each software – either Proprietary or Open source – require some degree of customization to fulfill the requirements of a particular country • Software requires that qualified staff be trained • Maintenance is required to address bugs and updates

Technological blocks	Application to rural land governance	Pros	Cons
e-Conveyancing	Online lodgment and registration of land transfer/transactions via a dedicated web-based platform	• The parties to a land transaction do not need to visit the land registry offices. Considerable time is saved. • The status of the registration process can be tracked online on the internet making the process more transparent.	• Requires a robust

Chapter 3 – Improving land governance through rural mobile connectivity

There is simply no 21st century technology that has had such a profound and irreversible impact on our daily lives than mobile technology. Mobile has not just redefined consumers' experience by creating a wide range of new business opportunities and services, it has also reshaped relations between human beings in ways never seen before, including in the field of land governance in remote areas.

As an "enabling technology", mobile connectivity may contribute to improve rural land governance by reducing the digital and internet divide in remote areas that are currently off-grid. For instance, extension of internet connectivity to remote rural areas is expected to boost the development of e-government land services in rural areas - such as e-Conveyancing – that are found exclusively in urban centers. In turn, the development of e-government land services in rural areas is expected to have a major positive impact to rural communities, which may extend tens of kilometers away from the nearest land registry offices, and therefore far more disproportionately from the absence of e-government services than urban communities. Besides, extension of mobile connectivity towards rural areas is also expected to have a benefit impact on those remote communities whose land rights are challenged by giving them opportunities to voice their concern and expose land rights violations through crowdsourcing platforms (see chapter 4).

In addition, and as land governance projects become increasingly dependent on internet connectivity, e.g. for uploading or downloading satellite imagery, getting accurate positioning real-time, or managing large land data repositories through cloud platforms, it shall not be surprising that this review of state-art technologies for better land governance begins with a review of current initiatives and experiments to close the internet divide through wireless connectivity.

Current status of the Internet Divide in the rural world

Mobile broadband penetrates developing economies much faster than cabled networks such as Fiber to the Home (FTTH) broadband. Wireless broadband infrastructure are better suited to bring connectivity to emerging countries than fiber optic networks which can cost $5,000–$8,000/km (source: UNCTAD, 2015). In its 2011 report on Crowdsourcing Support of Land Administration, RICS observed that the fastest mobile growth has been in developing countries, which had 73 percent of the world's mobile phones in 2010, according to estimates from the International Telecommunications Union[1]. In 2014, this percentage reached up to 78% and the number of additional mobile broadband subscriptions in developing countries increased by 1.6 billion in 4 years.

Pervasiveness of mobile technologies in developing countries has to do with innovations and growing demand that drive down the costs of infrastructure and services, including for rural and remote networks. Some estimates foresee mobile communications services reaching a price threshold as low as $1 per month for basic users. Even broadband prices are already decreasing to below $10 per month in some markets.

1 http://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

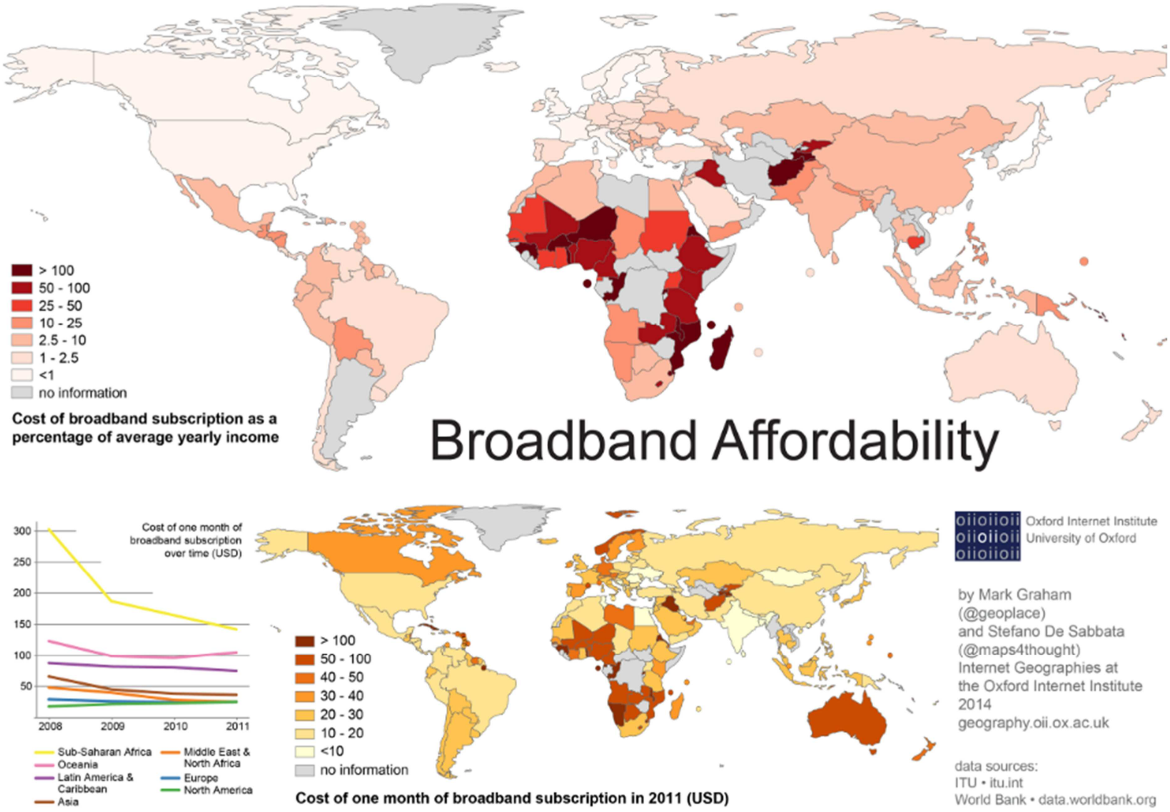


Figure 1. Broadband affordability around the world (source: Oxford Internet Institute)

However, this rather positive outlook should not overshadow the wide disparities that exist across the various segments of the population. While Internet and mobile telecommunications become fully embedded in every facet of our lives, 4.2 billion people are still offline, and the risk is high that substantial portions of this off-grid population are left behind. In its October 2014 study called "Offline and falling behind: Barriers to Internet adoption", McKinzey identifies these populations at risk as well as the barriers they face in adopting the Internet.

	Online	Offline
Population, 2013 (billions)	1.7	3.2
Living in rural areas[1]	~24%	~64%
Low income[2]	~0%	~50%
Illiterate[3]	~0%	~28%
Younger than 25	~47%	~42%
Older than 54	~7%	~18%
Female	~42%	~52%

Figure 2. Offline and falling behind in top 20 countries with the largest offline populations[2]

[2] Source - McKinsey - August 2014- "Offline and falling behind: Barriers to Internet adoption"

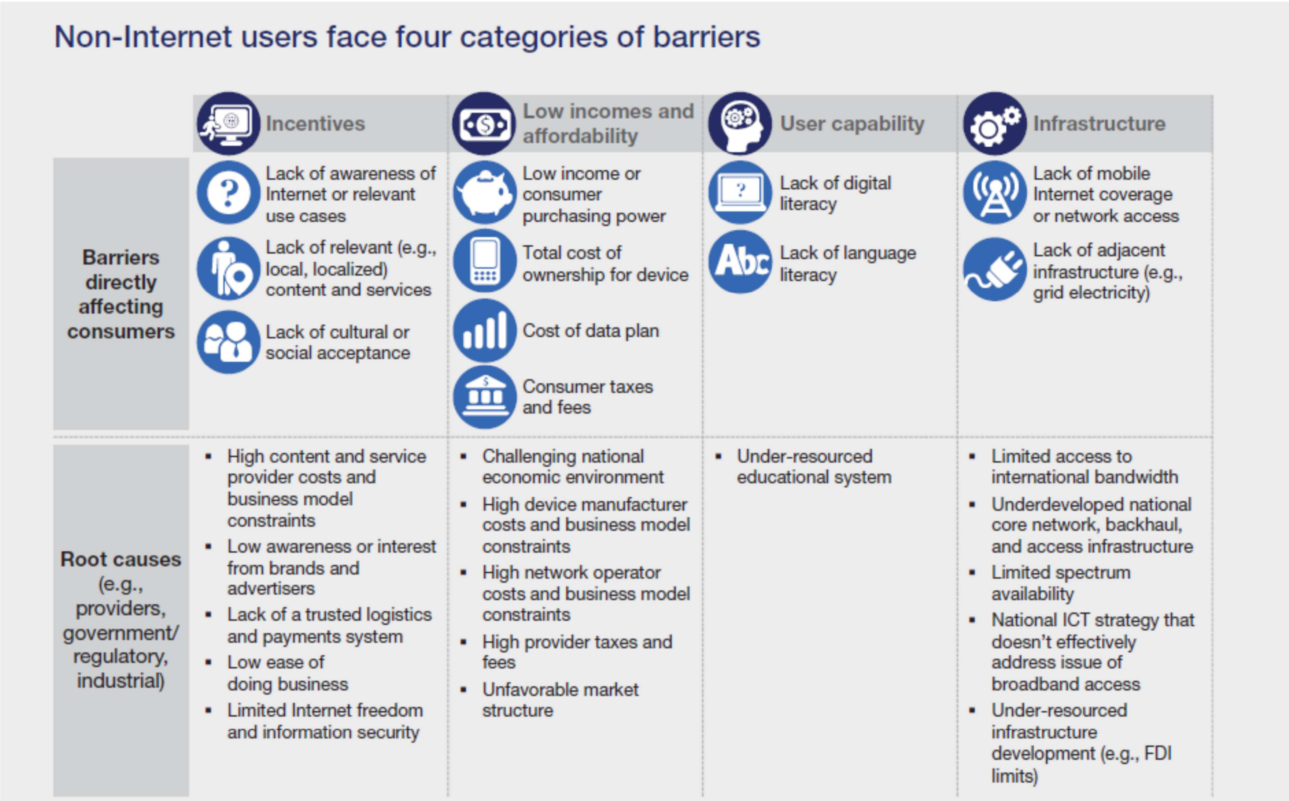


Figure 3. Non-Internet users face four categories of barriers (source: McKinsey, 2014)

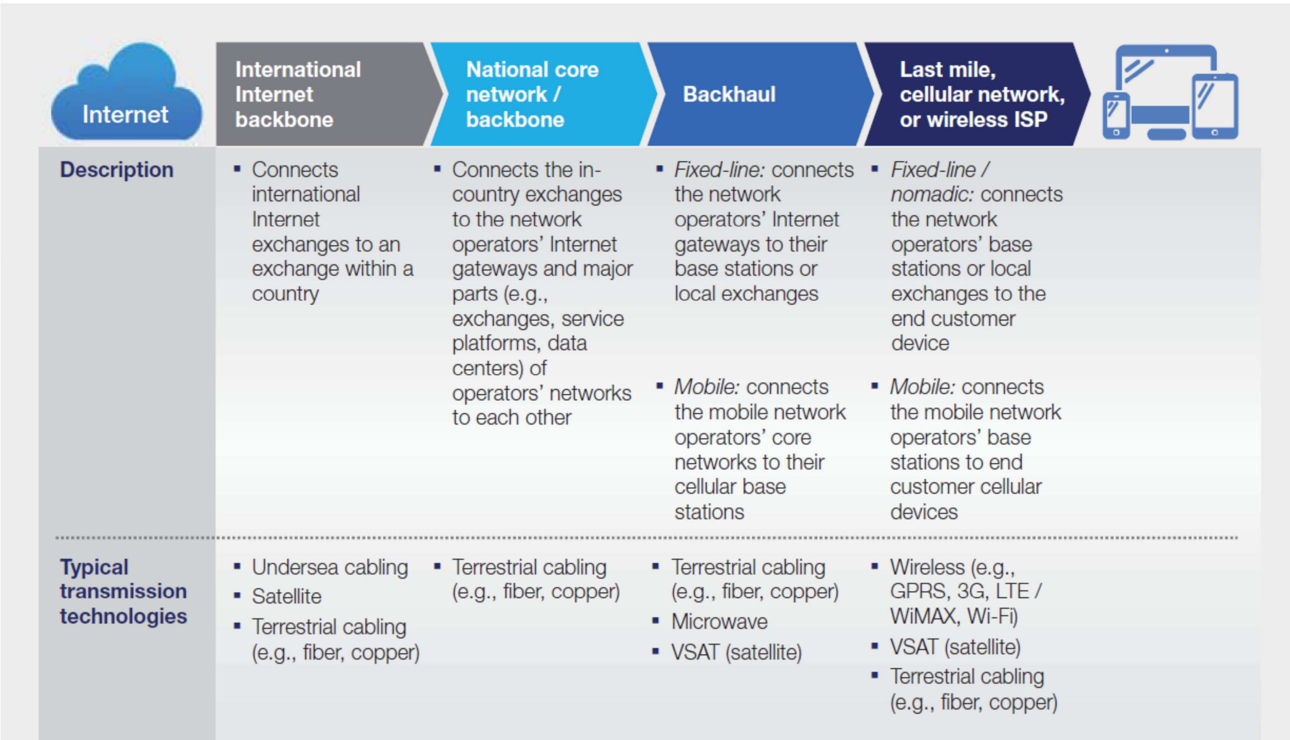


Figure 4. Data must travel through several networks to reach an end customer (source: McKinsey, 2014)

Small cells, big idea

“Small cells” is an umbrella term for mobile operator-controlled, low-powered radio access nodes, including those that operate in licensed spectrum and unlicensed carrier-grade Wi-Fi. Small cells typically have a range from 10 meters to several hundred meters and are emerging as the next big step idea towards global connectivity. Small cells are building upon easy-to-deploy femtocell technology, which were initially designed to extend mobile coverage inside residential buildings and support up to four simultaneous active users. The focus on making femtocell affordable led to developing standards, know how, software, open interfaces, and chips with low-power, self-configuration and optimization capabilities.

Small cells’ deployment - Indoor and outdoor - offers coverage for isolated locations and remote communities. Rural models are designed to meet the need to serve localized hotspots in remote areas, such as hamlets and small villages, which would otherwise be served from a distant and costly cell tower, or which might not otherwise be economical to serve at all. Rather than using a repeater, a small cell adds capacity and frees up the more expensive resource from the serving macrocell tower. It also allows deployment in rural places where there is no existing macrocell coverage.

The rationale of using small cell technologies to connect the rural unconnected has been best illustrated by an article published in SatMagazine in April 2014 by Gilat Satellite Networks, a provider of satellite-based broadband connectivity to remote users. This article emphasized that:

- Small cell technologies enable a more viable business case for low density area. Conventional broadband in high density urban areas is ensured by bulky and costly macro cells, which require very high capital expenditure (CAPEX) on costly towers, large diesel generators and indoor and outdoor equipment. These structures also require never-ending operating expenditure (OPEX) of high fuel costs and logistics. These costs cannot be justified when connecting a village of a few thousand people. Low-cost, outdoor small cells make rural connectivity a reality.

- Pro-rural digital-divide policies. Governments offer incentives to deliver affordable, accessible Internet connectivity to rural areas, in attempts to boost educational and economic opportunities. These incentives are offered by governments worldwide, and represent an opportunity—and challenge—to deliver not only Internet access, but quality, broadband access to rural areas. This trend is now becoming more prevalent in Africa, following the footsteps of adoption in Latin America.

However specialists insist that small cells on its own is not a full solution. To operate in rural areas, small cells require a backhauling technology, that is to say a primary connection to the rest of the telecom grid. In rural areas located in the vicinity of major urban centers, backhaul can be cost-effectively relayed through a network of microwave transmitters provided the areas to be connected are not too distant from the main grid and the relief is mild since microwave transmission requires a direct line of sight. In more remote areas, the backhaul recommended solution consists of High Throughput Satellites (HTS), an up-and-coming technology that uses multi-spot beams to optimize bandwidth, enabling reuse of the frequency band across coverage areas. This approach substantially increases satellite broadband capacity while reducing bandwidth costs.

Other challenges related to a wide-spread deployment of small cells includes a better understanding of interference issues which will inevitably impact signals carried over small cells, as well as potential challenges related to installing cells on non-telecom assets, which are difficult to protect, and shall therefore require support from rural communities.

Experts believe that small cell technology, once fully mastered, could lower monthly broadband prices in rural areas from over 10 US$ to possibly less than 5 US$ for basic usage.

Picture 1. One of the two small cells established in rural Zambia by Range Network. Total area covered 35 km2 (source: Range Network)

Low speed but high coverage: L-band messaging

Overshadowed by the rapid expansion of 3G and 4G mobile broadband solutions, L-band satellite systems offering machine-to-machine messaging services with a worldwide coverage and greater affordability have been around for decades but have been paid little attention by land professionals, with the notable exception of professional surveyors using L-band based global positioning systems.

Mostly used nowadays to support worldwide maritime and aeronautical communication, L Band satellite systems allow users to send and receive low speed to medium speed data using the on 1 to 2 GHz range of the radio spectrum (L-band). L band has a low bandwidth due to its low frequency range and hence is not suitable for streaming applications like video, voice and broadband connectivity. However, it features a wide range of other benefits that can be exploited for developing connectivity services to remote rural areas:

- Worldwide coverage. Unlike other mobile devices that rely on high power cellphone towers, L-band devices receive signals directly from L-band satellites which serve a worldwide coverage. This is the reason why L-band has been the preferred communication system for maritime communication, global positioning, fleet management and asset tracking.

- Text-based messaging. L-band signal is designed for transmitting text format messages from and to out-of-coverage facilities, such as merchant vessels at sea, flying aircrafts or offshore platforms. Transmitted messages may include geographic coordinates, instructions to remotely control facilities, or may include any other contents supporting basic e-government services, such as land administration.
- No pointing errors. Unlike broadband Ku- and C-band satellite systems that need careful pointing to the satellite to ensure a reliable connection, L-band terminals only require general pointing. L-band receiving technologies is therefore much cheaper to build and install.

- Rain-fade resistant: L-band terminals operate at a lower frequency, which means they are not susceptible to the weather-induced interruptions in communication that plague Ku and C-band equipment. The result is a reliable connection to your equipment regardless of the weather.
- Energy efficient. L-band messaging terminals can operate on small solar panels or even AA batteries making them less expensive to power and install. There is no need to install and operate generators to run equipment.
- Cost effectiveness and "pay-per-use" model: L-band messaging terminals are a third of the cost or less of mainstream broadband satellite systems while ongoing airtime costs can be an even smaller fraction. L-band terminals use a messaging protocol allowing users to only pay for the data that is sent over the satellite. Typically L Band data is "metered," which means payment is per minute or per MB.
- Small footprint: Ku-and C-band antennas can be up to 2.4 metres in diameter which is problematic if installation space is at a premium. [L-band] terminals are available that are less than 0.16 metre in diameter, which provide more installation flexibility.
- Smart: Beyond being a simple communication modem, L-band messaging terminals can function like a Remote Terminal Unit (RTU), allowing users to program local intelligence to support applications such as land-based application. This allows users to dictate under what conditions information should be sent over the satellite and keep airtime costs down while still receiving urgent communications instantly.

There has been intense debates about the saturation and rarefication of the available L-band spectrum due to the intensification of world maritime and aviation transport, and the price escalation risk that may result. Experience has however demonstrated that the global transportation industry tends to migrate to higher frequency bands offering higher speed and volume of data and tends to limit L-band communication as a backup solution only. This leaves a significant fraction of the radio spectrum available to support other applications. The industry of Global Navigation Satellite Systems such as GPS and GLONASS has already been exploiting the opportunities offered by untapped L-band spectrum to broadcast real-time correction messages (RTCM) supporting their precise point positioning capabilities (see chapter 5).

