Scaling up UAVs for land administration: Towards the plateau of productivity

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ABSTRACT

Unmanned aerial vehicles (UAVs) are considered an innovative tool for land administration. However, despite the prospects and market opportunities in the domain, there is a gap between experimentation and widespread technology diffusion. In this work, the Framework for Effective Land Administration (FELA) and the Hype Cycle concept are integrated to understand the dynamics of the innovation process of UAVs for the land administration sector. Empirical data stems from literature and interviews of UAV and land administration experts worldwide. The majority of experts estimate UAV technology to be in a phase in which the innovation needs to overcome initial unmet expectations to foster market development and increased adoption. The assessment indicates the changing importance of different FELA pathways during this process. Enabling laws and policies and supporting governance, accountability and institutions are crucial to create such a UAV-friendly national ecosystem early on and allay exaggerated expectations. Once this ecosystem has been made, market demand is expected to surge driven by partnerships, adapted standards, tech advocacy and awareness-raising campaigns, highlighting the superiority of high-resolution data amongst other benefits of UAV technology. These insights can be used as a baseline to direct national strategic decisions towards the increased adoption of UAVs in land administration.

1. Introduction

Providing equitable land and resource access for all people by 2030 is implicit and explicit to multiple targets of the Sustainable Development Goals promulgated by the United Nations (UN, 2015). To achieve this global agenda, it is recognised there needs to be a rethink of conventional land surveying and mapping practices, often rooted in western-style land administration systems. With current rates and methods, it is estimated that it will take many decades, if not centuries, to achieve global coverage to provide tenure security for all (McLaren and Lemmen, 2016). Researchers and practitioners worldwide have developed various innovative approaches and technologies covering spatial, legal, and institutional frameworks to tackle the challenge. Pilot studies have been carried out in different land administration contexts to test the validity of those innovations, such as remote sensing technologies (Santos, Fletschner and Daconta, 2014; Stöcker et al., 2019; Koeva et al., 2020), participatory mapping (Asiama, Bennett and Zevenbergen, 2017; Aditya et al., 2020), geo-cloud processing (Koeva et al., 2021), fit-for-purpose land administration (Enemark, McLaren and Lemmen, 2016), pro-poor land administration (Zevenbergen et al., 2013; Hendriks et al., 2019), and the continuum of land rights (UN-Habitat and GLTN, 2015), amongst others.

Amongst those tools, unmanned aerial vehicles (UAVs) are considered a viable technology to capture aerial images, which may even have the ability to revolutionise the toolset for land administration tasks (Rubinov et al., 2015) in various specific contexts. Compared to traditional labour-intensive in-field surveys with geodetic equipment, UAVs offer the opportunity to collect high-resolution and accurate data (Stöcker et al., 2020a, 2020b) for small to medium-sized areas (few ha to a few km\textsuperscript{2}) in a time-efficient workflow. This allows for the timely supply of geospatial products as base data for various land administration processes. Furthermore, the data provided by UAVs have been widely applied to derive insights on land use, land development, land value or land tenure, either during participatory mapping activities (Barnes and Volkmann, 2015; Mumbone et al., 2015; Ramadhan, Bennett and Nex, 2018; Stöcker, Koeva and Zevenbergen, 2020) or as input data for automatic scene understanding procedures and machine learning (Yu and Zhang, 2015; Crommelinck et al., 2018; Fetai et al., 2019).
Looking at the prospects of UAV technology from a global perspective, there has been hype and excitement around UAVs as a disruptor for cargo transport and professional applications (Freeman and Freeland, 2015; Giones and Brem, 2017; Figliozzi, Tucker and Polikakhina, 2018). On the business side, leading institutions predict a global UAV market to reach $21.8 billion by 2027 from $8.68 billion in 2019 at a compound annual growth rate (CAGR) of 14%, including military and commercial applications (Meticulous Research, 2019). Even though military applications are expected to hold the largest share, the retail market is likely to grow with the fastest CAGR, mainly attributed to the increasing demand for UAVs for commercial activities such as delivering goods or mapping and monitoring. In addition, sectors with a large proportion in automatable operational processes are likely to benefit the most by adopting UAV technology for their routine tasks, lowering lower costs and improved productivity (PWC, 2018). In their review, (Floreano and Wood, 2015) do not see significant technological or scientific barriers to advocating for autonomous vehicles in research and commercial applications. To create impact, the technology needs to be mature enough, economically feasible and efficient. However, this only considers the (technical) innovation, which does not necessarily guarantee a successful diffusion or adoption.