In their report "Global momentum and economic impact of the 1.4/1.5GHz band for International Mobile Telecommunications" (October 2015), the GSM Association (GSMA) further emphasized that the characteristics of L-band frequencies are ideally suited for mobile services as they are capable of delivering additional capacity and coverage over relatively large and remote areas, including inside buildings. A portion of the band is already allocated to mobile services worldwide and another is reserved for digital radio broadcasting, but is largely unused, creating an ideal basis for a wider mobile allocation. The range 1452-1492MHz could be made available for mobile services as early as 2018-2020, while the surrounding range could be available in many countries by 2025, with limited disruption to other services.

However, the challenge to open up the radio spectrum to new applications should not be underestimated since bandwidth allocation are subject to strict national and international regulations. Dedicating a particular bandwidth to support land mobile or machine-to-machine applications would require high-level agreements between governments, international regulatory bodies and private operators.

Internet on the fly: the Loon project

The Loon project is sponsored by Google and is an initiative to connect at an affordable price the two-thirds of the world's population are currently off the internet grid. Project Loon is a network of sun-powered helium-filled balloons floating in the stratosphere – about 20 km above ground and above weather – and designed to connect people in rural and remote areas, help fill coverage gaps, and bring people back online after disasters. In the stratosphere, winds are stratified into different layers, each one varying in speed and direction. By rising or descending into a layer of wind blowing in a desired direction, loons can be arranged into forming a large communication network.

Picture 2. Deployment of an experimental loon in Brazil (source: Google X)

Each balloon can provide connectivity to a ground area about 40 to 80 km in diameter using 3G and 4G wireless communications technology. Project Loon partners with telecommunications companies to share cellular spectrum so that people will be able to access the Internet everywhere directly from their phones and other LTE-enabled devices. Balloons relay wireless signal from cell phones and other devices back to the global Internet on Earth.

In July 2015, Google has entered into a memorandum of understand with the Sri Lankan government to deliver broadband Internet to every region of the island nation, making it the first country in the world to have universal and cheap Internet coverage. While 2.8 million of mobile phones are currently connected to the Internet in Sri Lanka, the intent of the memorandum of understanding is to connect the remaining 19 million mobile phones not yet connected. A total of 13 balloons are expected to be deployed by March 2016.

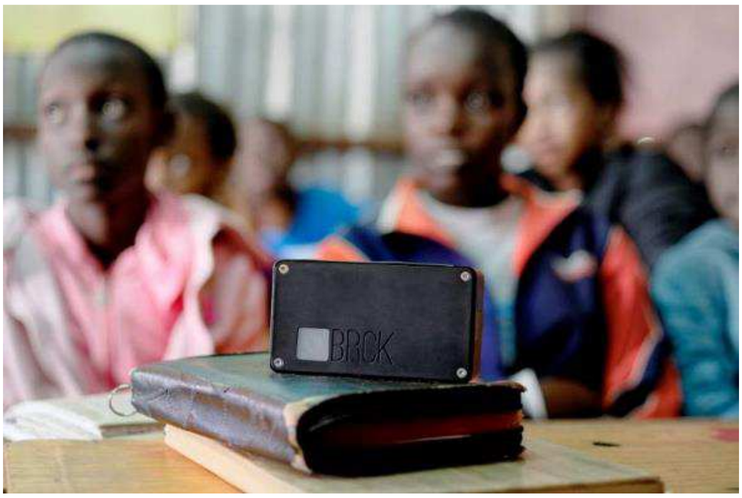
While the exact cost of one balloon has not been revealed, Google indicated that it is in the range of "tens of thousands" of US dollars. Google also hinted that internet connectivity could cost as low as 5 US$ per month per mobile phone. Local internet service providers will be entering into agreements with Google to access the floating communication network and bring down their transmission costs.

A major limitation of balloons resides though in their life expectancy: each balloon needs to be replaced every 100 days or so, due to the huge atmospheric pressure and up to 100 mph winds that the balloon polymer skin has to withstand. Although Google has brought major improvements to the polymer envelop, risk of failure is high and could occasionally disrupt internet services for a few days to a few weeks, defeating the entire purpose of the loon project.

The Internet multi-tool for remote areas: BRCK

BRCK is an initiative by Ushahidi which became a reality through an initial capital investment of 170,000 US$ secured through a crowdfunding platform. Also BRCK is usually presented as a Wi-Fi router integrating such different platform as it is in fact an internet multi-tool that can be programmed to ensures a continuity of services enables applications brings some degree of connectivity to areas which are currently not covered or not continuously covered by internet and power coverage.

The 200 US$ worth BRCK allows its users to access internet through a wide range of technologies including existing Wifi connections, Ethernet-cabled connections, GPRS/EDGE connections, 3G/4G simcard, or through its own dedicated virtual Mobile Virtual Network Operator (BRCKnet) that can provide global connectivity without simcard. BRCK features a GSM antenna extension that can amplify the GSM signal at the edges of the GSM coverage area. In return, BRCK generates a high-power Wi-Fi signal that can be accessed by up to 20 devices. The device has a rugged design specially fit for resisting dust, rain, wild voltage and hosts a battery with an 8 hour autonomy that can be recharged with a solar cell kit or car battery.



Picture 3. The BRCK device in a remote school of Kenya (source: BRCK)

Although BRCK is not making use of cutting edge technologies, its innovative approach lies in the integration of these "not so innovative" technologies with tailor-made content synchronized with a BRCK dedicated Cloud, making it possible for BRCK to continue serving up to 16 GB of content offline to its connected users. Content is synchronized as soon as internet connectivity is restored. This feature is particular relevant wherever internet connectivity is spotty rather than non-existent.

Although BRCK has until now mostly focused on the educational sector and the provision of internet-based content to remote schools, its versatility and flexibility can address connectivity challenges faced by land registries located in remote areas. As emphasized by Ushahidi, BRCK was designed keeping productivity in mind and any workflow – in particular data production workflow - that involves the connection of several agents to a collaboration platform that only requires occasional synchronization, for instance at night when bandwidth use is low, could potentially benefit from BRCK. As such, BRCK can be seen as a facilitating technology that can supplement or extend the usability of mobile/desktop applications for secure land tenure to areas with spotty internet connectivity.

Chapter 4 - The rise of Augmented Trusted Intermediaries

Trusted intermediaries have always been central to land governance projects. Traditionally, trusted intermediaries have been land professionals and/or public service officers, such as a notary public, chartered surveyor, conveyancer, justice of the peace, or liaison officer. For decades, such professionals have midwifed land governance projects through community awareness, collection of data, dispute resolution, and confirmation of rights. Yet, relations between these facilitators and land governance reform projects funded by the donor community have been somewhat ambiguous in the past two decades. It has to do with their perception that standards and technologies promoted by land reform projects would decrease their influence and ultimately phase them away from land administration. As a result, these professionals became gatekeepers if not fierce opponents to land reform.

In spite of this, the opinion is unanimously shared among land governance project implementation agencies that intermediaries are more than ever needed to reach out the “last mile” smallholder farmer, but in ways that are radically different than traditional intermediaries: by relaying and amplifying the voice of community members rather than gatekeeping land institutions. This chapter explores the renewed interest by the international community to identify and rely on alternative group of trusted intermediaries to support and improve land governance project.

Empowerment with mobile technology: the experience of Grameen foundation

Established in 1997, the Grameen foundation addresses the needs of the world’s poorest—people living on less than $1.25/day - by catalyzing the wide scale adoption of new technologies and new solutions to poverty. Central to Grameen foundation’s vision is the statement that economical poverty and information poverty are intertwined. Information poverty can be defined as that situation in which individuals and communities do not have the requisite skills, abilities or material means to obtain efficient access to information, interpret it and apply it appropriately.

To address information poverty, Grameen foundation pioneered in 2002 the initiative “Village Phone” to extend cellular connectivity to remote villages in Uganda. The initiative aimed at financially assisting micro-entrepreneur in buying a 200 US$ village phone kit – consisting of a re-engineered cellular phone, a 10 meter cable to connect to an external antenna and a battery to keep it charged – that extends regular cellular coverage from 15km to 30km in many cases bringing cellular connectivity to areas for the first time.

The experience of Village Phone not only highlighted the critical role played by mobile technologies in successfully bridging the connectivity divide, but also demonstrated how village-level entrepreneurs and operators acting as technology intermediaries have quickly become trusted leaders in their communities. They are relied upon for the communications services that they provide. They are required to relay messages, handle information of different types, and manage finances. They are also privy to important phone conversations, causing them to gain functional knowledge in areas such as currency markets, or health problems.

In 2010, Grameen Foundation built upon this success and started giving these intermediaries – rebranded Community Knowledge Workers (CKW) - a more active role, notably in collecting data from, and delivering content to villagers with the view to support a wide range of new services including access to health services, finance, and insurance. The CKW initiative is using a combination of mobile technology and human networking to bridge the last mile and connect remote smallholder farmers to the digital society.

In practice, Grameen has partnered with a wide range of technology providers – such as Nokia and Google - and pro-poor service providers to build a win-win economic model. Through the community knowledge worker equipped with his smartphone featured with content-oriented applications, small holder farmers can found practical answers to their most frequent problems – such as diagnosing the disease impacting his/her livestock or crops and finding appropriate remedies, locating marketplaces with the most advantageous market prices for his/her commodities – and in exchange for this service, agrees to dedicate his/her time to the community knowledge worker for participating in service-oriented surveys. Surveys are designed in such a way to profile the community of farmers according to criteria that are relevant to service providers such as micro-finance institutions, crop or livestock insurers, or health service providers. This win-win scenario has materialized in Uganda where nowadays over 1200 CKWs are serving over 300,000 farmers in 43 districts, and is being expanded to Colombia.

The main technological components of the Community Knowledge Workers' initiative include:

1. The Community Knowledge Worker augmented with mobile technology capabilities designed for collecting data and delivering content. CKWs are peer-selected among the smartphone-literate youth community as trusted intermediaries. CKWs undergoes training on how to use the apps, how to conduct the surveys and how to deliver appropriate content addressing the farmers' concerns.

2. TaroWorks™, that is a suite of mobile data collection and field management tools built on the cloud computing platform Salesforce, and accessed in the field via Android devices. Its modular design is optimized around remote field operations management and business analytics needs. TaroWorks functionality includes:
   - Registering — Register a new client, project or entity
   - Training — Deliver structured content (video, PDF, Word, Excel)
   - Monitoring & Evaluation — Integrate the Progress out of Poverty Index (PPI), measure impact overtime, track impact, project progress over time
   - Case Management – Assign clients or projects to field staff, who can view historical information offline
   - Transaction — Capture POS orders, track inventory
   - Performance — Manage performance, set goals, identify where additional support is needed

3. An Application Laboratory (AppLab) incubator, headquartered in Uganda that forms a community of developers and sector specialists designing, testing and delivering surveys as well as content-oriented applications in partnership with private service providers such as banking institutions, telecommunication operators, or medical service providers.

Through the CKW initiative, Grameen foundation is not just building upon innovative content-oriented technologies, it is also introducing an innovative economical model whereby farmers get an access to contextualized content addressing their specific concerns against an amount of time they dedicate to answering consumer surveys. This content-against-time bargain through trusted intermediaries is a very unique way of including the rural poor to the digital economy. First, it demonstrates that profiling data pertaining to rural poor have an intrinsic value especially for pro-poor service providers. Such data indeed signal the needs, habits, and consumption desires of the rural poor which accounts for 70% of the developing world's 1.4 billion people below the poverty line. Based on the analysis of such survey data, pro-poor service providers can design, refine, prioritize, and deliver new products or services to better defined and segmented targets, therefore with a minimized risk, at a lower cost than deploying their own field surveyors. Grameen experience shows that private service providers may be actually willing to sponsor the cost of survey data acquisition by incentivizing the community knowledge workers. One of such partnership has been recently concluded between Grameen Foundation, Coocafisa Cooperative and the Starburcks to connect 1,300 coffee farmers through the CKW model.

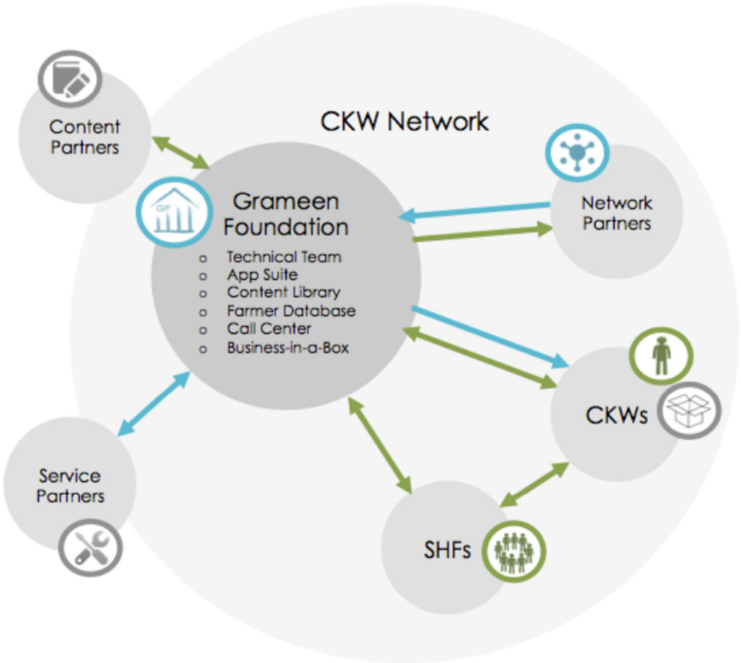


Figure 5- CKW model in Uganda – from Lessons Learned - 2009 – 2014 - Community Knowledge Worker - Uganda Program - ©2013 Grameen Foundation

From bare-foot to augmented surveyors: the MAST initiative

Although Grameen's CKW initiative did not specifically address the issue of land rights recognition, that is the mapping and monitoring in rural areas, the viability of the model it introduced has inspired a new generation of land governance projects relying on peer-selected and trusted intermediaries that are augmented with mobile devices with specific land rights-oriented applications.

The Mobile Application to Secure Tenure (MAST) pilot project that was implemented by United States Agency for International Development (USAID) under its Evaluation, Research and Communication Contract counts among the most promising land governance experiments implemented in the past 3 years. Experimented in several villages of rural Tanzania with the support of USAID implementing partner, Cloudburst Consulting Group, Inc., MAST applies the approach of trusted intermediaries to capture and manage land-related information using an Android-based smartphone application and a web-based data management infrastructure. The strength of MAST is its capacity to bring together state-of-the-art technologies and land-related concepts into a turnkey solution, and engage citizens in the process of recognizing and mapping land rights, as well as delivering titles in an affordable and fast-tracked manner.
Technologies have been integrated into an application suite consisting of two segments:

- The Mobile Data Capture Application built for an android-based smart phone and operated by trusted intermediaries. This application supports the on-screen digitization of parcel boundaries (see picture below), the capture of alphanumerical data – such as names, addresses, or dates, and the recording of multimedia information - such as pictures and video recordings, if needed.
- The web-based back-office Land Rights Data Infrastructure which is hosted in the cloud features:
    - A Mobile configuration module which allows users to customize field data collection form to match the specificities of each areas
    - An Administration module that can assign secure users according to roles and add data layers
    - A Data Management Infrastructure module that can ingest, manage, store, map land rights data as well as generate land rights reports, primarily a preconfigured land certificate.

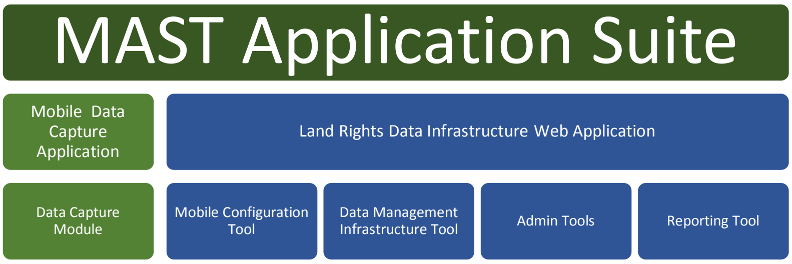


Figure 6 – Application Framework for "USAID's Mobile Application to Secure Tenure (MAST) Pilot Project (Source: Cloudburst Consulting Group, Inc.)

The MAST suite of applications is built on open source tools and include:

- GPS/GNSS-enabled smart phones and tablets operated by trusted intermediaries
- The state-of-the-art Open-source geospatial standards and technologies including:
    - Standards from the Open Geospatial Consortium (OGC): Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Services (WCS)
    - Geospatial data server to share, process and edit geospatial data: GeoServer
    - Geospatial database management systems (DBMS): PostgreSQL with PostGIS extension
    - Servlet container that manages requests between the web server (GeoServer) and the DBMS (PostgreSQL)
    - Standards storing geographical objects along with their non-spatial attribute in the mobile application: GeoJSON, an open standard format based on JavaScript Object Notation (JSON)
- The state-of-the-art Open-source standards for land rights administration standards: Land Administration Domain Model (LADM) and the Social Tenure Domain Model (STDM)
- High resolution satellite imagery to serve as a background image for onscreen digitization of parcel boundary directly from the mobile data capture application
- Google Maps Android Application Program Interface (API) for embedding maps and satellite imagery into the mobile application
- Cloud-based technology to store data collected either online or through a post-capture synchronization whenever connectivity is available.
- Smartphone-friendly format for application and data: Android Application Package (APK) for installing applications on Android smartphone and SQLlite/MBTiles format for storing and fast displaying maps and imagery on mobile screens

The attached workflows provides more details about the process of capturing and managing land rights data with the view to generate land certificates.

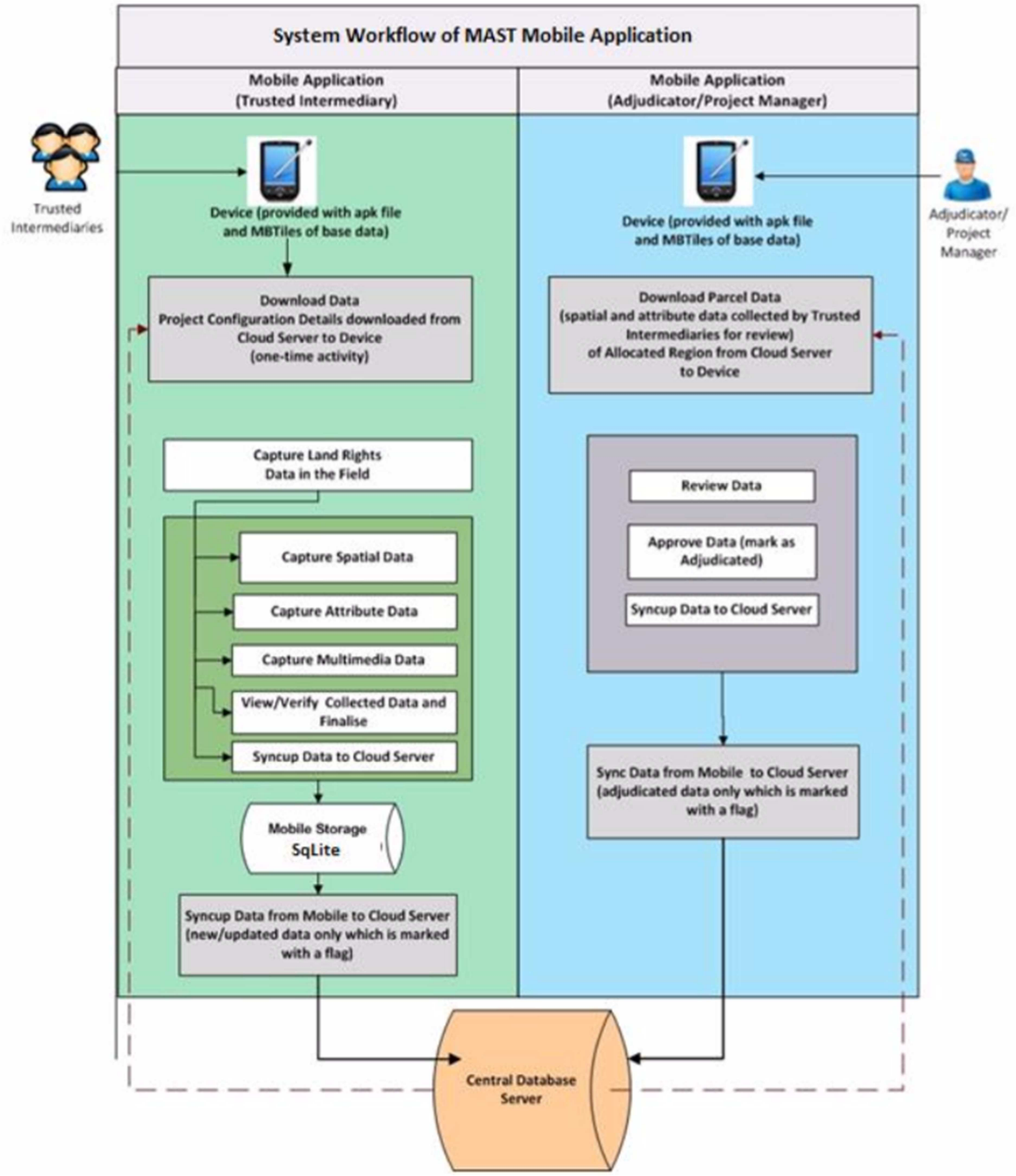


Figure 7 - Mobile Data Capture Application workflow
Extracted from the PPT presentations "USAID's Mobile Application to Secure Tenure (MAST) Pilot Project"
(source: Cloudburst Consulting Group, Inc.)

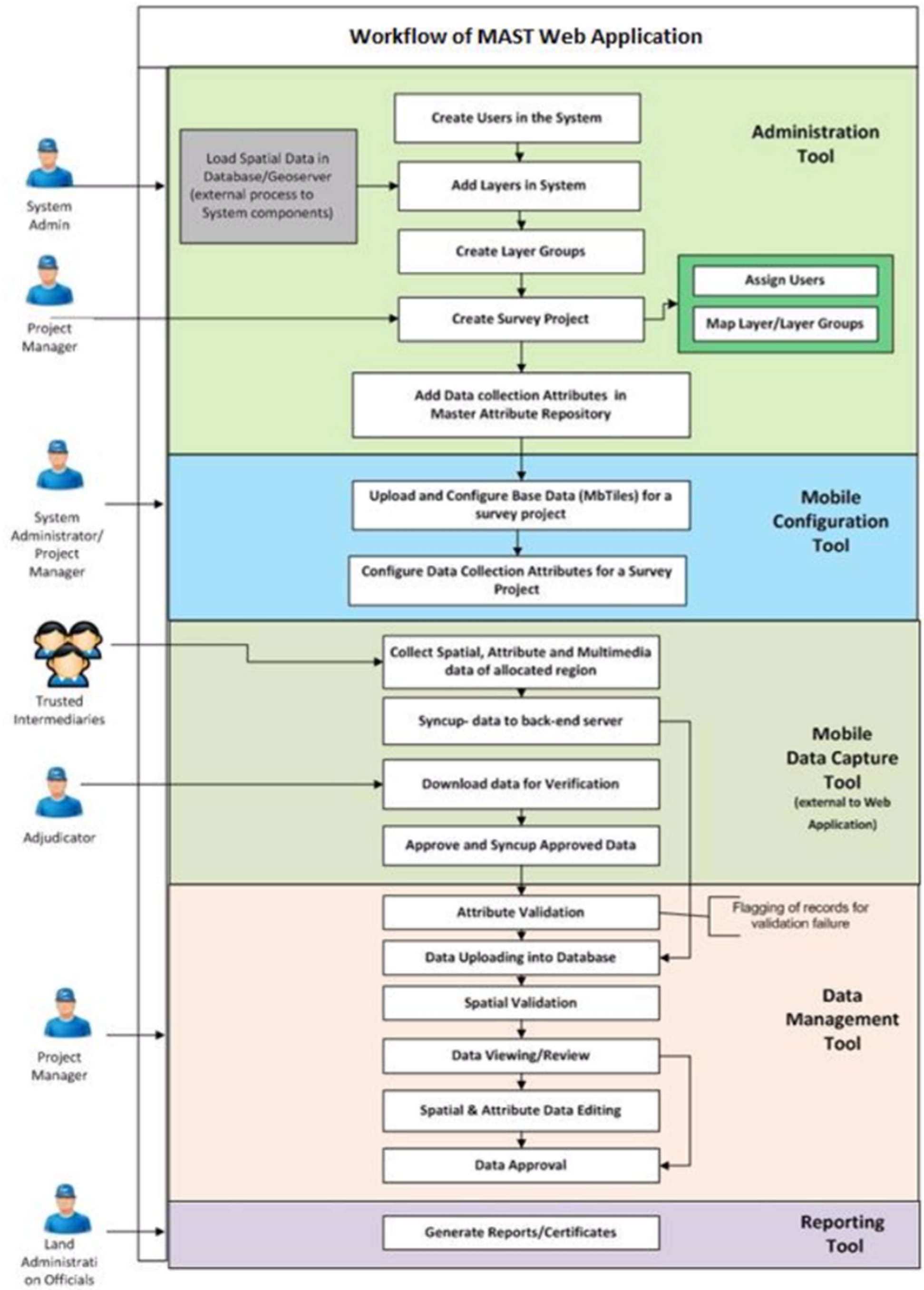


Figure 8. Land Rights Data Infrastructure workflow - USAID's Mobile Application to Secure Tenure (MAST) Pilot Project" (source: Cloudburst Consulting Group, Inc.)

MAST represents a convincing experimentation of intertwining open-source standards and tools, mobile technologies, citizens and land administration professionals in ways that were previously unexplored. It needs to be highlighted the engagement of the government agency in the MAST project, without which MAST project would not be possible. Most pro-poor recordation projects do not achieve this engagement and endorsement.

However, the scalability and replicability of MAST and its implementation methodology to other countries require a prudent approach:

- Tanzania offers an exceptionally favorable legal environment to the smartphone-based mapping of rural parcel boundaries, since Tanzanian laws and regulations does not require an excessively accurate mapping of rural parcel boundaries prior to issuing Certificates of Customary Rights of Occupancy (CCRO). Legal requirements for excessively accurate survey and mapping of land plots are unfortunately wide-spread throughout the world and remains a common obstacle to the adoption of fit-for-purpose land rights mapping solutions.

- In other countries, the small corp of land professionals, such as surveyors and conveyancers, represent a strong political lobby and therefore may aggressively challenge the introduction of new land administration solutions, as has been the case in Cote d'Ivoire, Nigeria or even Colombia.

- To date, the MAST initiative has been successfully implemented in one village in rural Tanzania, with 910 plots. This sample appears large enough to test the technology and provide first hand feedback about its usability and stability as a new technology, however, the technology although based on a flexible model has not been implemented in other countries with different social, legal, institutional and environmental (relief, forest cover, etc.) situations as encountered in Tanzania. MAST may soon be deployed in Burkina Faso, which will give a much-awaited additional feedback from a country with a different social and institutional setting.

- While USAID has not conducted a formal economic evaluation of MAST project, the cost per parcel for capturing, validating, adjudicating and issuing land rights certificates has been estimated to range from 15 US$ to 20 US$. This cost includes a flat 6 US$ fee that is required for the printing of land certificates on government crested paper or stationaries, and includes implementation costs for social programs and training, incentive costs for engaging trusted intermediaries, costs of telecommunication which are reportedly high in Tanzania, incentives to the trusted intermediaries, as well as the cost of cloud computing. This costs, however, does not include the cost of satellite imagery, which, in the case of Tanzania, was sponsored by USAID. The use of satellite imagery was deemed necessary as areas in which it was implemented the base mapping was poor and resolution of google imagery (MAST utilizes a Google API to stream google imagery) was not adequate. The effective use of satellite imagery in the mobile phone application is innovative, but is has implications for sustainability. The cost for the satellite imagery does not appear to be included in the cost per parcel – this shall not exceed 0.5 US$ for a typical 1.3 hectare wide in rural Tanzania – but its potentially high licensing costs to be disbursed upfront, typically 3,000 to 4,000 US$ for a minimum 100 square kilometer coverage.

The new kid on the block: the LandMapp initiative

Founded in 2015, LandMapp seemingly addresses a fundamental issue faced by most rural land governance projects around the globe, which is that land rights securing through the issuance of certificate of ownership or occupancy is often perceived by struggling farmers at best as a distant hypothetical and luxury advantage (e.g. possibility to access credit one day) while their immediate survival needs are not being addressed. In that perspective, LandMapp represents a promising innovation as it sets up a low cost platform to connect rural communities with private service providers such as banks, crop insurers, input suppliers, local and international agro-industrial processors or traders, and governments which all together share a common interest in securing business through formalized rights.

While a great deal of projects tend to consider the inclusion of the private sector "at a later stage" of the project development, LandMapp includes such partners from the onset of the project design. By doing this, such land rights recognition steps as the costly field data collection can be tailored to meet dual objectives of formalizing rights and profiling small holders for relevant business analytics. In that respect, LandMapp appears to be a promising synthesis of Grameen's CKW initiative and USAID's MAST.

Currently piloted in Indonesia and Ghana, the Landmapp initiative features mobile applications operated by trusted agents at the front-end, and a Web-accessible cloud platform at back-end. While the technologies and functions used are similar in nature to MAST, LandMapp applications are not developed exclusively with Open Source standards and tools. Besides, LandMapp cloud-based web application features business analytics functionalities that match the requirements of the private sector partners, such as:

- Asset valuation for crop insurer
- Credit assessment for financial institutions
- Product traceability for value chain auditing and eco-certification purposes
- Land use / crop production profile for commodity buyers
- Carbon footprint assessment

LandMapp is currently in its infancy but its results and lessons to be learned should be closely monitored and regarded as a new way forward in rural land governance.

Crowdsourcing as a new approach to land transparency

CKW, MAST and LandMapp are the most visible components of a more powerful trend in land governance which is tapping into the power of crowds and mobile connectivity to change the balance of power. The availability and interoperability of modern mobile communication tools make it very difficult nowadays to keep sensitive information secret, and has re-balanced powers from governments to the benefits of citizens: governments are more vulnerable to attack, either technological or political, while citizen groups can become less vulnerable and more effective due to their increased ability to report violations and organize themselves through social networks. Government also benefits from these social media applications, which facilitate real-time data collection and dissemination crowds to crowds, for example for reporting emergency situations or market price information.

Among the pioneers in crowdsourcing platform for better land governance is the Open Data Kit (ODK) developed by the University of Washington in 2010. ODK is an Android-based mobile application that enables fast collection and reporting of spatialized data, and is suited for organizations that need inexpensive ways to gather information. ODK has been successfully used by whistle-blowers and the Surui tribe in Brazil as a tool to expose illegal logging that was taking place on their lands and use this platform as a global campaign to advocate their case.

Since ODK, a dozen of other initiatives have emerged and are nowadays offering remote communities a venue for reporting their claims over land. These includes initiatives such as:

- Land Matrix (http://www.landmatrix.org/en/)
- LandMark (http://www.landmarkmap.org/map/)
- Land Portal (landportal.info)
- Cadasta (http://cadasta.org/)
- Missing Maps (http://www.missingmaps.org/)
- Mapping For Rights (http://www.mappingforrights.org/)
- Rights and Resources (http://www.rightsandresources.org/)
- PPGIS (http://www.ppgis.net/)
- Open Land Contracts (http://www.openlandcontracts.org/)
- Informal City (http://informalcity.org/)
- Open Land Contracts (http://www.openlandcontracts.org/
- Land Observatories (www.landobservatory.org/)
- FarmlandGrab (www.farmlandgrab.org/)
- World Forest Watch (www.globalforestwatch.org)
- Land governance programme (www.landgov.donorplatform.org/)
- Open Contracting Partnership (www.open-contracting.org/)

- Land Deals Politics Initiative (www.plaas.org.za/ldpi)

The rationale underpinning these initiative is that “transparency breeds self-correcting behavior” among all types of actors, since neither governments nor businesses or individuals want to be caught doing something embarrassing or illegal. However, organizations implementing these platforms have been insisting that crowdsourcing, as an information conveyance tool, does not necessary guarantee information quality and reliability as such, and a robust organization to validate the information shall be concurrently implemented.

Chapter 5 – Squaring the circle of affordable real-time spatial accuracy

Spatial accuracy in land governance projects is more often than not a trade-off between: i) mapping the spatial extent of land rights with enough details to minimize potential misinterpretation, ambiguity and disputes and ii) time and cost that projects' sponsors can afford. While an accuracy of 10 to 20 meters can be achieved almost instantly and at a low cost from GNSS-based field data collection, it is commonly admitted by the vast majority of land professionals that reaching sub-metric to centimetric accuracy would require: i) money to procure advanced survey equipment– and ii) time to process data using state-of-the-art software.

However, things have started changing radically in the past five years with the introduction of new technologies that are not making real-time accuracy a not-so-distant target but are also radically changing associated economic models towards greater affordability. This chapter reviews some of the most promising developments in this field.

The GNSS dilemma: Accuracy vs. Time vs. Cost

The utilization of GNSS technologies has been widely used in land governance projects for at least a decade to capture the coordinates of property parcel corners and other remarkable features on the ground. GNSS is the generic term used to describe any satellite-based navigation system using signals emitted by a constellation of satellites (the "space" segment) controlled by ground stations (the "control" segment). Signals sent towards the Earth are received and interpreted by ground receivers (the "user" segment). The ground receiver compares the delayed signal received from each satellite with its own generated code, and converts the measured delays into distances. Coordinates of the ground receiver is then computed using trilateration, a well-tried mathematical method aiming to determine the unknown coordinates of a point (ground receiver) using its distances from other points of known coordinates (the satellites). Space coordinates of satellites are indeed predicted by their orbital trajectory, also referred to as ephemeris data, and transmitted to the ground receiver simultaneously with the signal.

GNSS systems are usually backed and controlled by specific national governments, or group of governments, for military or civilian applications. Historically, two GNSS have been co-exiting in the past three decades:

- The pioneer NAVSTAR Global Positioning System (GPS) is owned and operated by the US government.
- GLONASS system is owned and operated by the Russian Government

Governments controlling GNSS system have not been charging fees to civilian users, but have occasionally degraded the quality of the signal, therefore the positioning accuracy, to maintain a military advantage during global crisis. This makes the technology accessible to any users who can afford to buy a GNSS receiver, as long as the technology is not restricted by the controlling government. Considering the wide range of civilian applications heavily depending on GNSS technologies, the low but real risk of technology restriction has motivated a number of other governments to design and deploy their own proprietary GNSS technology, which will be fully operational on or before 2020. This is particularly the case of:

- the GALILEO system sponsored by the European Union
- the COMPASS/BEIDOU system developed by the Republic of China
- the IRNSS system developed by the Republic of India

GNSS has been among the most volatile technological environment and illustrates quite well the concept of continuum of technologies: GNSS systems comes in a wide variety of receivers, accuracy, types of correction, data transmission modes and business models.

Until recently, GNSS was plagued by this seemingly unsolvable dilemma between time of acquisition and accuracy. The GNSS industry was then dominated between by two operating modes:

- <u>The "Autonomous" mode for fast acquisition but low accuracy.</u> Autonomous mode is the cheapest form of GNSS utilization and also the most inaccurate. This mode requires a simple standalone GNSS receiver whose cost nowadays varies from 100 to 500 US$. Depending on the location, weather and satellite constellation conditions, the accuracy of autonomous mode commonly fluctuates between 7 to 30 meters. This accuracy is very coarse and unfit for most land governance purposes. Autonomous mode is used for recreational and navigational applications that do not require an accurate positioning. Inaccuracies result from a number of factors including satellite orbits and clocks drift, atmospheric conditions, topographical configuration and other minor factors that all prevent a standalone ground receiver from calculating a precise distance from the satellites.

- <u>The post-processed differential mode for high accuracy but slow acquisition</u>. Errors affecting signals received by a GNSS receiver installed on a survey monument of accurately know coordinates (called the "base" station) can be easily quantified and used as a proxy of errors affecting signals received by GNSS receivers simultaneously operating anywhere within a radius some hundred kilometers away from the base station. Corrections are applied in office after the survey is completed hence the term "post-processing". Post-processing requires that the data simultaneously collected by two or more nearby GNSS receivers are being downloaded and jointly processed by an appropriate software package. The overall equipment cost to conduct GNSS survey of decimetric to centimetric accuracy in post-processed differential mode varies from 2000 to 5000 US$. Post-processing differential mode also requires that a network of survey monuments with accurately known coordinates is available. However, the density of survey monuments required to achieve a decimeter accuracy anywhere in a country is much less than in the case of a local geodetic network: base stations can be located a hundred kilometers away from the surveyed area, as opposed to a few kilometers in the case of traditional survey based on angular and distance measurements.

The advent of Real Time Kinematic (RTK)-enabled receivers in the mid-2000s somewhat changed things by enabling fast acquisition and high accuracy though at a significant additional cost. In the case of RTK data acquisition, corrective data are calculated and transmitted in real-time from the GNSS base station through GSM, UHF or VHF link and decoded by real-time capable GNSS receivers through a radio modem. This technique has pros and cons which can be summarized as follows:

1) **Pro**: RTK considerably limits the time of data acquisition as well as the processing time as it allows the surveyors to instantly record accurate coordinates of surveyed land features. Survey time is minimized. Besides, radio links do not require any license or subscription.

2) **Con**: RTK technologies increases the cost of hardware for transmission and real-time processing of data. Besides, RTK radio links are limited to short distances – typically 20 kilometers – and require a direct line of sight, which may not be achievable. Due to the limitations of radio links, radio transmission can be replaced by dedicated GSM transmission using the cellular communication network. GSM makes it possible to conduct RTK with a longer baseline distance – typically hundred kilometers instead of tens of kilometers – that do not require a direct line of sight. However, GSM transmission requires that both the base and rover stations are within the GSM coverage area which is not always possible, especially in emerging markets.

The gain in time performance is offset by an increased cost of equipment, principally the cost of real-time enable survey grade GNSS receivers and UHF, VHF or GSM radio transmission devices. This cost typically varies from 10,000 to 30,000 US$

Solving the dilemma: GNSS Augmentation Systems

Satellite-Based Augmentation Services (SBAS) encompasses a wide spectrum of technologies and service providers that have been taking over the burden of investing in Continuously Operating Reference Stations, referred to as "CORS", established around the world, processing signals and transmitting a continuous stream of signal correction data to fee-paying subscribers. In order to process real-time correction messages (RTCM), SBAS providers are mixing different techniques, from improved differential correction methods to more accurate techniques referred to as Precise Point Positioning (PPP). Unlike differential correction which only relies on correction data processed for the nearest CORS, Precise Point Positioning techniques uses signals received from an entire CORS network to model satellite orbit and clock drifts which are the main sources of inaccuracies.

Through a subscription to a SBAS, GNSS users do not need to incur an additional cost to set-up second GNSS receiver to base stations. They need to invest instead in GNSS receivers that have the capability to receive a streaming of correction data through GSM or L-band satellites. Because of L-band ability to carry weak signals and the relatively small amount of data contained in real time corrections messages (RTCM), L-band has been an increasingly popular mode of transmission for real time services.