Despite the prospects and market opportunities of UAV technologies, there is scant literature on the requirements and processes needed to support leveraging the technology innovation and to foster its wider adoption and diffusion in land administration contexts. Literature published so far dealt with the innovation process of UAVs with an emphasis on governance frameworks (Casiano Flores et al., 2020), institutional settings (Ho et al., 2019), or capacity frameworks (Tan, Flores and Crompvoets, 2021). By assessing the institutional dimension of innovation dynamics in Rwanda and Ethiopia, (Ho et al., 2019) conclude that UAVs, among other technologies, are still in the development phase determining a lack of financial resources as one of the significant barriers to scaled innovation. Interestingly, finances seem to be less of an issue for the scaling of UAV technology (Dijkstra et al., 2020). Instead, the authors identify the need for increased cross-sectoral partnerships and more national engagement and communication. Based on data from Rwanda, Casiano Flores et al., 2020 designed and evaluated a governance framework for the implementation of UAVs. It is reported that the governance context favours a top-down approach and that a strong focus on capacity development at local authorities could support an effective uptake for the implementation of UAV technology (Casiano Flores et al., 2020). Widening the scope to other innovative geospatial technologies (Bennett, Pickering and Sargent, 2019) identify political, socio-cultural and institutional settings within a system as the main determinants to steer the transformation of existing land administration processes. The studies presented thus far provide evidence that a holistic perspective, including technology and social and institutional systems, is fundamental to understanding the drivers and barriers to scale implementation of innovative technologies. However, in the context of UAVs, a comprehensive global analysis is absent.

To guide future decision-making processes, this work elaborates on aspects determining the dynamics of scaled implementation of UAV technology in a global context. Frameworks from innovation theories and land administration are integrated to unveil the dynamics of the innovation process of UAVs on the one hand and its adoption by land administration processes on the other hand. To account for the progression of adoption, a temporal dimension is added to the framework. Empirical data stems from literature and interviews of UAV and land administration experts worldwide, allowing to reflect on technology adoption rates among land administration stakeholders. The results of this paper will provide a generalised knowledge base to derive information on processes and resources that create an environment in which UAV technology can thrive. Going beyond single-lens perspectives and adding a temporal aspect to the framework for efficient land administration, it is hoped that this article can guide decision-making processes on policies and implementation strategies concerning the application of UAVs in land administration.

The remainder of this paper is structured as follows. Section 2 provides background information on the applied and combined innovation theory and land administration framework. Methods used for data collection and data analysis are outlined in Section 3. Results are presented in Section 4, laying out the assessment of experts concerning different stages of the uptake of UAV technology. The analysis and the subsequent evaluation on the importance of different pathways then provide the baseline for Section 5, where progress and prospects for the scaled implementation of UAV technology in land administration are discussed. Finally, main conclusions and several future research directions are outlined.

2. Background

This research lies at the intersection of remote sensing, land administration, information systems, and innovation and draws on relevant frameworks and theories as outlined below.

2.1. Framework for Effective Land Administration (FELA)

The framework for efficient land administration, in short FELA, is an overarching policy guide prepared by the Expert Group of Land Administration and Management of the United Nations Committee of Experts on Global Geospatial Information Management (UNGGIM), finding endorsement from UNGGIM in August 2020. With the aim to contribute to closing the cadastral divide (Bennett et al., 2013), it guides countries that want to develop or reshape existing land administration and management systems (UNGGIM, 2020). Based on the concept of Integrated Geospatial Information Framework (IGIF) prepared by UNGGIM, FELA specifies nine strategic pathways to strive for effective land administration. Yet, it is not considered another concept in addition to existing approaches, such as fit-for-purpose land administration or pro-poor land administration, but rather as an all-encompassing umbrella framework that accounts for and includes the existing knowledge base. Fig. 1 depicts all nine pathways, including Legal and Policy; Finance; Data; Innovation; Standards; Partnerships; Capacity and Education; Advocacy and Awareness; and Governance, Institutions and

![Fig. 1. Nine Pathways of the Framework for Effective Land Administration (UNGGIM, 2020).](image-url)
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Accountability. It is recognised and should be noted that even though nine pathways are defined, some of the focus areas are linked and necessarily overlap (UNGGIM, 2020).

With FELA’s mission to support responsible innovation for effective land administration, this framework is helpful to analyse opportunities and hindrances for the scaled implementation of UAVs in land administration workflows. However, being only endorsed in 2020, translation of FELA into other languages, implementation tools, and methods remains ongoing at the time of writing. That said, the high-level framework already finds application for gap assessments, if not project design work, in various country contexts. For example, one study describes a preliminary investigation in Nepal utilising FELA’s categories to evaluate the role of UAVs and their impact on the land sector by using a traffic light assessment (Dijkstra et al., 2020). FELA was further used to investigate various land administration systems in the MENA region (Bennett et al., 2021). Although this worked well for describing the status-quo of land administration systems, this approach shows limitations concerning the progress of technology diffusion, which is highly likely to be different across various geographical regions. Some argue that especially countries of the Global South have a considerable potential to accelerate technology adoption by skipping early and less efficient versions of innovation, i.e. technology leapfrogging (Davison et al., 2000). Thus, the next step involves selecting a suitable model that represents the innovation process over time.