Nowadays, GNSS users have access to a wide range governmental and private SBAS providers including:

Government operated augmentation systems:

- the Wide Area Augmentation System (WAAS), operated by the United States Federal Aviation Administration (FAA)
- The European Geostationary Navigation Overlay Service (EGNOS), operated by ESSP, a consortium of European National Aviation Administration, on behalf of the European Union.
- The Multi-functional Satellite Augmentation System (MSAS) system, operated by Japan's Ministry of Land, Infrastructure and Transport Japan Civil Aviation Bureau (JCAB).
- The GPS Aided Geo Augmented Navigation (GAGAN) system being operated by the Government of India

These government operated augmentation system operates at a sub-continent level and provide a sub-metric accuracy. Data are available free-of-charge but are not public: they are subject to an approval. The European Union has mentioned its intention to make EGNOS data available for a fee in the future.

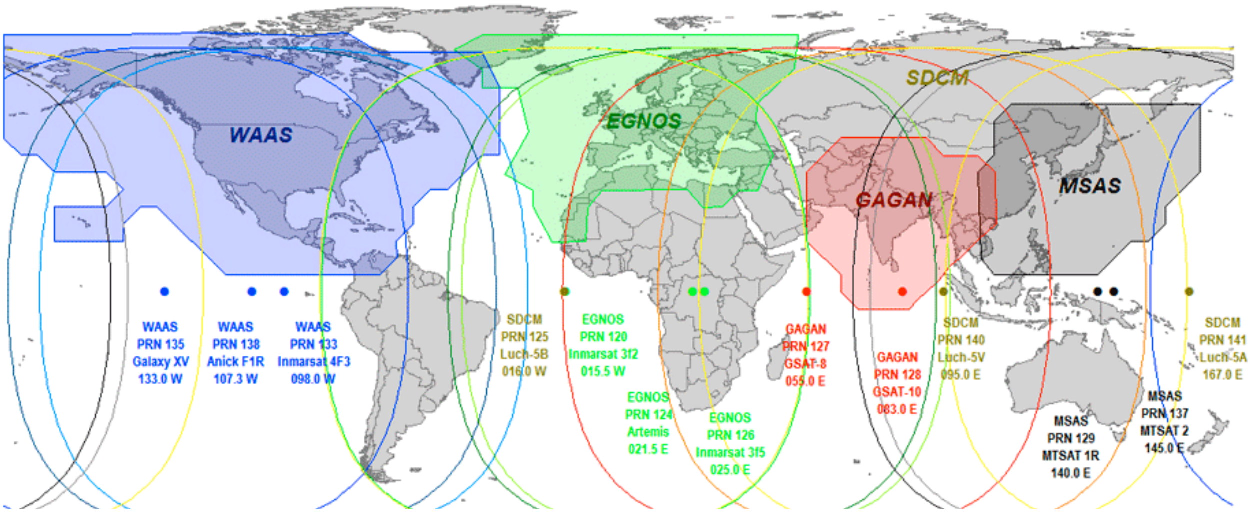


Figure 9. Worldwide SBAS Coverage - March 2013 (source: Geneq Inc.)

While operating governments confirm that their system can be potentially used beyond the geographical extent they are initially intended for, no guarantee is given as for coordinate accuracy beyond these limits

Commercial augmentation services:

- Trimble's CentrePointRTX considered as the most accurate subscription services currently available worldwide (4 cm accuracy)
- OmniSTAR developed and operated by Trimble Fugro, based on a network of 105 reference stations
- StarFire developed and operated by NavCom , based on a network of 40 reference stations
- Atlas, developed and operated by Hemisphere, based on a network of 200 reference stations
- Terrastar developed and operated by Veripos, based on a network of 80 reference stations

Subscription to an augmentation services typically vary from 50 US$ for one day to 4,000 or 5000 US$ for an annual subscription. Transmission is achieved through a continuum of technologies including radio beacons, or via a large choice of L-band satellites or any combination of both.

Although most augmentation service providers claim a positional accuracy of 5 to 10 cm anywhere in the world, this accuracy may be considerably degraded depending on the topographical conditions and L-band satellite configuration.

Case study: Colombia

Implemented in Colombia by Kadaster, IGAC, the Ministry of Agriculture and Rural Development, ESRI and Trimble, the project objective is to deploy an affordable solution to accelerate the formalization process in rural areas, stimulating agrarian production. Indeed, over 3.6 million parcels are either unregistered or partially registered with the National Cadastral authority, and therefore requires fast formalization process in rural areas. In that perspective, a fit-for-purpose technological approach was experimented. This approach combined:

- A smartphone app, based on Esri's Collector App,
- A Trimble R1, uses for sub-metric accuracy with Virtual Reference Stations (VRS) and Real Time eXtended (RTX) correction services, to achieve sub-meter accuracy in real-time, without the need for post-processing,
- An Android tablet and smartphones
- A Cloud-based database supported by the the Social Tenure Doma
- in Model platform, which provides the concept for the app.,
- A high resolution satellite images (50cm)

Figure 1 -The Trimble R1 receiver connects wirelessly to a smart device via Bluetooth connectivity.

Community involvement is a key component of the Fit-for-purpose approach, requiring participation of neighbors, family members, trusted intermediaries, etc. Therefore, the mayor is informed in advance to ensure awareness and involvement of all parties. Everyone can follow the process on-site in the field. Collected data can be sent directly to a cloud-based GIS environment, enabling everyone to follow the process remotely – this is important for the involvement of stakeholders who cannot be on site – and it is possible to set up transparent access to this cloud environment. Usual procedures, such as public inspections, are conducted at village meetings in the town hall accompanied by trusted third parties.

As mentioned by the Kadaster team "Data collection should be fast, reliable and cheap (i.e. grassroots surveyors can do the job). It is expected that this app for field data collection will speed up and improve the formalization process. The app should support acquisition of spatial data and administrative data in an integrated approach. If only handheld devices are being used (i.e. no survey equipment is needed), the work can be done in very efficiently".

According to them "The proof of concept has been much debated and well received in several forums, both inside and outside Colombia, and the results are promising". Finally even if this tech solution approach is much cheaper than the traditional high accuracy and time consuming methods, it still quite expensive considering that the Trimble RT1 cost 3000$, the Mobile App, is free of cost but can only be used in a ESRI environment, requiring at least to acquire one desktop license, the rug Android tablet being 1200 $.

An Open Data Initiative to support low cost real-time accurracy : the International GNSS Service (IGS)

The International GNSS Service (IGS) is an international voluntary initiative initiated in 1994 by the International Association of Geodesy (IAG). As of October 2015, IGS network is a network of 471 heterogeneous Continuous Operating Reference Stations (CORS) operated by over 200 different organizations pooling their resources under the IGS umbrella with an open data policy. While stringent rules are inconsistent with the voluntary nature of the IGS, participating stations must agree to adhere to the standards and conventions contained herein, which ensure a consistent quality across all IGS network and products.

Records from IGS CORS stations form the basis of a wide range of products which are made available online and without restriction through the IGS web portal: http://www.igs.org/

To ensure interoperability of data collected by different receivers, records are made available as a format called Receiver Independent Exchange (RINEX) format. These data can be openly retrieved and used by GNSS users for post-processing accurate coordinates of points located in the vicinity of the IGS reference station.

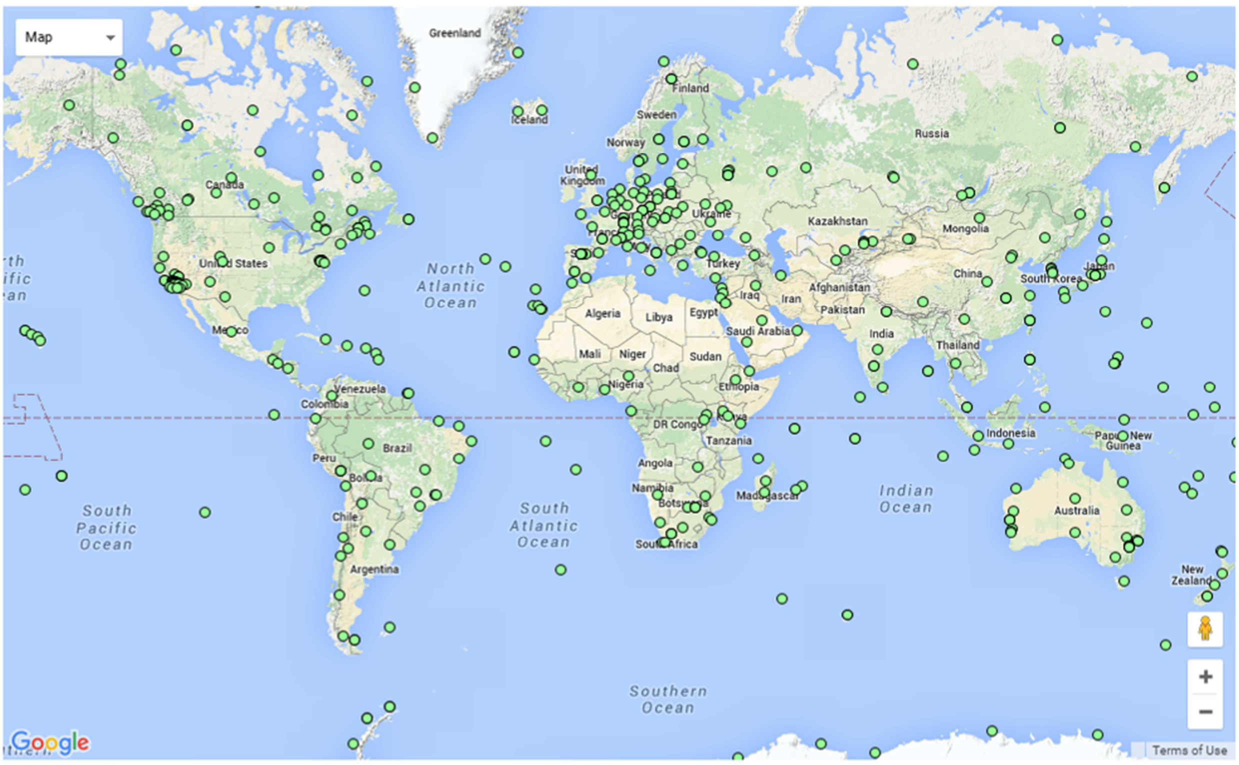


Figure 10. CORS operated under the IGS umbrella

Previous flaws with IGS data

IGS data to be considered as an excellent well-structured, free-of-charge, open source entry point for post-processing positioning data, even though for years, the system has occasionally suffers from disruption of time series services. Indeed,

- As a voluntary initiative, there is no financial provisions made at the IGS level to support operations and maintenance of CORS stations by participating organizations. As a result, disruption of GNSS services at a particular reference stations may occasionally be experienced. Some land governance projects relying on IGS data in Africa and Asia have reported that, except in the case of scheduled maintenance operations, such disruptions have occurred in unpredictable manners and for an extended period of time – few hours to few days. This used to make reliance on IGS data in certain geographical areas quite unpredictable.
- In certain geographical areas, the closest CORS station is located hundreds of kilometers away from the surveyed area which has considerable effects on the accuracy of computations. This is the case of Central Pakistan, which is a thousand kilometers away from the nearest IGS permanent station. In such case, the accuracy of post-processed coordinates may not be better than 40 to 50 centimeters.

Current trends

The advent of Precise Point Positioning (PPP) techniques has considerably reduced the impact of a CORS station disruption of records on the computation of accurate coordinates in the vicinity of the disrupted stations. This is because PPP does not only rely on the records of nearby CORS stations but on more complex satellite orbit and clock drift calculations based on data recorded by the entire CORS network.

The availability of IGS PPP open data made it possible for IGS affiliated organization to develop online data correction applications such as AusPOS, GAPS, magicPPP, APPS and NRCanPPP. These portals perform free of charge correction of RINEX observation files uploaded by users with a consistent accuracy of 10 cm, possibly better.

Interestingly, IGS also intends to deploy a free, open data, real time PPP services, which will constitute a major leap towards affordable and accurate GNSS data across the world. Called Real Time Service (RTS), this service is currently partly operational as a beta version for GPS only (not GLONASS).

Chapter 6 – Revolutions above the Earth

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to onsite observation or measurements by field survey instruments. Because remotely sensed data are rich and exhaustive, they considerably limits the needs for field data acquisition and its related costs. Aerial photography is the earliest form of remote sensing and has been applied to identify and map land use parcels since the mid-20s. Since then, remote sensing for land management has kept on evolving continuously incorporating technological innovations notably in the fields of digital imagery, photogrammetry, space industries and more recently drone technologies.

Remote sensing is nowadays a mainstream technology applied to rural land governance. Remotely sensed data is being extensively used to identify land use parcel boundaries and detect changes that occur over time in land patterns in cost effective ways. Remote sensing makes use of digital sensors embarked on various types of carrier, namely aircrafts, satellites or more recently, drones. Selecting the most suitable type of carrier depends on the ground resolution and accuracy foreseen, the extent of the area to be surveyed and other considerations that are summarized below.

Table 2. Comparison table between remote sensing technologies

	Satellite	Aircraft	Drone
Ground resolution	0.4m to 10m depending on satellite services used	0.2m to 1m depending on flight altitude	0.05m to 0.2m depending on flight altitude
Typical area to be covered	> 25 km2	> 1,000 km2	< 25 km2
Cost	Cost per km2 is quasi constant in the range of 20 US$ per km2 for archived high resolution product to over 50 US$ per km2 for newly tasked acquisition	Cost per km2 drastically decreases as area increases, typically: 100 US$ per km2 for 1,000 km2 down to 10 US$ for 10,000 km2 Minimum costs of aerial acquisition commonly exceeds 100,000 US$ due to mobilization and demobilization.	Cost per km2 is in the range of 1,500 to 2,000 US$ per km2. Alternative to aerial photography for small areas
Weather sensitiveness	Sensitive to clouds. An additional 10 US$ per km2 is usually required to guarantee a cloud free acquisition	Sensitive to clouds. Poor weather condition can dramatically increases cost per km2	Un-sensitive to clouds as drones commonly fly below cloud level
Ease of obtaining flight clearance	Does not require clearance	Require high level clearance	Requires medium level clearance

Although remote sensing does not provide certainty over the boundaries of land rights' parcels, this technology provides a *de facto* and anecdotal evidence of land utilization by rural communities, and provides a graphical support for participatory mapping of land claims.

A resilient technology: Aerial imaging

Many times announced as an obsolete and its end predicted, aerial photography was never phased away from land governance projects, in spite of the rapid growth of high resolution space imaging. This is because aerial imaging still offers unrivalled cost-benefits ratios for country-wide land mapping projects.

Aerial photography consists in acquiring pictures from a camera embarked on an aircraft. Historically, aerial photography used to rely on plastic films coated with a gelatin emulsion made of microscopic silver halides sensitive to light, hence the technology referred to as analog argentic photography. However, with the advent and fast development of digital cameras since the early 2000s, argentic photography has nowadays been completed phased out of land management projects.

With digital imagery, ground information is captured directly in digital format and ready to be processed with appropriate photogrammetric software applications. The market of digital aerial camera system is broadly divided into large format camera systems – with resolution exceeding 200 megapixels - and medium format camera systems with typical resolution of 60 to 80 megapixels. Large format camera systems are currently dominated by Microsoft's Ultracam systems (formerly known as Vexcel) and Leica's ADS camera systems featuring a 375 megapixel resolution. Four medium-format systems are nowadays competing namely:

- Trimble's DSS camera (formerly known as Applanix)
- IGI's DigiCAM
- PhaseOne's IXA camera
- Visionmap's A3 Edge camera

As a general rule, the cost-effectiveness of aerial photography increases as the project sizes increases, or said otherwise, the cost of aerial photography per square kilometers decreases as the surveyed area increasing. This results from the economic model of aerial photography which integrates a wide range of factors, principally:

- The mobilization and demobilization of the survey aircraft. Mobilization consists in moving the survey aircraft from its regular airfield to an airfield close to the surveyed area. Costs pertaining to mobilization and demobilization may vary from 5,000 US$ to over 50,000 US$ per project depending on the distance between the aircraft regular airfield and the survey area's operating airfield.

- Immobilization costs are airfield fees (also referred to as tiedown or hangar price) incurred by an aircraft operator to maintain its aircraft on the ground and benefit from an airfield facility for a period of time. They include other costs such as aircrew idle time and living costs. Immobilization costs are generally incurred on a daily basis. There are several factors impacting immobilizing costs, the most unpredictable being weather conditions, such as clouds over the surveyed area that would compromise data acquisition. The presence of clouds can be a severe constraints in certain tropical regions where dense clouds form all year-round.

- Flying time impacts the overall cost of aerial photography. Flight costs includes aircrew costs, fuel costs and other flight supplies. Flying time varies with the size of the surveyed area, but also and most importantly with the combined effect of the flight altitude and camera angle or swath. Flight altitude and camera swath will both be factored into the flight path with the number of turns (hence distance and hours flown) required to guarantee sufficient overlapping area for aerial triangulation.

- Finally the type of aircraft, sensors and other inflight equipment has a significant effect of the final bill, mostly as a result of amortization, insurance and inspection requirements.

The above listed factors highlight the difficulties to establish a formula that can accurately predict the cost of aerial photography. This cost may vary for a factor 1 to 10, depending on the peculiar conditions found on site. It may range from 10 US$ per km2 for a 30 cm resolution if ideal conditions are met, to an outstanding 100 US$ per km2 or higher in the worst case scenario.

Also, it is critical to mention that due to high mobilization, immobilization and demobilization costs, aerial photography does not make sense for areas less than 1,000 square kilometers.

It is also worth mentioning that there is currently no restrictions concerning the redistribution of aerial imagery acquired in the framework of a land governance project. However, relatively few projects make the necessary provisions to allow for a full and open utilization of the imagery by third parties.

Towards in-flight production of orthophotos through Direct Georeferencing

Among the various aerial camera systems currently in use, the Trimble DSS system has been prefiguring the new paradigm in aerial photography, through an innovative system equipped with a rapid in-flight orthophoto production line, referred to as In-FlightOrtho. This is made possible by combining GNSS positioning technology, inertial navigation system, digital imagery and aerial photogrammetry techniques to process and deliver aerial orthophotographs real time, thus reducing processing time and costs.

The technological leap comes from the combined use of Inertial Measurement Units (IMU) - that measure and record in real-time the flight attitudinal parameters, namely the pitch, yaw and roll, - and real-time GNSS positioning techniques to accurately model the Exterior Orientation (EO) which can then be used to directly georeference digital images, without any need to survey Ground Control Points (GCP).

Emerged in 2005, Direct Georeferencing methods have still not replaced aerial triangulation due to the significantly high cost of accurate real-time GNSS/IMU systems able to compete with the high accuracy of GCPs. However, the current trend is to make use of hybrid methods, referred to as Integrated Sensor Orientation (ISO). ISO techniques combine both Direct Georeferencing – for Exterior Orientation - and Aerial Triangulation for calibration. ISO techniques do not require as many GCP as a conventional aerial triangulation which is a considerable gain in time and costs.

A highly versatile multipurpose technology: Space Imaging

Satellite imagery has emerged in the 1970s, but did not become a cost effective alternative to aerial photography until the late 2000s with the advent of civilian sub-metric sensors. While high resolution satellite imagery was dominated in the 1980s and 1990s by two satellite – LANDSAT and SPOT – there is nowadays more than a dozen space-borne sensors available to the public on a commercial basis.

Space imaging technology has broad similarities with aerial imagery. Main difference lies into the business model. The great advantage of space imagery is that it does not require the mobilization of any aircraft over the surveyed area and associated contingencies. Space-borne sensors are embarked onto satellites with sun-synchronous orbits. Particularities of such satellites is that they complete 14 rotations around the earth per day - each time with a shift of about 25 degrees in the satellite trace – which means that a sensor embarked on a sun-synchronous satellite may capture data over any point of the earth surface at least once a day, although not always in optimal conditions.