2.2. Technology innovation and diffusion models

According to some researchers (e.g. Rogers, 1995), emerging technologies typically progress through different stages before they eventually reach majority and acceptance, fostering widespread adoption. In this context, the definition of key terms might be helpful to guide further discussion. (Rogers, 1995) defines innovation as an idea or object perceived as new and representing an alternative with new means of solving problems. The same author outlines that diffusion can be understood as the process by which an innovation is communicated through specific channels over time. In contrast, the rate of adoption describes the relative speed at which entities of a social system adopt an innovation (Rogers, 1995).

Several models evolved during the past decades to predict the fundamental dynamics of diffusion and adoption of emerging technologies. The performance S-curve (Foster, 1986), the Adoption Curve (Rogers, 1995), and the Hype Cycle (Linden and Fenn, 2003) are ones widely used in existing works (Fig. 2). All three curves indicate the evolution against time but consider different dependent variables on the y-axis. The time aspect is considered individually for each innovation, as not all technologies progress at the same speed. It is important to note that the rate of processing of innovative technologies is never the same and, in some cases, difficult to predict using such models.

The S-curve represents the general evolution process of the technology maturity over time, showing a sinusoidal line that is slightly increasing during the embryonic phase followed by a steep incline during the growth stage and again decreasing the slope when the technology reaches its maximum performance level. In contrast, the adoption curve model visualises the percentage of adoption, which is considered a normal frequency distribution, and concludes that not all individuals adopt an innovation simultaneously. At a conceptual level, (Rogers, 1995) distinguished five different categories: Innovators (2.5%), Early Adopters (13.5%), Early Majority (34%), Late Majority (34%), Laggards (16%). Each category manifests different characteristics in terms of socioeconomic status, personality, and communication behaviour. Introduced by Gartner in 1995, the Hype Cycle depicts a curve showing expectations/visibility of emerging technologies based on the assumption that innovations will initially face overenthusiasm followed by disillusionment and eventually reach productivity. The curve merges the hype level curve (based on human attitudes) and the classical performance S-curve (Dedeheayir and Steinert, 2016). Interestingly, most often, the invariant in the equation is people rather than technology, causing that most technologies conform to the Hype Cycle (Linden and Fenn, 2003).

Technology innovation and diffusion models have been increasingly used in the land domain, e.g. to understand the factors affecting the adoption of a land information system (Zeng and Cleon, 2018), to discuss the expectations of UAV applications in agriculture (Freeman and Freeland, 2015), or the diffusion of GIS technology in land and mapping agencies (Chan and Williamson, 1999), amongst others.

Although UAV technology has reportedly reached a certain level of technology maturity, its use in the land administration domain is arguably not widespread (Ho et al., 2019; Stocker et al., 2019). Like other technologies, UAVs go through various stages before they are finally accepted and adopted by society. Since the Hype Cycle reflects on this phase, it is well suited to understand different levels of expectations and visibility in this early yet critical stage (Freeman and Freeland, 2015).

2.3. Gartner’s Hype Cycle

Each year Gartner Inc. publishes Hype Cycles for 100 + technologies to advise firms on market potential and the (predicted) promises of emerging technologies. Aside from innovative technologies, Gartner Inc.’s scope is extended to strategies, standards, management concepts, competencies, and capabilities (Gartner Inc., 2021). The Hype Cycle takes place at an early stage of the technology’s life cycle. As depicted in Fig. 3, the Hype Cycle model proposes five sequential phases: innovation trigger, the peak of inflated expectations, the trough of disillusionment, the slope of enlightenment, and the plateau of productivity (Fig. 3).

(Linden and Fenn, 2003) suggest that the first rise in the hype is triggered by R&D and early investigations with substantial media coverage. The sharp peak of exaggerated expectations is often followed by disappointing early results, causing the hype to collapse into a trough suddenly. Early adoptions fail to meet performance expectations, and adverse media reporting accelerate the decline in expectations, resulting in the trough of disillusionment. After some time, early adopters, who continued to work with the innovative technologies, eventually gain benefits. Investments are needed to push technology performance. Adoption will slowly rise, causing the rate of expectations to recover slowly. Methodologies and best practices evolve, and the technology starts to be socialised. The Hype Curve ends at the plateau of productivity where technology is realistically valued, and adoption exceeds the rate of 20–30% of the potential audience.

3. Methods and material

Grounded in theories that are suitable to derive insights on the technology diffusion process in land administration, this research study followed a pragmatist philosophy (Tashakkori and Teddlie, 1998). As shown in Fig. 4, data collection was guided by the underlying analytical frameworks, including the Hype Cycle model and FELA. Drawing on observations and experiences of experts in the land administration and UAV sector, results unveil a global perspective and best-practice examples. To this end, this research is more explorative than confirmative in nature and envisions how UAV technology in land administration could reach the plateau of productivity. Data on the progression of UAV technology in land administration stems from a qualitative content analysis of interview transcripts from semi-structured expert interviews. The analytical framework and methods for collecting and analysing data are further outlined below.
3.1. Combining the Hype Cycle with FELA

FELA provides an all-encompassing umbrella framework. Justified by its aim to support responsible innovation for effective land administration, this study utilises FELA to set the context in which the diffusion of UAV technology occurs. The strategic pathways guide the analysis aiming to derive insights on how to embrace innovation and institutionalise UAV technology in land administration processes. However, FELA does not account for the temporal aspect of the innovation diffusion, which, as indicated above, revealed to be essential to understand the progression of emerging technologies. Thus, the Hype Cycle and FELA are fused with FELA to determine nine pathways that need to be considered for implementing effective land administration systems and five phases of the Hype Cycle, which add the temporal dimension of the emergence of UAV technology. This results in a two-dimensional matrix with 45 cells (Fig. 5).

As outlined by (UNGGIM, 2020), all FELA pathways need equal attention. At the same time, finding sufficient resources for innovation in land administration systems are an often reported challenge. By adding a temporal dimension to FELA, we are able to differentiate the importance of each pathway during the various stages. For this assessment, a three-level rating scale was developed to reflect on the relative importance of a FELA pathway at a given time: high importance, medium importance, low importance. High importance means that a pathway was reported to play a crucial role in the progression of UAV technology as an innovation in land administration. If this aspect is not being addressed, the advancement of UAV technology might slow down or not progress any further. Medium importance implies that a pathway needs attention but is less essential for the progression at a given time. Low importance indicates that a pathway plays a minor role and is not explicitly crucial. If this pathway is not being addressed, it will only have a marginal impact on the advancement of UAVs in the land administration sector. It is essential to note that the ranking is relative and not meant to be quantified across different pathways. Thus, it cannot be

Fig. 2. Prominent innovation curves plotted together. Source: (Linden and Fenn, 2003).

Fig. 3. Scheme of the Hype Cycle. Source: Gartner Inc. 2018
translated into similar resources, be they financial and human, that need to be put in place for two or more pathways. The authors intentionally kept the scale to three categories to provide a simple relative assessment comparable to the works of (Casiano Flores et al., 2020; Tan, Flores and Crompvoets, 2021). Overall, it is hoped that the nuances can support policy and decision-making processes as they explicitly show which aspects to focus on most at a given time.

3.2. Data sources and analysis

Qualitative empirical data is used to derive insights on the diffusion process of UAVs in the domain of land administration which provides the basis for the three-level scale assessment of the combined Hype Cycle – FELA matrix. A linear sequential approach guided the data collection and analysis phase. From November 2020 to February 2021, the authors conducted nine semi-structured interviews via Zoom with national and international experts considered knowledgeable about the topic being investigated. The criteria for selecting experts were the documented engagement in a project that used UAVs for land administration purposes, with emphasis on technology implementation in ‘real’ practical projects. Data collection was designed to be cross-sectional and included nine experts from the public sector (3), donor organisations (1), not-for-profit organisations (3), and the private sector (2). In general, the expertise of interviewees covered the following country contexts: Bulgaria, Germany, Ghana, Kenya, Korea, Kosovo, Indonesia, Namibia, Nepal, Peru, the Philippines, Rwanda, Senegal, Switzerland, Tanzania, and Vietnam. After some open-ended questions about the involvement in UAV-related projects, more targeted questions followed, covering aspects of all FELA pathways. Here, the use of UAVs in land administration only referred to the generation of base data for subsequent
boundary delineation and adjudication. The interviewees were further asked about characteristics of an environment that would allow increased uptake of UAV technology. Additionally, another question sought to understand the main hindrance factors for scaled implementation, including reflecting past, present and potential future developments. Overall, the interviews took between one to two hours and were recorded after obtaining informed consent.

Data analysis followed the steps of a directed qualitative content analysis of interview transcripts (Hsieh and Shannon, 2005). Key concepts reflected the FELA pathways were used as coding categories (Policy and Legal; Financial; Data; Innovation; Standards; Partnerships; Capacity and Education; Advocacy and Awareness; Governance, Institutions and Accountability). One of the challenges of this method is the inherent bias of the qualitative interpretation and the risk that the researcher finds more data that is supportive rather than non-supportive of a theory. However, this risk is mitigated as the subject of this analysis is not whether a particular view - in this case, the Hype Cycle - is validated but how the respondent reflects on different FELA pathways at a specific time. By following this approach, the authors attempt to maximise the objectivity of the analysis accounting for increased validity and reliability (Potter and Levine-Donnerstein, 1999).

4. Results

The results of this research study are twofold. First, the Hype Cycle curve is analysed based on reflections of the interviewees towards the emergence of UAV technology in land administration. Findings of the past progression, current status and future developments are reported. The second part elaborates on the combined FELA-Hype Cycle model and assesses the importance of FELA pathways during the course of the Hype Cycle.

4.1. Hype Cycle analysis

The majority of land administration experts could relate to various stages and name factors that negatively or positively contribute to technology diffusion in the land administration domain. Undeniably, it requires generalisation to look at this process globally, and various geographical contexts progress at a different speed. Some stages might be more influential than others as economic, governmental, or socio-cultural factors can considerably alter the advancement of technology adoption (Freeman and Freelund, 2015). However, overall, a similar pattern could be observed.