Satellite imagery can be broadly divided into 4 categories:

- Low resolution imagery with a pixel size representing 100 meters or more on the ground
- Medium resolution with a pixel size representing between 10 to 100 meters on the ground
- High resolution with a pixel size representing between 1 to 10 meters on the ground
- Very high resolution with a pixel size representing 1 meter or less on the ground

The table below shows the different types of sensors currently available as well as their specifications, access conditions and suitability for land management projects.

Table 3. Review of space imaging suitability to land governance

Category	Sensor	Resolution*	Accessibility	Suitability for land governance
Low resolution imagery (100m -1000m resolution)	NOAA METEOR SUOMI MODIS NERIS PROBA-V	1 km 1 km 1km 500 m 300 m 100 m	Open source	Not suitable for land governance projects
Medium resolution imagery (10m-100m resolution)	ENVISAT SENTINEL ASTER LANDSAT	12.5 m 10 m – 60 m 15 m 30 m	Open source	May be suitable for detecting medium to large scale changes in land use and mapping some general collective rights *(e.g. passage rights, grazing rights, water rights)* which do not require an excessively high accuracy
High resolution imagery (1m-10m resolution)	SPOT RAPIDEYE FORMOSAT CARTOSAT ALOS	1.5 m 5 m 2 m 2.5 m 2.5 m	Fee-based	Suitable for mapping such communal land use rights and individual land use rights as passage rights, grazing rights, water rights, and farming rights but not suitable for mapping individual ownership rights
Very high resolution imagery (less than 1m resolution)	GEOEYE WORLDVIEW PLEIADES IKONOS KOMPSAT QUICKBIRD SKYSAT	0.4 m 0.4 m 0.5 m 0.8 m 0.6 m 0.6 m 0.9 m	Fee-based	Suitable for mapping individual ownership rights

* Pixel resolution on the ground

In order to adapt their offer to the wide spectrum of user needs, space imagery providers have developed a variety of data quality and services and elaborated distribution policies. To summarize:

Archived vs. newly tasked data

Space imagery providers build up large repositories of readily available data by continuously acquiring images, even in the absence of orders. These repositories form the base of archived data that are available to the public for a nominal fee per square kilometer. A minimum amount of square kilometers must be purchased, for example 25 km2.

However, under certain circumstances, archived data do not meet requirements of a particular user. For instance, archived data are deemed to be too old to reflect the current situation on the ground, or some images are plagued with excessive cloud cover preventing effective image interpretation. In such cases, a special acquisition may be tasked and the additional tasking cost – typically 10 US$ per square kilometer - is charged to the user. The minimum amount of square kilometers to be purchased increases as well, for instance 100 km2 instead of 25 km2.

Standard vs. Priority and cloud-free services

In case of new tasking, tasking costs increase in case acquisition is requested on a rush basis (“priority service”) and in case a maximum cloud coverage requirement must be met, for instance 5%, 10% or 20% maximum cloud cover. The latter is justified by the fact that weather conditions on a next available acquisition slot may not match the cloud cover requirements and repeated tasking efforts may be needed to achieve the required no cloud specifications.

Panchromatic vs. multispectral pan-sharpened images

Earth observation satellite includes different sensors that are sensitive to different bands of the electromagnetic spectrum.

The 5 most commonly found sensors include:

- The red band (i.e. the band that is sensitive to light whose wavelengths coincide with the visible red portion of the electromagnetic spectrum)
- The green band,
- The blue band,
- The near infrared band
- The panchromatic band, which is a large band covering the red, green and blue portion of the electromagnetic spectrum indiscriminately.

EO satellites that are relevant to land management projects includes the 5 above listed spectral bands. Some of these EO satellites – e.g. WorldView 2 and WorldView 3 - feature additional sensors and offer up to 8-band-imagery for an additional fee.

In practice, panchromatic imagery constitutes the most basic product offered by service provider, with the highest resolution and grey, while panchromatic sensors offers richer colored imagery but at the expenses of a lower resolution. To mitigate this drawback, most space imagery providers offer a hybrid product called multispectral pan-sharpened products. To produce multispectral pan-sharpened imagery, multispectral imagery of coarse resolution are re-sampled using the finer resolution of panchromatic image. The result is a composite image made available to the users for an additional fee.

Raw vs. processed products

Similar to aerial imagery, space imagery is flawed with geometric distortions that need to undergo a photogrammetric rectification process. Space imagery providers offer different levels of rectification services, also referred to as product levels or accuracy levels, at an additional fee. These accuracy levels can be broadly divided as follows:

- Unprocessed stereo-pair imagery, which has undergone radiometric correction of distortions due to miscalibration of sensor array components. Unprocessed stereo-pairs are the most basic product offered by space imagery providers and intended for users who wish to perform their own geometric corrections.

- Basically processed imagery, which has undergone basic geometric correction of systematic effects such as panoramic effect, earth curvature and rotation. Accuracy is coarse. Basic imagery is designed for qualitative photo-interpretation and thematic studies only.

- Georeferenced imagery, which incorporates a model of sensor's Exterior Orientation and a coordinate reference system to transform a basic imagery into a geo-referenced imagery with geographic or grid coordinates. Because this transformation is performed without GCPs, georeferenced imagery has a moderate positional accuracy, typically 5 meters.

- Orthorectified imagery, which factors GCPs and a digital elevation model into the rectification process. The result is an orthorectified image with a high positional sub-metric accuracy similar to aerial orthophotographs.

Ownership vs. End User License Agreement (EULA)

Unlike aerial imagery whereby the payer retains full ownership over the data produced, space imagery users do not retain ownership rights over space images, only a right to use. Space imagery providers have been severely restricting the redistribution of space imagery through stringent end-user licensing provisions. Under such provisions:

- Licensed data cannot be sublicensed, sold, transferred or disclosed to any third party
- Products derived from and containing portions of the licensed data, even at a reduced resolution, cannot be sublicensed, sold, transferred or disclosed to any third party
- Web posting is allowed but restricted to non-commercial purpose, in a non-downloadable, and non-distributable format.
- Licensing fees increase with the number of independent users who are recipients of the data.

The revolution of Maps APIs

There has been a growing awareness among providers of satellite imagery about the limitations of their distribution model based on the extraction of data over the user's area of interest and delivery to the user through DVDs or FTP. Digital Globe, the largest provider of commercial satellite imagery – including QuickBird, Ikonos, GeoEye and Worldview imagery – admits that this delivery model is costly for the provider itself, as it involves manual extraction and processing of data, but is even more costly for the users themselves, who have to invest in GIS software and IT infrastructure in addition of bearing the provider's extraction and processing costs. Also, this this delivery model implied that a user had to wait days or weeks before a user could see the data from the time a satellite collected it.

The widely acclaimed Google Maps delivering satellite images onto web and smartphone applications
Instantly and almost for free has heralded a new delivery model that satellite imagery providers nowadays rushing into. This model is making use of Maps Application Programming Interface (Maps API) for dynamically embedding imagery archived on the provider's cloud repository into the user's application, i.e. manual intervention. Through Maps APIs, users do not need to download massive size of data: data are segmented into tiles (such as mbtiles) that are dynamically loaded or discharged from the application depending on the context.

Maps API is having a massive impact on the satellite image users' experience. Images can be delivered within minutes after they have been collected, as opposed to weeks before. Images are delivered directly into the users' application in the correct format and geographic system and therefore ready to be used. Digital Globe is also reporting that data are made available at a much more competitive price than before and users are nowadays proposed tailored pricing plans according to their coverage and updating needs. By way of illustration, Digital Globe reported that the provision of API-featured images updated on quarterly basis could be available for as low as 20,000 US$ a year while it would have cost the user over 50,000 US$ with the conventional delivery model, not including software and IT infrastructure costs.

To facilitate the development of new applications built upon their imagery, Digital Globe has also put in place programming libraries and a platform for independent developers. This platform, called GBDX, aims at providing such developers a development environment for building, accessing and running advanced algorithms designed for information extraction from imagery datasets at scale. Examples of already developed applications accessible through APIs include algorithms dedicated to orthorectifying, land cover mapping, car counting and atmospheric compensation.

Valorizing historical archives: Landsat, Spot, Digital Globe

The release of historical images acquired over the past few decades by Earth Observation Satellites is an interesting trend that deserves some attention.

The United States Geological Survey (USGS) showed the way in the early 2010s by releasing its Long Term Archives (LTA) consisting of worldwide declassified high resolution military imagery acquired by CORONA, ARGON, LANYARD, and KEYHOLE satellites from 1960 to 1984, as well as medium-resolution LANDSAT imagery. Data are accessible free-of-charge via the USGS EarthExplorer (EE) and Global Visualization (GloVis) portals.

Following the example of USGS Long Term Archives, the French *Centre National d'Etudes Spatiales* (CNES) kick-started in 2014 the Spot World Heritage (SWH) programme whose objective is the free availability for non-commercial use of orthorectified products derived from multispectral images of more than 5 years old from the Spot 1-5 satellites family. Nearly 30 million images have been acquired by this satellite family since 1986, this archive may be considered as a world heritage. While a first batch of 200,000 images is currently under processing, CNES has solicited the international donor community in order to contribute to other large image batches while covering the processing costs. The access to the SWH database is being made freely from the Theia portal (www.theia-land.fr) and will be allowed for any user registered for a non-commercial usage. The first products have been available in September 2014 and will continue to be released on a regular basis.

Unlike LTA and SHW initiatives that have been releasing their historical archives for free, DigitalGlobe has opted for a different model. Its *BaseMap +Vivid* product is a seamless, cloudless, haze-free mosaic of 50cm archived imagery images not older than 5 years, made available at a massively reduced price rather than for free. Basemap +Vivid is currently available over the entire African Continent, Middle East, Central Asia and is rapidly expanding and can be accessed trhough Digital Globe Maps

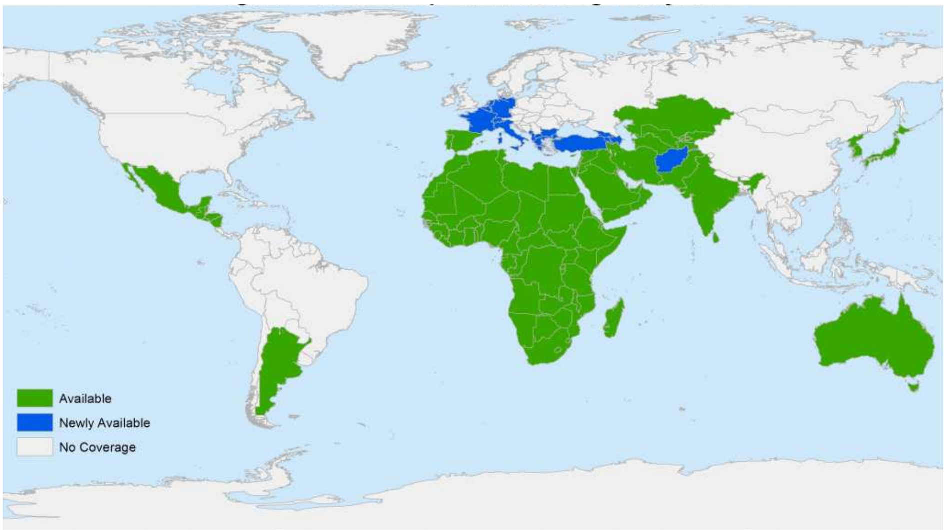


Figure 11. Availability of Digital Globe Basemap +Vivid 50cm resolution mosaic as of July 2015

Although Spot World Heritage and Basemap +Vivid builds upon archived and partly outdated images, they are certainly attractive low-end products for supporting land governance projects in remote areas that have not undergone massive land cover changes over the past decade. In fact, the rationale for releasing historical imagery for free or for a reduced fee is twofold. First, historical data have a considerably reduced value as opposed to recently acquired images; consequently, their release at a massively discounted price does not constitute a profit shortfall for the satellite image provider. Second, SHW and BaseMap +Vivid are expected to widen the community of SPOT and Digital Globe image users that will reflect on future sales on the upcoming SPOT 6 and 7 as well as Worldview 3.

Free-of-charge access to high resolution imagery for environmental and disaster management

Considering the costs of satellite imagery perceived as a barrier to development, a number of initiatives to relax the conditions to access or re-use imagery have emerged. Major initiatives include:

- The European Space Agency (ESA) Open Science 2.0 initiative consolidates ongoing ESA efforts to foster a broader utilization and applications of satellite imagery. ESA has entered into a partnership with major providers of medium and high resolution imagery to authorize a free-of-charge access to data via the ESA web portal (https://earth.esa.int) for eligible research and development projects. The initiative does not include operational projects such as land management projects.

- Occasionally, space image providers agree to release satellite data free-of-charge as a response to such natural disasters as earthquake, tsunamis or hurricane. The International Charter established in 2000 epitomizes international efforts to provide a unified system of space data acquisition and free-of-charge delivery to those affected by natural or man-made disasters through Authorized Users. To date, 21 member agencies – public and private space imagery providers - have committed resources to support the provisions of the Charter and help to mitigate the effects of disasters on human life and property. By way of illustration, the International Charter has been "activated" not less than 30 times since the beginning of 2015, to support rapid response for such events as:

- Floods: Bangladesh, Argentina, Chile, Myanmar, Vietnam, Brazil, Australia, Madagascar, Malawi, India, Turkey
- Earthquakes: Chile, China, Nepal, India
- Landslides: Guatemala, Colombia, India
- Volcanos: Chile, Grenada, Costa Rica
- Fires: Russia, Chile
- Typhoons: Mariana Islands, Vanuatu, Australia, Malawi, Philippines
- Oil spills: Vietnam

However, it must be emphasized that there has not been any similar examples of dialogues and coordinated efforts in the fields of land administration and land governance projects.

An example of open medium resolution imagery: SENTINEL

SENTINEL is the Earth Observation mission of the European Space Agency (ESA) as part of the Copernicus programme in support of environmental monitoring. Sentinel sensors provides optical imagers of the earth with a resolution that varies from 10 to 60 meters. 10 meter resolution data are currently achieved by the Sentinel-2 sensor. Sentinel data are available free of any restriction after proper registration on Sentinel Scientific Data Hub (SSDH). This hub makes it possible to query the large Sentinel data repository through user-friendly geographical tools. As data commonly exceed a couple of Gigabytes, access to the data require a robust and broadband internet connection. Sentinel imagery is refreshed every 10 days.

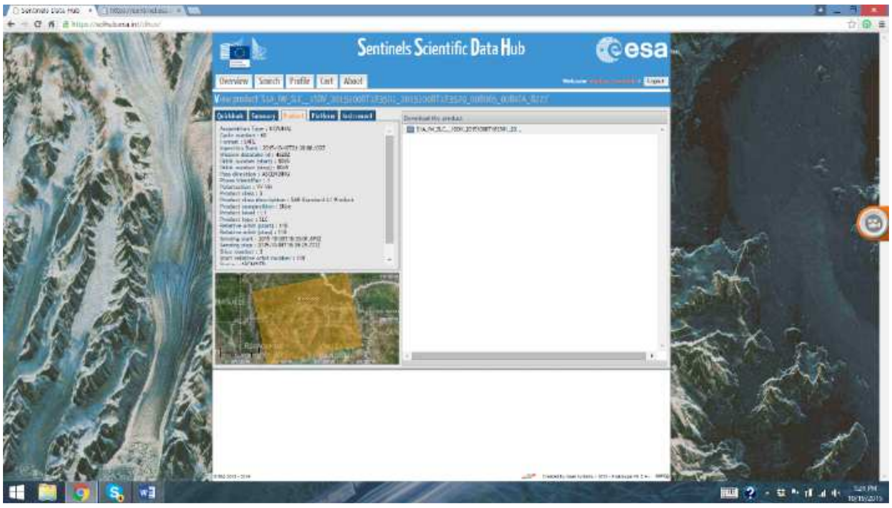


Figure 11. Extract of Sentinel product metadata


Figure 12. Example of Open Source Sentinel 2 image with a 10 m resolution

While SENTINEL resolution does certainly not match the needs of land governance projects that requires the delineation of land tenure parcels with certain accuracy, SENTINEL may instead constitute a powerful and cost-effective tool to track and monitor illegal land clearing activities adversely affecting the rights of indigenous communities.

Pilotless drone for supporting small-footprint land projects

Unmanned Aerial systems (UAS), also referred to as survey drones, are the latest technology in the field of remotely sensed data applied to land governance project. Initially confined to military uses, drone-based aerial photograph for civilian survey has been under experimentation since the mid-2000s. However, until recently, the cost of drones, the performance of batteries, the weight of sensors and the lack of dedicated processing software did not make the use of drones an economically viable technology for land surveying. With the advent of lightweight lithium polymer batteries, low-cost drone technology, lightweight digital cameras and advances in close-range oblique aerial photography in the past 5 to 7 years, experiments of drone-based cadastral surveys have intensified. Experiences in China, Namibia, Ghana and Albania (Walter Volkmann and Grenwille Barnes) are reporting significant advantages of UAS-based surveying:

- Drones are reportedly well suited for surveying and mapping property parcels over areas which are not larger than a few square kilometers. Deploying a drone on a specific area is quicker than conventional aerial surveys or programming of satellite imagery.

- Current state of the technology includes embarked GPS receiver and mission planning software that enable the semi-automatic capture of data.

- Drones foster a level of participation from local communities that is way higher than in the case of conventional aerial photogrammetry and satellite imagery. This is because of the ability of the very high resolution drone imagery to accurately depict the ground reality with a pixel resolution of 2 to 5 cm.

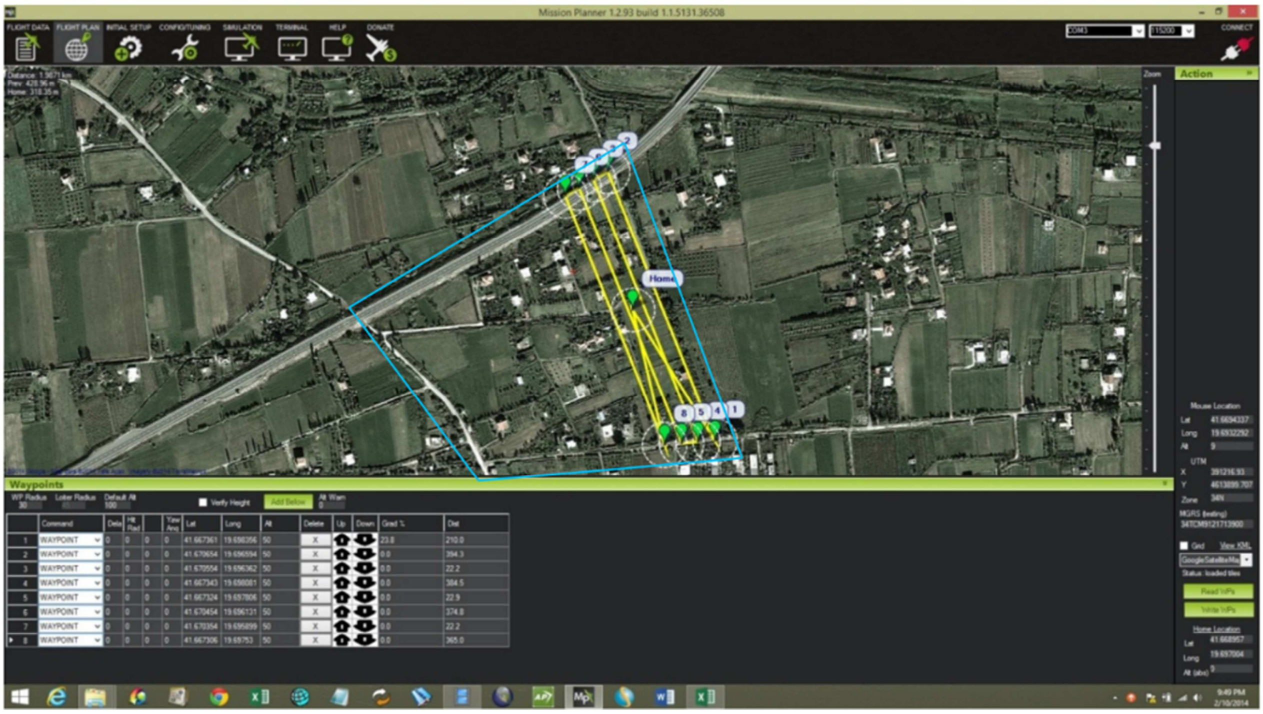


Figure 13. Drone flight planning

However, among the cons, the following constraints can be emphasized:

- Lithium polymer batteries powering drones still offer limited capabilities as drones cannot currently fly for extended period of more than 20 minutes.

- Although the cost of drones has significantly decreased over the past 5 years, it may still be viewed as a significant investment. The price of commercial off-the-shelf drones currently ranges from 30,000 US$ to 75,000 US$, in addition to the cost related to pilot training.

- Drones come in different size and shapes that all have their strengths and weaknesses. While fixed-wing drones can quickly acquire data over an entire village though with a decreased accuracy, rotary wings can survey selected homestead with a rather high resolution and accuracy. There is not at this time a multi-purpose drone that can fulfill all types of missions, and several drones may be needed to cover the full spectrum of land administration projects.

- Administration procedures for importing a survey drone can be cumbersome and challenging in certain countries, due to its being largely associated to military purposes.

Case studies

Indonesia. Indonesian geographer Irendra Radjawali used a UAV to help the indigenous Dayak people of Borneo document the boundaries of their land and track deforestation and other illegal usage. In 2014, Radjawali mapped 30 hectares of land in West Kalimantan with a tricopter equipped with a Canon SX260 camera with an internal GPS. The Dayaks said their land had been damaged by a bauxite mining operation. As Radjawali's goal was simply to document the damage, he did not use surveyed ground control points—specific, accurately surveyed points on the terrain—to create the map, but instead relied on the GPS inside the camera, as well as his hand-held Magellan eXplorist 310 GPS. The resulting map, processed in VisualSFM, was accurate enough to show the general location of the mining damage.

Namibia. Researchers from the University of Twente in the Netherlands wanted to use a UAV to map customary land-use parcels in Namibia. As the goal of the mission was to produce an inexpensive and accurate property map that could be used for the adjudication of land borders, geographical precision was a very important consideration. To that end, the researchers designated and surveyed a total of 23 ground control points throughout the area to be mapped. The numerous ground control points were used to ensure that some would remain if the markers were blown away by the wind or removed by local people. The mission was a success, producing a map that could be used for enforcing customary land rights boundaries.

Peru. The Land Alliance, a nonprofit dedicated to the study of land issues, has recently begun experimenting with UAVs for cadastral mapping in Peru, where many thousands of people lack land title. It emphasizes an approach in which government policy is linked to geospatial data and community participation, using the UAV's ability to quickly gather aerial information to permit a more realtime mapping process. Landowners are actively involved in planning, marking the boundaries of land parcels so that they are visible from the air, and reviewing and verifying the resulting information. Per the Land Alliance, regional government representatives are also intimately involved in the process, helping to resolve disputes and mediate the process.

Albania. Micro Aerial Projects recently completed a World Bank-funded mapping project in Albania, one of the least developed countries in Europe. After the People's Socialist Republic of Albania was officially dissolved in 1992, the country embarked on a large-scale property privatization effort. Many observers considered this effort to be corrupt and largely for the benefit of people with political connections—the privatization efforts were carried out with inadequate access to information and with a lack of transparency. Albania introduced a computerized land administration system in 2012, based on international standards, but only 20 percent of the nation's properties are currently covered in the database, while almost 80 percent are covered only by paper maps that are of insufficient quality to be used in the database. The project was intended as a pilot test of a UAV-based method of cadastral mapping that could be used both to support land registration efforts and to improve geospatial data that already existed. While there are existing high-resolution orthophotos of Albania, covering the entire country, the imagery dates from 2007. Besides, lower-resolution imagery from Google Earth, which dates to 2012, was deemed inadequate for identifying and defining property boundaries. The UAV was able to fill this coverage gap, generating high-resolution, up-to-date imagery that could be used immediately. UAV mapping system was tested in three locations: an agricultural area called Fushe Milot, a dense urban area known as Komuna Farke, and a strip of the Elbasan national highway, all in the general vicinity of Tirana, Albania's capital. The Elbasan highway site and the Fushe Milot site were chosen as examples of how UAV imagery can provide useful information for infrastructure development and management. Plans for a new highway and a new water pipeline would route them through areas where land ownership is unclear—an information deficit the dronemapping project was meant to help close. The team used a custom-built UAV equipped with a Samsung NX1000 camera and 16mm lens, with the intent of keeping costs low and thus accessible to residents of a developing country. They flew their mapping UAV 75 meters above the ground at the Fushe Milot and Elbasan highway sites, and at 50 meters at the urban test site at Komuna Farke. The flights were designed so there would be 80 percent forward overlap and 70 percent side overlap of images, which resulted in large data sets and long processing times. The mapping process itself did not take the team very long. A total of three hours to carry out field surveying for the Fushe Milot site were needed, which way below the three to four weeks such a survey would have taken in the past. To cover 23 hectares at the Fushe Milot site with a ground sampling distance (GSD) of 1.8 cm, the UAV required four flights of about 10 minutes in length. However, processing the data took many hours, and it proved to be the limiting factor. A week after the aerial survey, the team was able to show an orthophoto to local landowners, who were asked to define the boundaries of their property. In approximately 3 hours the boundaries of 29 property parcels on the orthophoto were defined.

Nanosatellites, myth or reality?

As commercial grade satellite imagery has been popularized by such online browsers as Google Earth, demands for affordable earth observation data in real-time or near real-time has grown. The rapid development of microsatellites -less than 100 kg- and nanosatellites -less than 10 kg- makes it possible nowadays to envision the fast and cheap deployment into space of hundreds of Earth Observation devices in the next 2 to 5 years.

Three such initiatives are currently under development, namely SkyBox, Planet Labs and Satellogic. The purpose of such initiatives are to make regularly updated satellite images with a metric resolution available online. Current plans are to update images every week (Planet Labs) to every hour (Satellogic). Satellogic summarizes its vision as providing “satellite imaging and data at a fraction of current cost and thousands of times higher in frequency, turning Big Data from Space into a fundamental part of daily decision making for all branches of government, organizations, industries and individuals.”

It is expected that such initiatives will greatly benefit land governance projects through a wide range of potential applications:

- Detecting and monitoring of land extractive activities – such as forest logging or mining – in the vicinity of rural communities (see picture below)
- Detecting of changes in land tenure patterns
- Facilitating the valuation of rural land through the detection of seasonal crops or livestock
- Detecting anecdotal evidence of collective or individual land rights to support claims

Picture 4. Weekly monitoring of logging roads and oil palm plantations’ expansion in Pulau Pini (Indonesia) acquired by Planet Labs’ CubeSat on an experimental basis (source: Planet Labs)

Chapter 7 – Towards trustless land transactions

Protecting land records against fraud has been a constant challenged faced by land administration professionals. Governments have arguably addressed this issue by adding many layers of control with dozens of signatures required to authenticate a right, creating venues for rent-seeking behaviors and defeating the superior objective of such controls which was to build trust around the registry.

Trust is indeed central to land records' security but computer-based technologies introduced in the past three decades have raised more concerns than they addressed the issue, especially in rural areas. Obvious reservations have first to do with the capacity to operate and maintain sensitive computer servers in remote rural areas that are plagued with such basic issues as power disruption, wild voltage fluctuations, slow connectivity as well as dust, heat, and humidity. But they also have to do with the poor technical capacity of local governments, their reluctance to simplify and modernize registration workflows, their failure to deliver land tenure security in an affordable and time-effective way, all of this contributing to fuel defiance of communities towards their local governments.

Interestingly, emerging technologies have been attempting to address the issue of trust by … removing it from transactions. This chapter reviews some of these of these technologies.

Securing registries with block-chain technology

Among the various emerging technologies used to secure tenure, blockchain technology is certainly the less immediately accessible to land professionals' understanding. Blockchain technology has been the foundation of crypto-currency such as bitcoin and aims at addressing the issue of trust in transactions. The basic goal of blockchain technology is to get rid of any form of trusted central authorities in securing transactions. In the context of land transactions, the purpose of blockchain technology is to provide an immutable way to record titles to a land, that is to say, a way that makes it impossible for any third parties – land authorities and hackers alike – to alter any record without the consent of the legitimate right holder.

To achieve this level of security, blockchain technology relies on a network of anonymous computer nodes participating to the blockchain security according to the following principles:

- The registry or ledger of transactions is not kept in the hand of any single party. The ledger is public and duplicated at the level of the many participating computer nodes inside and outside the country. The more nodes, the more secure the system.
- When a legitimate transaction occurs, the transaction is simultaneously broadcast to all participating nodes. A digital signature ensures that transactions are consistently broadcast without alteration or modification of their content.
- Each participating node verifies the validity of the newly broadcast transaction by linking it back to the original asset owner through an undisrupted chain of transaction (or asset transfer).
- The main security hole in such a decentralized system resides in the order transactions are broadcast. Because multiple copies of the transaction are sent to multiple nodes through different routings, transactions will not reach all the nodes at the same time. This time propagation issue, known as latency, can be exploited by ill-intentioned parties to feed the nodes with illegitimate transactions thus creating for their own benefit discrepancies in the decentralized ledger. Blockchain technology is precisely designed to address this security hole by collectively agreeing about the chain of transactions that is deemed legitimate.
- All recent transactions received by each node are grouped into a "block" that will be added to previous blocks to

form a "block chain". Because all new transactions are not received in the same order, each node will generate its own blocks and propose its blocks as a suggestion for a new block to other nodes.

- To generate a new block, each node will need to spend some amount of computer processing time to solve a mathematical puzzle - called a cryptographic hash - that can only be solved using random guesses and several weeks or months of guessing. However, due to the high number of participating nodes, it would only take a few minutes before one participating node luckily solves the math puzzle and proposes its own next-in-line block to the other nodes. This makes it extremely unlikely that an isolated fraudulent party actually solves the math puzzle before the other nodes working collectively.

Beyond crypto-currencies such as bitcoin that have contributed to make blockchains popular, the blockchain technology can be used – and has been used - with different settings. Instead of financial transaction, blockchain technology can be used to hash and store any kind of entries such as land and property registries, loans connected to them, mineral rights, medical records, insurance records, and others.

The real innovation of blockchain technology lies in the fact that it removes the need for any third party or central authority to guarantee the security of records. Security and immutability of records are guaranteed by a globally distributed network of nodes working collectively but anonymously, as long as there are enough participating nodes. With respect to land governance, this does not mean that blockchain technology intends to completely phase out Land authorities from the registration of land rights. The initiative conducted by Factom and Epigraph in Honduras still largely builds upon the Land Authority as the conveyancer of rights but simply not as the record keeper. The mission of keeping land records is being outsourced to a blockchain-like platform in order to prevent the counterfeiting, forgery and corruption surrounding land titles.

Factom and Epigraph emphasizes that land tenure security has been ranking high in the political agenda of Honduras politics, with a high level of distrust among the various political parties, each party blaming the other parties for trying to manipulate land records to satisfy their own constituency. At the end of the day, building up a record keeping system that is independent from partisan considerations is making sense in Honduras and explain the willingness of some political parties to support the blockchain initiative.

Epigraph do admit that there is still a lot to be done before the blockchain technology can be showcased as a successful and widely accepted method of securing land records. Besides, they have been rightfully emphasizing that blockchain technology only addresses some of the security issues commonly encountered with land tenure rights registration, the most important being to prevent the creation of false entries in the land records.

However, blockchain technology is not currently addressing other key aspects of land tenure security in rural areas, which will require to be associated with other technologies:

- Identity theft by deceptive impersonators. Bitcoin mitigates the risk of identity theft through the assignment of a randomly generated private digital key - known to its owner only and used for encrypting transactions - and paired to a public digital key used for decrypting transactions. This technique is particularly convenient in the case of transactions initiated from one's computer or mobile device, but does not appear to be suitable in the case of rural land transactions, where the practicality for rural poor to keep a private digital key secret could be questioned. The emergence of mobile biometrics could potentially address the issue of keeping private key safe, or generating it whenever needed, directly from the automatic recognition of very personal physiological or behavioral traits from sensors equipping most of today's smartphones. A particular section on mobile biometrics is provided in the next sections.

Is there an ideology prevailing behind the promotion of the blockchain technology?

The general state of corruption of land administration, its inefficiency, slow, unsafe and cumbersome processes are some of the "evidences" that are underlying behind the need for cryptographic technology. It suggests that to get a secure, efficient and transparent land registration process, land administrations should be removed from the landscape, the wisdom of crowd coupled with a peer to peer approach proving the best treatment to those troubles . The blockchain technology, is thus replacing the trusted third parties (ie. the land administration).
However, going one step further, as suggested by *Peter Laarakker, Jaap Zevenbergen, and Yola Georgiadou*, in there articles *"Land Administration Crowds, Clouds, and the State – Sept 2015"*, the blockchain technology might encourage marginalization of the traditional Land administration apparatus, denying a systemic and inclusive approach , including all components and segments of the system to come to an optimum compromise.

Blockchain technology meet cosmopolitan supporters, as mentioned by the Economist in the "The great chain of being sure about things" article (October 30th 2015), ranging from the "left-winger", which sees the way it could undermine the giant repositories of data like Facebook, Libertarian who wants to get rid of state regulations, and certain Financial institutions which consider it, like the Bank of England, as "significant innovation" with "far-reaching implications" in the financial industry.

- Deprivation of inherited land rights by a close relative. Inheritance and other family-related disputes account for a substantial fraction of conflicts affecting land tenure around the world. Some land governance initiatives in Afghanistan (LTERA) and Nigeria (GEMS3) even suggested that inheritance is involved in 60% to 80% of rural land disputes in these countries. Inheritance-related land disputes are particularly noticeable in rural land tenure systems in which plots of land are held in trust by one family member on behalf of the other family members. In such systems, it is not uncommon that trustees misusing their trust power to conduct transactions for his own benefits and without the consent of other members. To date, little attention has been paid by emerging technologies to this particular aspect of tenure security. However, Epigraph hinted that blockchain technology could in the long run be extended to the lodgment of caveats to blockchain-secured registries by any person who wishes to be informed that a transaction is being conducted on the properties they have an interest in.

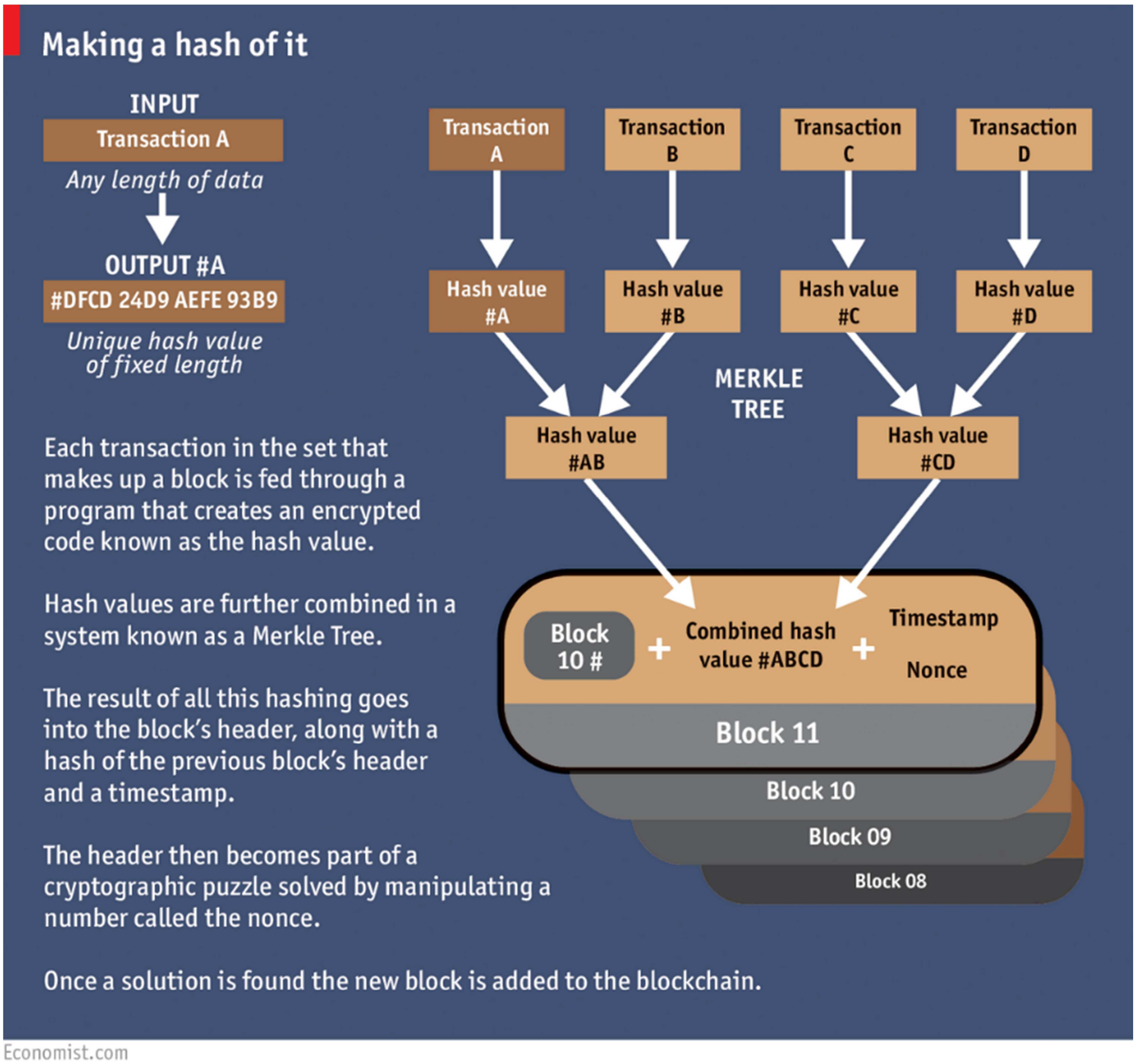


Figure 25 - From The Economist - October 31st 2015 - The great chain of being sure about things -

Homo biometricus

As mobile applications tend to increasingly infiltrate every aspect of daily lives, even in rural areas, the issue of personal identity authentication has grown commensurately. The most apparent reason is that the conventional means of identification such as passwords, secret codes and personal identification numbers (PINs) can easily be compromised, shared, observed, stolen or forgotten.

Mobile biometrics are defined as the use of biometric techniques on mobile devices to automatically recognize a person using distinguishing traits. Modern mobile devices include very powerful processors, large storage, high resolution cameras, microphones, fingerprint sensors that ultimately offer a wide range of strategies for recording and processing personal physiological or behavioral features. Mobile biometrics encompass the development of mobile devices to acquire biometric signals, software algorithms for identification and verification, and data stores to house biometric data for comparison.