4.1.1. Innovation trigger

The use of UAVs for land administration was triggered by research and development projects between 2013 and 2017, mainly led by research institutions or donor organisations and presented at international conferences (Barnes et al., 2014; Kelm et al., 2014; Barnes and Volkman, 2015; Mumbone et al., 2015; Meha et al., 2016; Koeva et al., 2017). The promotion of technology was heavily surrounded by other alternative concepts promoting aerial images instead of classical field surveys (Lemmen et al., 2015; cf. Enemark, McLaren and Lemmen, 2016). Since UAV technology has not been placed in concurrent land administration processes or organisational contexts, research mainly focused on the development and prototype stage.

As reported by the interviewees, the first pilot projects were initiated to collect aerial data to show the advantages of high-resolution imagery. At this time, most UAV flights did not require extensive flight permission procedures, and study areas covered only a few hectares (Manyoky et al., 2012; e.g. Rijstdijk et al., 2013; Devriendt and Bonne, 2014). However, through media reports in professional magazines and conference presentations, the idea of using UAV technology in land administration started to diffuse among the expert community. Through the spread of its potential impact (Kelm, 2014; Rubinov et al., 2015), UAV technology expectations and visibility have begun to rise towards the second stage of the Hype Cycle.

4.1.2. Peak of inflated expectations

In contrast to the innovation trigger, the time of the peak of inflated expectations is more challenging to define and differs substantially from country to country. Expectations culminate in a peak, and benefits were reported to relate mainly to cm-level accuracy (often rooted in a misconception between accuracy and resolution), unlimited access to technology and widespread application of it. Although technology-wise, these expectations can be satisfied, at least largely; legislative, administrative and institutional settings were not yet ready to allow the full exploitation of UAV technology in land administration at that stage. Throughout the interviews, several aspects were identified concerning problems of implementing UAV technology and contributing to a decline in expectations. First and foremost, pre-mature and prescriptive UAV regulations were mentioned, making it almost impossible for early adopters to enter the market. With the growing UAV industry, more and more concerns arose around public safety and data protection. As a response, countries enacted regulations determining procedures to receive flight approval (Stocker et al., 2017). If UAV regulations are not in place, UAVs are criminalised by default and service providers cannot take the risk of adopting this technology and face challenges in finding capital, insurance and clients. However, most experts look to the future with optimism and see a trend towards risk-based or triage-type UAV regulations, with the new EU regulations as a prominent example for harmonised international UAV regulatory frameworks (European Parliament, 2018; European Commission, 2019).

Second, some interviewees reported on UAV-based mapping services that did not consider accuracy requirements. For most applications, information on survey accuracy and data quality is pivotal for further land administration tasks. However, the complexity of ground truth measurements and the relation between flight configurations and the quality of data output (cf. Stocker et al., 2020) is often underestimated, if at all considered. Particularly in the global South, the ease of flying a UAV by just pressing a few buttons and observing the automatic flight mission creates incentives to adopt the technology by a layperson, at the expense of understanding requirements towards data processing and analysis. Several projects also witnessed technological failures related to the communication link between the ground control station and the UAV or issues with the autopilot, a somewhat typical reality of first-generation products available on the market (Linden and Penn, 2003). Some experts mentioned that, as a consequence, actors in the land administration profession slowly appeared to lose their interest in UAV related data products. Several respondents reported on such bad experiences with UAV technology which spread faster than success stories and led to a bad reputation.

4.1.3. Trough of disillusionment

However, amid the disillusionment and scepticism of stakeholders that feared disruption, some UAV advocates are still trialling and piloting to unveil the realistic potential and show clear limitations of UAV technology for land administration. To realise these pilots, it has been said that UAV regulations need to be appropriate; otherwise, entrepreneurial efforts are halted from the beginning. Workshops by relevant stakeholders, including civil aviation authorities, government agencies, and private sector companies, were reported to support institutionalising adequate UAV-based workflows in a given country context. Ideally, this dialogue unveils the values UAV technology can add to concurrent surveying practices side-by-side of classical aerial photography and ground surveying methods.

2 Appropriate UAV regulations were characterized by three conditions: risk-based, affordable, and timely.
4.1.4. Slope of enlightenment

Cross-sectional advocacy can ultimately pave the way towards policies and standards accommodating and legitimising the use of UAVs in existing land administration procedures. Real-world experiences by a growing number of actors adopting UAV technology can contribute towards a holistic understanding of the technology’s applicability, benefits and risks signifying the beginning of the slope of enlightenment (Linden and Fenn, 2003). Backed by political will and a clear understanding of the value added by the technology, an organically created demand for UAV-based products is likely to push the market to grow. Several interviewees shared the opinion that if the value that UAV technology can add to existing procedures is understood, there will be money for it. This is considered a crucial aspect during this phase because what counts in the end is profitability. The interviewees further outlined that only if the implementation of UAV technology is profitable actors can become self-sustainable and advance from donor-funded projects.

4.1.5. Plateau of productivity

To reach the plateau of productivity, which is characterised by a mainstream adoption (approx. 20–30% of the target audience) and a complete acceptance of the innovative technology, substantial capacity-building efforts, both in UAV piloting and UAV data processing skills alike, are required. Almost all interviewees raised data literacy and data processing capabilities as a condition for increased technology adoption.

Overall, each stage’s characteristics and the perceived conditions to proceed through the Hype Cycle argue for an interplay of top-down and bottom-up strategies, as summarised in Fig. 6. R&D efforts in the first stage by research institutions and donor organisations and piloting by public and private institutions in the third stage are clear bottom-up initiatives trying to advance and advocate UAV technology in the land administration sector. However, the content analysis suggests that if top-down decisions on UAV regulations, land policies, and standards are not in place or in favour of allowing and accelerating the widespread use of UAVs, technology diffusion and adoption is likely to slow down or even stall as indicated by the red circles in Fig. 6.

As already mentioned above, this model is highly generalised, and various countries are likely to proceed at different speeds through this development. However, among the contexts covered during the interviews, a significant difference in innovation diffusion becomes apparent. A few interviewees indicated that they see the county where they worked just at the peak of inflated expectations. In contrast, the majority saw respective countries already sliding into the trough of disillusionment. More economically developed countries, in particular, were assessed to be on the slope of enlightenment. Besides empirical evidence sourcing from expert interviews, various reports have already been published about the status of UAV technology concerning the Hype Cycle. Although they do not focus on land administration applications, this assessment indicates the global evaluation of UAV technology. First and foremost, Gartner Inc. themselves published an extensive report summarising that commercial UAVs are currently sliding into the trough of disillusionment and seem to reach the plateau of productivity only in 5–10 years from now (Gartner Inc, 2019). Opposed to this, Drone Industry Insights (DRONEII) concludes in its yearly report Drone Industry Barometer that the UAV industry is already in the trough of disillusionment (DRONEII, 2019) – a phase to prove the concept with significant pressure to offer viable products.

4.2. The relevance of FELA pathways during the progression of UAV technology in land administration

The importance of the nine pathways of FELA was assessed individually for each of the five stages of the Hype Cycle. This results in a matrix with 45 positions (Fig. 7). Whereas the assessment of the first stages is based on real-world experiences and derived best practices, the assessment of the last stage (the plateau of productivity) is based on future predictions of the interviewed experts. Overall, each focus area shows a slightly different succession of its relevance, moving up and down over time. Some, like innovation obviously, seem to be key on an early stage and reduce in importance later. Some others are rated with the same importance at the beginning and the end but have gone up (like legal or down (like finance) in the middle steps. Standards and capacity appear most relevant towards the end of the Hype Cycle once more actors adopt UAV technology. Almost all pathways, except for innovation, could be equally relevant at the slope of enlightenment, the most crucial phase when it comes to the commercial launch of an innovation. The peculiarities of each of the nine FELA pathways during the five stages of the Hype Cycle are described below. It should be noted that the scope of each pathway follows its definition in the Framework for

![Fig. 6. Reflections on the Hype Cycle of Gartner Inc. A: Assessment of experts on the status of implementing UAV technology in land administration processes. B: Strategies and forces influencing the innovation process, hindrances indicated in red circles.](image-url)
4.2.1. Governance, institutions, and accountability

The pathway concerning Governance, Institutions and Accountability is deemed a cross-cutting issue and fundamental throughout the innovation diffusion process. However, emphasis is put on different aspects at different times. Key actors named during the interviews refer to land administration agencies, civil aviation authorities, donor organisations, private surveying companies, research institutes, UAV consulting companies, grassroots initiatives and UAV vendors. During the innovation trigger phase, the primary responsibility lies with research-oriented institutions (i.e. both R&D organisations or start-ups with an R&D mindset such as Micro Aerial Projects\(^3\)). Afterwards, an incremental process is seen as necessary to adequately support UAV technology/data governance in centralised cadastral agencies, which cannot be achieved without political will and adequate support from administrative instructions. In line with FELA, this can only be realised through strong leadership, tech-advocates and agents of change (public or private), which become particularly important during the trough of disillusionment and the slope of enlightenment, as reported in Ghana and Tanzania. But not only governmental institutions impose particular challenges to the adoption of innovative technology. For example, it was often mentioned that the surveying profession is “a tough nut to crack”, with a lot of vested interest, uncertainties and worries around accuracy.

Experts mentioned two main opportunities in which UAV data can positively impact existing governance and institutional structures and contribute to the FELA goals. First, due to its high spatial and temporal resolution, UAV data can significantly increase the transparency of land administration processes. For example, instead of lines and numbers, UAV data can enrich cadastral maps by adding a detailed base map that allows civil society to participate in the surveying process and substantially improves accessibility, particularly for the poor and vulnerable. Secondly, at the plateau of productivity, UAV data creation and sharing mechanism can break down the silos that often exist between land administration and land management authorities and ultimately strengthen multi-sectoral collaboration.