Although mobile biometrics has been flourishing in the mobile banking and mobile trading industries, its fundamentals are applicable to securing land transactions, by authenticating the identity of the right holders. The industry is still exploring how consumers can use their own bodies to maximize security. Many companies are testing the use of fingerprints, voices, irises and faces to validate that you are who you say you are when making a purchase or other transaction. MasterCard recently announced that it is testing facial recognition technology to authorize transactions. Alibaba is looking at using a selfie to pay and verify with facial recognition. Samsung is looking at both fingerprint, voice and iris recognition for its Samsung Pay offering. Apple allows fingerprint authorization for iTunes purchases and payments with Apple Pay.

Although each biometrics technique is subject to limitations – voice recognition can be challenged by background noise or a person affected by a cold, facial recognition can be spoofed with a photo or video, fingerprints can be copied on a latex cast -, identity authentication tends to be improved though the combined use of two or more techniques and the progress made in the field of keystroke, handwriting and gait recognition by mobile devices.

Mobbeel, a Spanish based start-up specialized in mobile biometrics solutions, envisions that mobile devices could in the future unambiguously authenticate a land right holder by comparing its biometrical credentials with those stored at the time of a previous transaction, and therefore confirm the legitimacy of a land transaction with less than 0.1% error, which still appears as a considerably error rate.

Table 4. Review of biometric technologies

Biometric recognition procedure	Attribute	Representation of the biometric attribute
Physiological characteristics		
Fingerprint	Skin pattern of the fingerprint	Image of the ridges on the finger, classification, characteristic features (minutiae)
Hand	Measurements and shape of fingers and palms	Length of the fingers, hand geometry
Face	Facial image and geometric attributes	Transformation approach: Covariance analysis of facial images; attribute approach: attributes such as nose; eyes, etc. and their specified geometric sizes and structures
Iris	Tissue pattern surrounding the pupil	Texture analysis
Retina	Pattern of the blood vessels at the rear of the eye	Texture analysis of the circular scan of the retina/the blood vessels behind the retina
Behavioural characteristics		
Voice	Voice	Set texts or independent solutions
Signature/writing	Writing behavior	Speed, pressure, acceleration of the writing action
Keystroke	Keystroke rhythm / speed	Measurements of pressure duration and intervals between keystrokers

Security through bar coding and digital signature: the HALRIS initiative

For centuries, security printing has been the preferred technology is to prevent forgery, tampering, or counterfeiting of valuable document such bank notes, identify cards or land certificates. Security printing makes use of a paper that incorporates special features – such a watermarks, intaglio, guilloché, color-changing ink, hologram or security thread - that proves difficult if not impossible for counterfeiters to reproduce or duplicate without exposing the fraud.

A wide-spread issue related to security printing is that it requires expensive state-of-the-art printing equipment or special type of paper that contributes to increase the cost of issuing such official documents. Moreover, security printing also poses logistical problems to supply security papers to remote areas. In some of the cases reported, local governments had even stopped issuing land certificates for months due to shortage of security papers (State of Kano, Nigeria).

To get rid of costly security printing while ensuring authentication of records, the Haryana's Land Records Information System (HALRIS) in Northern India has introduced 2D Bar codes in the desktop application generating Records of Right (ROR) and developed an *adhoc* mobile application that can scan the 2D barcode and authenticate the ROR in seconds. The authentication is twofold:

1) The 2D barcode is a cryptographic hash generated at the time the Record of Right is digitally signed by the Chief Land Registrar (*patwari*) using its private key. It therefore confirms that the Record of Right has been duly signed by the *patwari* and is therefore a legitimate entry in the land registry.
2) It confirm to prospective lenders and buyers scanning the barcode for authentication that the certificate holder has valid registered rights over his/her property.

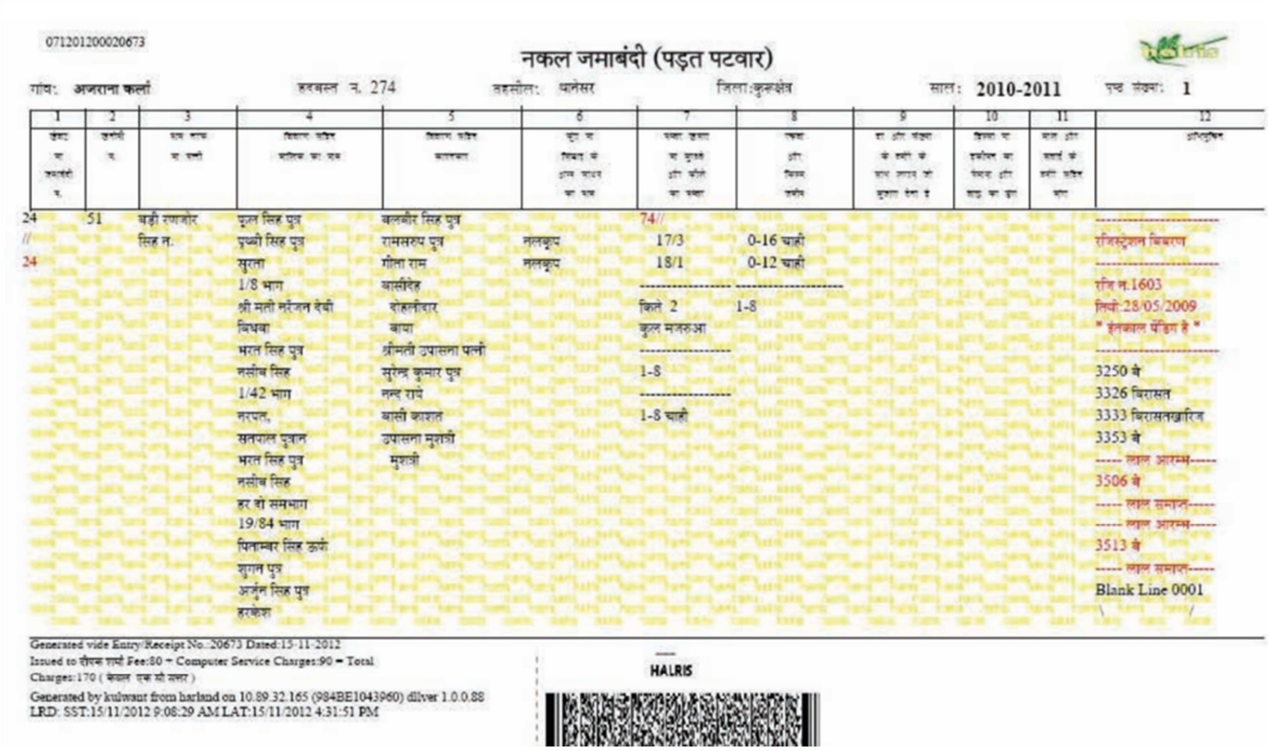

071201200020673
नकल जमाबंदी (पड़त पटवार)
साल: 2010-2011
HALRIS
Generated vide Entry/Receipt No.:20673 Dated:15-11-2012
Generated by kulwant from harland on 10.89.32.165 (984BE1043960) dlver 1.0.0.88
LRD: SST:15/11/2012 9:08:29 AM LAT:15/11/2012 4:31:51 PM

Figure 16. HALRIS record featuring 2D bar code

The system developed by HALRIS has reportedly created a feeling of trust among the landowners and other parties such as banks and other financial institutions operating in the State of Haryana. HALRIS received India's National Silver Award on e-Governance 2013-14 under the category "Incremental Innovation in Existing Project".

Chapter 8 – Unlocking Open Land Governance

There is anecdotal evidence that free and open source software (FOSS) applications are nowadays emerging in Africa and, to a lesser extent, Asia and Latin America, as the mainstream software technology for computer-aided land administration. Use of free and open source solutions to support land governance project is not new: applications such as GRASS GIS and ILWIS have been around for about 30 years, with limited functionalities compared to their well-established commercial-based equivalent solutions. What seems to be new, however, is that open source platform are not anymore restricted to pilot, experimental or research-oriented projects as they used to be, but tend to be adopted as the preferred solution for developing nation-wide land administration systems. FOSS application are the corner stone of national land information systems in Ethiopia (REILA project), Uganda (DESINLISI project), Ghana (GELIS), Rwanda (RLAS/LTRSS) and are considered in other countries such as Tanzania, Lesotho, Ecuador, Bolivia and Peru.

Remarkably, a number of countries that had experimented commercial-based land administration software solutions on a pilot basis, have made the choice to adopt a FOSS approach for their roll-out plans. This is notably the case of the DESINSILI project in Uganda, or SIGTierras in Ecuador. The rationale for shifting from commercial-based to FOSS solutions is manifold and briefly listed hereafter:

1. In spite of their significant licensing fees – some fully fledge solutions may cost up to 30,000 US$ per license - commercial-based solutions are not as versatile and flexible as it was expected. Even the most complete commercial-based land administration solutions requires to be customized, translated and further redeveloped to match the land governance workflow requirements of a particular country. Customization/redevelopment costs may add up to 300,000 US$, that comes in addition to licensing.

2. The pricing policy of commercial-based solutions lacks predictability. When opting for a commercial-based solutions, costs of licensing upgrades are unknown, which may jeopardize the long term sustainability of the system. Unfortunately upgrades are inevitable to re-align the land administration solutions with the requirements of continuously changing operating systems.

3. FOSS solutions have made tremendous technical progress to bridge the gaps with their commercial-based equivalents. This is due to the emergence of a solid and growing community of developers and users which contribute to make open source products more robust, reliable, versatile and flexible. In the fields of GIS, such solutions as PostgreSQL, PostGIS and QGIS are getting incredibly close in terms of functionality to the GIS leader ESRI ArcGIS.

4. In some countries, some ideological approaches aim at limiting the dependence of government agencies on private software edition companies perceived as potentially affiliated to foreign interests. This is the case in Ecuador which is in the process of migrating its land information system from an ESRI proprietary platform to an Open Source KOSMO platform.

All of these various reasons are creating a momentum for worldwide adoption of FOSS solutions in the framework of land governance project. However, it should be emphasized that, to date, the vast majority of FOSS-based land governance projects are still under implementation and there has not been much hindsight and evidence to boldly state that FOSS have succeeded where proprietary software have failed.

By using and improving open-source software, cadastres and land registers can build local knowledge and contribute to the public development of open-source projects (via for example web communities) that can in turn benefit other cadastres world-wide However, little knowledge and experience is yet available on the introduction of open-source systems in land registration and cadastral systems. While there are several examples of FLOSS used successfully in land records (see Chapter 3 of this booklet), land agencies in developing countries generally lack the IT expertise to build up a digital land records and mapping systems without external support.

From Open Source Community to Open Source Ecosystem

The existence of a strong open-source global community of developers and users is undeniable. Such solutions as PostgreSQL, PostGIS, QGIS, MAST, LandMatrix and even BRCK would simply not have been possible without a strong and coherent community that have paved the way for such developments to exist.

But the trend in Open Source is going way beyond the mere existence of a community of developers and users. To reflect this trend, IT industry observers have chosen the term “Open Source Ecosystem”. This ecosystem consists of three components - open communities, open standards, and open technologies – which can be accessed for free and without restriction, that deliver three outputs – products, services and competences - which are indeed royalty-free but not free-of-charge. The very existence of this “charge” contributes to stimulate an Open Economy that is not protected by any copyright barrier or other economic rent. Anybody can participate this economy without entry cost other than an internet connection giving access to source codes through platforms like GitHub. No wonder the open source model has been attracting young African talents that can now earn their living from selling their open source development skills.

It should be emphasized that members of the open source ecosystem are not just individuals. An increasing number of IT and software development companies are joining the Open Economy, without necessarily giving up proprietary solutions from their business offers. In fact, a growing number of IT and business decision-makers are identifying, pursuing, and succeeding with initiatives that employ elements of the open source ecosystem to achieve meaningful immediate and sustained business benefits. Visionary IT executives tend to take a business-centric, holistic, and pragmatic approach to the open source ecosystem to take maximum advantage of relevant elements while avoiding the risks associated with unnecessary or irrelevant elements.

As open source solutions, technologies, and vendors evolve, the open source and proprietary/closed source ecosystems are increasingly converging, each picking up ideas from the other. For example, open source vendors are increasingly focused on providing "enterprise-class" interoperability, service and support and are moving to more traditional business models, while many vendors of proprietary solutions are now also selling offerings based on free and/or open source technologies, and leveraging community development. This is best exemplified by the previously discussed example of Digital Globe that supports the open source development of Maps API to offer new opportunities to their imagery. This continuing convergence underscores the need for IT executives to evaluate candidate open source solutions and their vendors using the same criteria by which proprietary and closed source alternatives are measured.

The growth and evolution of the open source ecosystem has shifted the priorities and importance of key elements of that ecosystem. Integration and interoperability, among open source solutions and between them and other IT infrastructure elements (including closed source and proprietary solutions) join support as key challenges, and potentially very significant business benefits, to solution providers as well as to enterprises. These issues represent key differentiators, more important than any particular technologies, whether open source or not. Customer environments are increasingly likely to be a heterogeneous mixture of open source and closed source. IT executives should ensure that their own strategies and those of their vendors address these issues adequately, to maximize business value and alignment.

Five years of implementing Solutions for Open Land Administration (SOLA)

Started in 2010, Solutions for Open Land Administration (SOLA) is by far the most consistent efforts from the donor community to develop a low cost, flexible, easy-to-maintain open source solutions to provide some form of land rights recognitions to communities

The original design of SOLA builds upon the Land Administration Doman Model (LADM) – see next section – and was intended to assist land registries move from paper based tenure records and related processes – such as transfer of properties, parcel subdivision, lodging of interest, etc. - to computerized systems based on digital data flows. This move was previously largely based on proprietary software and had been observed as slow, costly and often unsustainable. To address that issue, FAO, supported by the Finnish Cooperation, proposed a system that provided support for registration and cadastral functions in a typical district land office and a small open source community. In that sense, SOLA was not just about developing a land registration software but also to test its deployment, operability and maintenance in the reality of emerging countries that are characterized by:

i) government-backed land offices with limited technical capacity and
ii) IT-savvy youth communities eager to learn new skills and become part of the open economy.

The initial SOLA solution (now called 'SOLA Registry' was piloted successfully in Nepal, Samoa and Ghana involving local teams of software developers. The SOLA piloting effort coincided with the Committee on World Food Security's endorsement of the Voluntary Guidelines for Responsible Governance of Tenure of land, fisheries and forests in the context of national food security (VGGT) in May 2012 (FAO, 2012). With this endorsement, FAO took on a lead role in the global effort to assist countries, especially in the developing world, to implement the VGGT. In that role, FAO recognized very early that many of the principles encapsulated in the VGGT implied the use of technology including the use of computerized systems. For instance, it is expected that land administration agencies anywhere in the world must facilitate transparency in the authoritative tenure records they hold and also in the performance of the services they deliver to the public. Current expectations of transparency imply as a minimum computerized indices and computer generated reports. Most commonly transparency implies computerized access to actual tenure records and service delivery by land administration agencies. In this way, SOLA appears as a tool for assisting land administration agencies in providing greater tenure security to the public they serve and therefore a tool for enforcing the VGGT.

It shall be noted that the VGGT do not just apply to formal land administration. Considerably more land and other tenure arrangements exist outside of formal systems such as land administration systems and are therefore out of reach of the SOLA Registry. There was therefore a need to complement SOLA Registry with additional tool inspired from the Social Tenure Domain Model (STDM) that allow far more flexibility than the LADM model in documenting informal rights and providing weak and vulnerable groups within society with tenure security. This led in 2013 to the development of SOLA OpenTenure, a crowdsourcing approach to the collection of tenure related details by communities themselves using mobile phone technologies. OpenTenure has large similarities with MAST and LandMapp, but seemingly puts more emphasis in building a local community of OpenTenure developers that may tomorrow lead the development of new applications based on OpenTenure or participate in the customization of OpenTenure to new countries.

OpenTenure also features a participative environment whereby communities discuss and agree to the way tenure right claims are to be collected, moderated and displayed. Typically the workflow include these stages:

- Community information dissemination;
- Community Recorders download details of existing tenure rights and fit-for-purpose map imagery;
- In-the-field recording of claim details including mapping of claims and the collection of document images and photos;
- Upload claims to an Open Tenure Community Server (preferably cloud-based) ;
- Display of claims and the potential submission of challenges to claims on Community Server;
- Review of claims (and associated challenges);
- Moderation of claims (community endorsed) including modification of claims based on community based consensus;
- Publishing of community endorsed tenure rights on Community Server.

Each implementation SOLA has contributed to increase the international SOLA open source community, resulted in more and better software functionality within the generic version of SOLA software and given FAO a better appreciation of what the needs are for future extensions to SOLA. It has also reinforced the importance of training and using local software developers in the software customization that is required to ensure SOLA complies with local laws, regulations, administrative processes and can deal with local tenure records. An essential element in maximizing the likelihood of a sustainable solution is the availability of local software developers capable of providing as a minimum first level software support and ideally, in the future, for these local SOLA software developers being able to extend and modify the customized version of SOLA when new demands are placed upon the SOLA based system.

Picture 5. OpenTenure piloted Meanchey Community Forest group in Cambodia (Source: FAO)

Having said that, some words of caution must be stated. While SOLA Registry and OpenTenure certainly bear a promise for easier entry of developing countries to the era of IT system-managed land administration, their potential should not be over-estimated. The idea that IT systems can be installed within a limited amount of time and then used permanently thereafter is simply a common misconception. Building a digital land administration system, as any other digital administration system, is a continuous process rather than a one-time event. After installation, there are new requirements and additional functions to be added. Hardware and software will need to be upgraded, which is costing time and efforts. Maintenance of the system must be planned and taken into account. System sophistication cannot exceed the available long term resources and in particular local capacities. System development relying in external know how should be used only with a credible exit strategy building local capacities. Although the costs of software maintenance and support when adopting SOLA-based solutions will probably be lower than would be the case with proprietary software, they are not to be underestimated. SOLA may make the maintenance easier, as problems can be solved without external support also making use of international user and developer communities, and cheaper, as license fees can be reserved for the maintenance and further development of the system. However, all IT systems require substantial budget and skills for maintenance, and developing country cadastral agencies have traditionally struggled to establish adequate resources for maintenance. Application of SOLA will not change the fact that a proper business plan is the key requirement for introducing IT systems for land records.

Application of SOLA to land registration and cadastral systems is likely to succeed in countries where the government embraces the idea of using open-source software for their information systems, and support the use of SOLA in education and research activities. In such a national context, it will be easier to find local IT specialists who are familiar with SOLA products that form the base and ability to maintain systems beyond their initiation.

A well-proven open standard for recognizing land rights of the poorest: STDM

The Social Tenure Domain Model (STDM) emerged in the late 2000s as an attempt to characterize and provide some form of recognition to complex customary and informal tenure systems that are largely ignored by conventional land administration systems. Indeed, most developing countries are still unable to bridge the gap between formally registered land ownership units and those that are not registered or unaccounted for. According to GLTN, the limited success in achieving increased cadastral coverage shows that, about 70 per cent of land ownership units in developing countries are not formally registered. This situation adversely affects individuals, families and communities who are on this unregistered land and, in most cases, these are poor and disadvantaged communities whose aspirations to improve their living conditions or movement on the property ladder are not addressed. The tenure insecurity experienced by communities in informal settlements and owners of unregistered properties is illustrated by forced evictions, land grabbing by elites or farming investors, inadequate compensation when it is considered, and a lack of poor urban service delivery, etc.

STDM was developed by Global Land Tool Network (GLTN) facilitated by UN-HABITAT to operate both as an open data modelling standard whose use by other parties is largely encouraged, as well as an open source software for those users that want a ready-to-use, free-of-charge application to support basic collection and documentation of tenure claims.

STDM as a model

While Conventional Land Administration Systems are based on the “parcel approach” best illustrated by the Core Cadastral Domain Model (CCDM) later on improved by the Land Administration Domain Model (LADM), customary and informal systems are based upon a more loosely defined concept of spatial units. In some cases, it is simply not possible to map the spatial extent of applicable informal rights. By way of illustration, the USAID LTERA project reported the example of Southern Afghanistan’s tribal area where community land extends as far as one can hear the shout of an adult man standing right next to the farthermost house from the village center. Needless to say how subjective boundaries mapped from such a definition can appear. Interestingly, the STDM model was designed to address this kind of tenure relationship.

CCDM	LADM	STDM
Natural person, group	Natural person, group, cooperatives	person, company, municipality, cooperation, married couple, group, group of groups, ministry
Parcel, building, right of way, protected region	Parcel, building, land surveys	Text description, single point, set of unstructured lines, 3D volume
Formal ownership, apartment right	Restriction, responsibility and right abstraction	Formal ownership, apartment right, fishing right, hunting right, cooperation, customary, restriction, miri, waqf

Table 5. Comparison of CCDM, LADM and STDM concepts (source: GLTN)

The versatility, flexibility and ease of implementation of the STDM model has made it a de-facto standard widely acclaimed by pro-poor land governance project such as MAST and OpenTenure. It is also becoming adopted by proprietary software solutions too. Indeed, STDM forms nowadays the core of the OpenTile™ solution developed by Thomson-Reuters.

<u>STDM as a software application</u>

To facilitate the implementation of STDM, UN-HABITAT further developed a computer application capable to assist in the collect and organization of informal tenure records, and implemented in a number of different situations including Uganda, Kenya and Haiti.

In Kenya for example, STDM emerged as an adequate land information management tool to capture both enumeration and mapping data for informal settlements which have not been captured under the formal cadaster. It had the capability to record the informality and complexity of the various tenure situations exhibited in the many informal settlements in Kenyan towns/cities. As such, STDM bridged the gap between communities and land professionals, and addressed slum questions with pragmatic and attainable solutions.

The information generated by the communities from the two pilot sites has contributed to various Government interventions including tenure regularization, relocation and planning. The communities have used the information to negotiate with land sector stakeholders. STDM has helped the residents to assert the existence of their settlements and to move ahead towards recognition and security of tenure which have been challenging for most Kenyan informal settlements. Against the Governments plans for enhancement of tenure security in the pilot sites, the project has managed to demonstrate that land rights are a continuum.

Chapter 9 – The new "old way"

"Continuum of technologies" is an increasingly popular term that covers the wide range of technologies - from no-tech to high-tech – which currently available to land governance project owners in order to implement better land governance. While investigations conducted during the study focused on emerging technologies that have had a positive impact on both data "productivity" aspects – such as reduced time and cost of land rights data collection and processing - and rural community participation and buy-in, old ways may have some merit – social, if not technical – that may contribute to increase successes of land governance project.

Digital pen capture

Digital pen and paper platform has been emerging as a quick, easy and reliable way of capturing and sending field information to a back-office. This technology has been experimented in the field of participatory land rights mapping projects by the Dutch Kadaster in Rwanda in 2010 as an alternative technology to speed up acquisition of social and tenure data about landholders.

Digital pen operates together with normal paper overprinted with a dotted pattern watermark and captures the pen strokes with a tiny camera. It records an exact image of the handwriting and the form it was written on. The data is securely uploaded via a compatible mobile phone or by docking with a PC. Better yet, the digital pen can also convert handwriting to text, saving on unnecessary re-keying time.

The benefits of digital pen data capture were assessed by comparing this technology with the conventional pen method of acquisition over Musezera and Kibenga rural districts of Kigali municipality. The digital pen system tested consisted in the Penx© digital pen and CapturX© software, both develop by the US-based Adapx company. Capturx software enables paper forms, designs, maps, and notebooks to be filled out or marked up with a digital pen that digitizes the handwriting and integrates the data directly into Microsoft Office, SharePoint, and leading GIS and CAD systems. The pen-readable dot pattern is printed as a watermark on normal office paper and is unique to each application and file, while the digital pen consists of a processor, sensor, and memory. As the pen writes, the handwriting is digitized and stored on the pen. When the pen is docked to a PC, Capturx integrates the data directly into the original SharePoint, Microsoft Office, PDF, or ArcGIS sources.

Picture 6. Data capture by regular pencil (left) and digital pen (right). (source: Kadaster)

Field data capture using digital pen and dotted paper has been shown as having noticeable advantages over traditional method using conventional pencil during the data acquisition phase:

- Using digital pen is natural and easy since it works quite identically to common pencils. Consequently, any candidate with a primary or secondary school level can apply as a para-surveyor.
- Parcel boundaries data and identification are collected directly in digital format and stored in the digital pen memory
- Parcel boundaries delineated by digital pens are directly georeferenced in a vector format and can therefore be mapped without the need for further processing
- The digital pens is deemed to be less sensitive to climate conditions
- While data acquisition takes as much time as the conventional pencil method, data post-processing in the case of digital pen has been estimated to take 60% less time than conventional pen, since geo-referencing of printed sheet and vectorization of hand-delineated boundaries are not required any longer.

However, some severe limitations are currently hindering a widespread adoption of digital pen systems as mainstream field data capture technology:

- Digital pen is currently limited to legal systems whereby general boundaries - as opposed to fixed boundaries – are being enforced
- At the time of the Rwanda experiment, the software that was used could not capture and store alphanumerical information such as parcel ID or right holder name as an ASCII formatted text. Alphanumerical information could only be stored as graphics.
- Boundary lines captured by digital pen suffers from geometric errors and jagged lines. Besides, snapping is not possible, which often leads to overlapping polygons, gaps and misinterpretation.

The digital pen industry has been aware of these limitations and is currently seeking to address them through improved handwriting recognition algorithms. Until these limitations are addressed, the usability of digital pen systems for the identification, mapping and tilting of clean land rights will be severely limited, or restricted to land governance that do not require the issuance of land titles, for example valuation of land parcels prior to land acquisition.

Cadastre gets to the point

First introduced in Honduras in the 1990s by the US-based company PADCO under the name of "lots-by-dots", the concept of Point Cadastre has been occasionally used in land governance projects around the world as a fast and low cost alternative to the conventional land parcel mapping approach. Paradoxically, in spite of its extreme ease of use and affordability, it has not been the subject of much attention by the mainstream survey profession until the concept was revisited 3 to 5 years ago by the Dutch Kadaster.

Unlike conventional cadastral systems that records the location and geometry of each single land parcels as georeferenced polygons, a point cadastre does not keep records of parcel boundaries and simplifies the geographical representation into a point approximately taken at the centre of the parcel. This point is assigned a unique identification number (the parcel number) that can be associated with rights and right holders. Adoption of a point cadastre over a conventional cadastre can result in a 90% reduction of data acquisition time and 50% reduction of data processing time as reported by the Dutch Kadaster.

The renewed interest in Point Cadastre is explained by the emergence of high resolution satellite imagery with unprecedented resolution, freely available topographic maps of decent quality (for example Open Street Map), global navigation satellite system (GNSS) and cloud-based information system, which all combined together offer in certain cases a viable alternative to conventional cadastre. In a 2012 publication[3] aimed at providing land surveyors with a blueprint for

[3] The Requirements for Point Cadastres. Robert Antwi, Rohan Bennett, Walter de Vries, Christiaan Lemmen, Co Meijer. 2012 FIG Working

consistently implementing point cadastre, Kadaster rightfully hints that not all land governance projects require the delineation and adjudication of accurate parcel boundaries, when it is not economically feasible to do so. In that respect, point cadastre appears to achieve a fit-for-purpose objective.

Building upon the continuum of technologies to achieve productivity and inclusiveness

The continuum of technologies in land governance may be defined as the wide range of technologies, from no-tech to high-tech, which are currently available to land governance project owners in order to implement better land governance. While investigations conducted during the study focused on emerging technologies that have had a positive impact on both data "productivity" aspects – such as reduced time and cost of land rights data collection and processing - and rural community participation and buy-in, old ways may have some merit – social, if not technical – that may contribute to increase successes of land governance project.

By way of illustration, the USAID LTERA project reported in 2009 that old fashioned optical survey instrumentation had been successfully re-introduced in its tenure formalization programs in Kunduz, Mazar and Taloqan cities because this instrumentation, although outdated, had the merit of being available in almost every Afghan districts and most importantly, made it possible to include in survey crews senior citizens that were known and respected from the local communities, hence contributing to build trust.

Picture 7. Two generations of Afghan land surveyors involved in the USAID Land Titling and Economic Restructuring in Afghanistan (LTERA) project (source: Cardno EM)

Combining both outdated and modern technologies can help build technologically balanced solutions that can achieve both productivity and inclusiveness.

Week.

Chapter 10 – Concluding remarks

In many ways, this scoping study raises many more questions than it provided answers. It should be kept in mind that the manner technologies were grouped together and presented in the present report is largely arbitrary. For example, the boundary between connectivity, positioning and data capture technologies is getting increasingly blurred with the advent of smartphone applications such as MAST or LandMapp. If time had allowed, many more aspects would have been investigated, notably the following aspects:

Benchmarking fit-for-purpose technologies

Although the review of the emerging technologies highlighted in this scoping study has been driven by fit-for-purpose considerations, it was not possible to characterize this "fit-for-purposeness" other than in general qualitative terms. Even the seemingly simple concept of "affordability" led to considerations that rapidly extended beyond the immediate scope of the scoping study. Seemingly, none of the technology proponents encountered during the study had conducted a robust affordability or willingness-to-pay survey against which various technological options could be benchmarked. While most of the proponents encountered during the study did seriously consider investment and recurrent cost associated with their technologies, none has really sketched out the lines of a workable economical model that would sustain the technology in the medium to long run.

The same goes with other fit-for-purpose associated concepts of Flexibility, Inclusiveness, Participation, Reliability, Attainability and Upgradeability. It is a fair statement that all the approaches reviewed – from no-tech to high-tech – do comply with these concepts at least to a certain degree. However, defining the degree from which the technology would qualify as "fit-for-purpose" is rather subjective in the absence of clearly defined threshold or objective criteria.

Fit-for-purpose approach nonetheless raises the right questions about the conditions for emerging technologies to percolate through the society and durably take root. The donor community should certainly join efforts to devise a workable definition of fit-for-purpose, as a starting point for benchmarking technologies.

Seeking scalability through a coalition with private sector technologists

In spite of their relevance and technical prowess, emerging solutions in the fields of land governance are facing, or will face at one point or another time of their development, the issue of their scalability. As already highlighted above, the vast majority of project leaders and proponents of innovative technologies admitted that the economic models underpinning their technological innovations are yet to be devised and field-tested.

Not surprisingly, the imperative to develop viable economic models without which scalability cannot be achieved, is integrated in early stages of technology developments sponsored by the private sector rather than the community of donors. This does not imply in any way that the donor community has no interest in sustainability and scalability. In fact, it has. But the imperative of profit making in the context of poorly endowed rural communities motivates the private sector to devise ingenious, fit-for-purpose products matching the users' willingness and ability to pay. By way of illustration, this imperative of matching technology offer with demand led DigitalGlobe to develop the first-of-its-kind "Basemap + Vivid" product, a 50cm seamless mosaic of cloud-free Digital Globe archived imagery covering the entire African continent and available to customers at a massively reduced price.

More generally, it is thought that a coalition between the donor community and profit- oriented technology entrepreneurs will make it possible to identify those innovative technologies having a strong business case. Such coalitions between and aid-oriented organizations and the private sector are not new: Grameen Foundation and Nokia partnered in developing the successful Village Phone initiative. Other initiatives like LandMapp that seek to embed private agro-industrialists right from the design of their projects should be encouraged.

Devising multi-purpose technologies serving broader social and economic objectives

Land governance projects in rural areas follow a different dynamic than in urban areas. While in urban areas, high land values create an incentive for right holders to pay for securing their land, such an incentive does not exist in rural areas. The issuance of certificate of ownership or occupancy in rural areas is often perceived by struggling farmers as a distant hypothetical and luxury advantage (e.g. possibility to access credit one day) while their immediate survival needs are not being addressed.

It is believed that technologies for recognizing, mapping and monitoring rural land rights should be concurrent and embedded within projects having a broader economical scope and requiring some form of tenure security. Particularly promising are public-private-community development projects aiming at setting up integrated agricultural and agro-industrial supply-chains in rural areas. The Staple Crop Processing Zone (SCPZ) stands for such a good example of well-coordinated efforts between the Nigerian government, Cargill, a major agro-allied company, the donor community - IFC, Worlld Bank and DFID – the rural community of Kabba in Kogi State. Although the recognition and mapping of land rights within the 15,000 hectares impacted by the project constitute a fraction of the project itself, all parties - including Cargill - rightfully recognized these activities as a contractual pre-requisite to support the overall investment. Clarification of land rights is indeed central to:

- equitably indemnify rural right holders for potential land losses or land-based revenues losses
- document land lease agreements, if any, between local land owners and farmers
- establish cassava root supply contracts between Cargill and local farmers
- document differed payment arrangements between local farmers and input suppliers
- document credit facility arrangement between local farmers and lenders
- establish crop insurance contracts between crop insurers and local farmers

Such an example of integrated project contribute to increase community buy-in to land rights recognition and mapping process as the benefits of tenure security becomes immediately visible to the farmers. It also reveals opportunities for avoiding data collection cost duplication by devising technologies and acquisition methodologies serving the purposes of all partners at once.

Appendix 1: Key informants

Name	Organisation	Title
Frank Pichel	Cadasta	
Ioana Bouvier		Land's Sr. Geospatial Analysts
Iris Krebber	DFID	Head – Agriculture Team + Senior Land Policy Lead
Robin McLaren	Know Edge Ltd	Director
Ken Banks	kiwanja	Founder: kiwanja .net
Jorge A. Muñoz	world Bank	Practice Manager Global Land / Rural / Geospatial Unit Social, Urban, Rural & Resilience GP
Gregory Myers	world Bank	
Matthias Hack	GIZ	Junior-Advisor Rural Development and Agriculture Sector Project Land Policy and Land Management
Matt Regan	Epigraph	co-founder and CEO of Epigraph
Paul Munro-Faure	FAO	
Romy SATO	Global Donor Platform for Rural Development	Secretariat
Gerda Schennach	FIG	Head of the Commission 7
Neil Pullar	FAO	Land Administration (IT) Officer /SOLA Open Source Software Climate, Energy and Tenure Division (NRC)
Thea Hilhorst	World Bank	Global Coordinator Land Governance Assessment Framework at The World Bank
Peter Veit	World Resources Institute	Interim Director Governance Center of Excellence World Resources Institute
Jeff Ploetz	cloudburst group	Director of The Cloudburst Group's Land Tenure and Natural Resource Management practice area
Fabrice Dubertret	WAIPT PROJECT	PhD student, principal operator
Katie E. PICKETT	LandMapp	Presenter Landmapp Commission 7
C.J kees de Zeeuw	Kadaster International	
Annalisa Mauro	ILC secretariat at IFAD	
M. C. J. Kees ZEEUW	Kadaster International	Director Kadaster International
Jeffrey Euwema	Clouburst	MAST project Team Leader
Karol Boudreaux	Clouburst	Land Tenure Practice Lead
Christiaan Lemmen	Kadaster International	Senior Geodetic Advisor at Kadaster International
Caitlin Burton	Grameen Foundation	Manager, Institutional Relations, Africa
Sean Paavo Krepp	google	Support Strategy, Google Play Payments
Peter Laarakker	Kadaster International	Land Administration Strategy and Research

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Appendix 3: Interview frameworks

Global Donor Platform
for Rural Development

SCOPING STUDY ON OPEN DATA, INNOVATIVE TECHNOLOGY-BASED SOLUTIONS FOR BETTER LAND GOVERNANCE

Questionnaire 30 October 2015

Introduction

The Global Donor Platform for Rural Development (Platform) is a network of 38 bilateral and multilateral donors, international financing institutions, intergovernmental organizations and development agencies. Members share a common vision that agriculture, rural development and food security are central to poverty reduction, and a conviction that sustainable and efficient development requires a coordinated global approach. The Platform provides a forum to exchange knowledge, build consensus and formulate joint approaches around critical or emerging issues.

The Global Donor Working Group on Land (GDWGL) was established in the summer of 2013 hosted by the Donor Platform. Its purpose is to improve land governance transparency and enhance the coordination of efforts undertaken by its bilateral and multilateral donor members with each other and with key external government, non-governmental and private sector stakeholders at the global, regional, and national level. The objectives are to advance information sharing, lesson learning and coordination at the international level, highlight existing challenges around land governance, and to agree on joint actions wherever this may be suitable. The current chair of the GDWGL is held by Germany's Ministry for Economic Cooperation and Development (BMZ).

Objective of the present questionnaire

As part of GDWGL efforts to strengthen land-related information exchange, coordination and cooperation in rural development, GDWGL has commissioned a scoping study aimed at identifying State-of-Art of technologies supporting rural land governance transparency across the world and comparing these technologies against a set of relevant criteria. This scoping study will build upon the findings from the present questionnaire that aims at taking stock of land governance-related emerging technologies implemented or experimented around the world with the support of the donor community, as well as from semi-structured interviews which will take place throughout November 2015.

Your organization/company has been identified as a key player in supporting and implementing such technologies. As such, we would be grateful if you could take 20 to 30 minutes to fill out in detail the present questionnaire (one questionnaire per project).

Thanks in advance for your cooperation.

GDWGL Consultant

DEFINITIONS

Rural land governance betterment

In the context of this questionnaire, rural land governance betterment project is defined as a project aimed either at:

- Improving the recognition, mapping, registration and update of formal and/or informal rights in rural areas
- Providing fair and equitable compensation to local communities prior to land acquisition for investment projects, or
- Increasing transparency and accountability about land deals in rural areas

Innovative technology

An innovative technology means here a technology that is new or different and renders the service it is designed for in ways that are faster, more reliable, more secure, more affordable, with a wider coverage, and generally speaking, that are better than previous practices. It may include as well existing technologies previously applied to other fields but applied for the first time in the field of land governance.

Your answers might not necessarily refer to a project, even if it is preferable, but also to experiment you might have heard off and which seemed to you innovative and promising.

QUESTIONS

Q1. Which technologies have you recently implemented to support rural land governance betterment projects? Please provide a brief description of where, when and what kind of technologies.

Q2. Would you consider (some of) these technologies are innovative and to which extent? Please refer to the definition of innovative technology above.

Q3. How are these technologies perceived and supported

3.1. By the rural communities?
3.2. By the public authorities?
3.3. By local land professionals *(e.g. surveyors, notary publics, solicitors, etc.)*?
3.4. By the donor community?
3.5. By other stakeholders?

Q4. What challenges are you facing while implementing these technologies? How are these challenges being overcome?

Q5. Please elaborate on the advantages achieved/to be achieved by these innovative technologies compared to previous practices?

5.1. Increased reliability and security of data and processes
5.2. Increased interoperability between data and/or between technologies
5.3. Increased time-efficiency
5.4. Increased cost-efficiency and affordability for communities
5.5. Increased ease of access, use and/or maintenance
5.6. Increased inclusiveness and coverage
5.7. Increased upgradability and scalability
5.8. Other advantages foreseen?

Q6. Which improvements to these technologies are envisioned in the future?

Q7. Among the various technologies you have experimented/implemented in the past five years, could you please list the most promising ones for the 3 years to come?

Q8. Today what is your perception of the most cumbersome bottlenecks/obstacles to make technologies accessible/affordable and endorsable to the rural population?

Q9. Which technology has the most promising immediate/medium term social impact?

Q10. Does your organization has a clear strategy to promote any kind of technologies for land right mapping/registration/monitoring? If so could you please elaborate briefly?