4.2.2. Legal and policy

Except for the first and last stages of the Hype Cycle, which are assigned with medium importance, Legal and Policy are judged to be of high importance when adopting UAV technology throughout. In this aspect, our assessment includes the legal frameworks surrounding land policies (including land administration) and UAV-specific flight regulations and, thus, extends the scope of FELA for this focus area. During the innovation trigger stage, the relevance was judged to be medium. With targeted R&D projects, donor organisations and research institutions are encouraged to influence policymaking from the very beginning. At the following stages, adequate UAV regulations are considered one of the most necessary pre-conditions for scaled implementation in the land administration sector. All interviewees agree that a risk-based approach is the most favourable option for regulating UAV missions as prescriptive regulations impose substantial entry barriers for innovators and early adopters, as reported from Kenya. In addition, it has to be ensured that UAV regulations are managed by trained staff and that administrative, operational and technical requirements to obtain flight permissions are appropriately communicated to the public. This was experienced in Germany, but not so in Rwanda. Next, and equally important, UAV technology needs to be adopted in land policies as a means to collect spatial data on land. Only if the use and application of UAV technology are legitimised, a market can start to develop. Once the legal foundation is laid with enabling UAV regulations and land policies, the relevance of the focus area Legal and Policy is expected to decrease at the slope of productivity slightly.

4.2.3. Finance

Besides the fact that all experts characterised UAV technology as a low-cost alternative to field surveying and its prominent contribution towards a more cost-efficient land administration system, the pathway Finance plays a crucial role during the innovation and adoption phase. Almost all interviewees mentioned a lack of finance as one of the main impediments to scaled implementation. Particularly expenses related to

\(^3\) https://microaerialprojects.com (accessed on 13.07.2021)
maintenance, import taxes and fees. Typically, R&D activities during the innovation trigger phase are hardly paying off initially and need substantial government investments. Thus, they are rated with high importance. Subsequent stages involve piloting activities financed by donor organisations or venture capital funds of hardware or software companies. Only once expectations are starting to grow again and first adopters implement UAV technology for land administration workflows, the question of sustainable business models arises - a requirement that is also acknowledged in FELA. Without exception, all interviewed experts reported that the projects for land administration purposes alone could not cover all direct and indirect expenses related to hardware, software, maintenance and staff rates. It was further stated that a substantial amount of time is needed to be spent on stakeholder engagement – a service that is typically not paid.

Consequently, private or public institutions offering “drones as a service” (DaaS) are not only serving the surveying and mapping market but also executing orders related to promotion, videography, monitoring, or inspections, among others, as reported from Bulgaria and Germany. However, international experts in particular, predict that after extensive awareness-raising campaigns and further proceeding through the innovation process, at least at the slope of enlightenment, the added value becomes more tangible. Once this is the case, service providers are expected to gain more revenue from mapping and surveying jobs.

4.2.4. Data

When data is the product of innovation, its quality is crucial for its uptake. Throughout all stages of the Hype Cycle, the pathway Data is perceived to be of high importance. Experts reported that the data product triggered excitement at the early stages and supported market development later on. High-resolution aerial photography, digital elevation models, or even 3D point clouds unveil details that were not visible before and allow to map cadastral boundaries on base maps that are more meaningful than satellite or aerial images. Guidelines and best-practice examples need to be developed to ensure that the data meets the requirement set by the land policy, an aspect where standards are becoming equally important. All experts discussed the concept of accuracy and highlighted the opportunities to serve a range of different technical specifications offered by various UAV sensors or ground control strategies.

Moreover, it was mentioned that UAV technology has the ability to empower local stakeholders to collect and own data by themselves by enabling a decentralised data collection strategy that is independent of the central government, as exemplified in Ghana, Tanzania, or Indonesia. High-resolution images were perceived as a game-changer that opened the discussion about land rights to a much wider audience, including marginalised groups and illiterate people. With the opportunity for high spatial and temporal resolution, UAV data can significantly contribute towards the FELA goals calling for reliable data and service quality. Aside from data quality, privacy and data protection concerns need to be accounted for and adopted from global ethical standards pertaining to locational UAV data.

4.2.5. Innovation

The relevance of the pathway Innovation is assessed to be high at the beginning stages and decreases towards the plateau of productivity. Following FELA, most interviewees reflected on technology push and societal pull as driving factors for innovation. In this aspect, the interviewees particularly mentioned the opportunities for process improvement and advancements concerning various sensors that can be deployed at the UAV (LIDAR, Radar, multispectral cameras). By adding UAV technology to the toolbox, the surveyor has yet an additional complementary tool to ensure that his services best fit with the administrative requirements set by the contracting authority. Societal pull calls on the ability of UAV technology to contribute to alternative land administration concepts. In particular, interviewees mentioned the opportunity to bring the data back to the community, or even provide it immediately, and foster a decentralised land administration system.

The growing number of UAV-related sessions during world-leading land conferences such as the Land and Poverty Conference or the FIG Conferences prove the growing importance of innovative UAV-based solutions throughout the last years. Furthermore, recurring expos and events such as the Africa Drone Forum 2020 and the Lake Kivu Challenge, which started in 2020, help mature the Global South’s innovation culture.

4.2.6. Standards

This focus area is a cross-cutting issue and is closely related to Data and Legal and Policy. All experts agreed on the importance of adding UAV technology to existing (surveying) standards to accelerate technology uptake by legitimising its application. Thus, the relevance of the pathway Standards increases once the public and private sectors start to adopt UAV technology towards the slope of enlightenment. Interviewees referred to necessary national standards on processing aerial photography, standards on map production and standards on survey accuracy. For instance, although UAVs are widely used in Indonesia for several years, only recently they have been accepted by the spatial agency to serve as means to collect data for base maps for further land administration processes. Despite the General Data Protection Regulation safeguarding personal data at the European level, no international standard was reported on dealing with the use of UAV data for land administration. Perhaps, this could be a future area for international professional organisations such as the FIG.

4.2.7. Partnerships

As the implementation of UAV technology cuts through multiple actors, the pathway Partnerships were perceived to be important throughout the process. However, particularly during the stages where pilots are set up and the market is expected to develop, the importance of partnerships was rated as high, as demonstrated in Tanzania. At the beginning of the innovation process, partnerships with international organisations and academia facilitating R&D and pilot projects are deemed essential to convey the message: “There is some new technology out there. Here are the options of how to use it here is how to use it safely here are cost implications.”. However, later in the process, Public-Private-Partnerships gain importance to establish an enabling environment where UAVs are offered as a service. Moreover, UAV technology provides a huge opportunity to increase the responsibility of non-governmental actors and to play an active role in current data collection efforts, as reported from Ghana and Namibia. Additionally, regulating bodies such as civil aviation authorities should be engaged with from the beginning. Nepal has shown that this kind of partnership can be particularly valuable to co-create efficient procedures for flight authorisation (Nepal Flying Labs, 2020).

4.2.8. Capacity and education

Capacity development is crucial for creating local innovators and entrepreneurs. Similar to the focus area of Standards, the relevance of Capacity and Education increases over time. For the use of UAV technology in land administration processes, capacity development comprises various aspects. For example, most experts reported that UAV piloting is not an issue due to its simplicity and improved automation. Additionally, the flying capabilities are also covered in national UAV legislation, which typically mandates basic practical and theoretical pilot training. This contrasts with data processing and data literacy, two aspects perceived to be among the main hindrances for scaled implementation. However, most countries that were covered during the interviews recently embedded UAV-related educational courses in existing GIS or surveying curricula which are expected to produce young professionals (e.g. in Bulgaria, Kenya, Kosovo, Nepal). Training courses by established international academic institutions or sophisticated online workshops are seen as an additional opportunity to enhance local knowledge. A key challenge was identified concerning data literacy,
understanding the value of the data and its contribution to land administration processes.

4.2.9. Advocacy and awareness

Similar to the statement in FELA, interviewees showed consensus that the application of UAV technology in land administration cannot flourish without the support and acceptance of stakeholders and society. Once pilot studies are in place and expectations are still declining, awareness-raising campaigns and advocacy become essential and the importance of the pathway Advocacy and Awareness increases. In this context, two main themes were identified as most crucial.

First, awareness-raising campaigns should not focus on the technology but on the value UAV data can add to solve land administration challenges. One of the experts reports that “The problem that I see with drones is like everybody gets super excited and then everybody wants to do it, but nobody asked themselves like what was the end goal here? What are you actually trying to achieve? What is the outcome, not the output?”.

Second, sensitisation and advocacy with the organised profession play an essential role. The majority of interviewees reported the private surveyors or government staff are afraid that somebody will take their jobs or become redundant. If this is not acknowledged during the innovation process, the actors expected to adopt will renounce UAV technology.

5. Discussion

The findings demand reflection on two main aspects relevant in the current debate of technology adoption. First, institutional constraints and opportunities offered by UAV technology to embed change into existing land administration workflows are discussed. The second part elaborates on the applicability of the Hype Cycle and FELA as global frameworks and their relevance for national contexts.

In the past, land reforms and technology innovations were significant drivers of regime change (Jepsen et al., 2015). However, at the same time, institutions oppose this social force with stability and consistency. Thus the relationship between innovation and institutions is often connotated with tension (Ho et al., 2013). Reflecting on the findings, UAV technology offers various opportunities to incept change but is also challenged by rigorous institutional frameworks and vested interest. One central aspect concerns the organisation of land administration activities. UAVs can facilitate local actors with a surveying tool to realise a meaningful engagement of communities and local citizens as an integral part of effective land administration systems. In this vein, the central government or other dominant organisations (e.g. donors) would no longer be the only data provider of high-resolution aerial data, and local communities or agencies can determine the data collection strategy according to their requirements. However, particularly in authoritative countries, this decentralised approach can be resisted by government institutions fearing to lose power and control. Similarly, the increased transparency provided by UAV data related to land use and land management might be an undesired by-product hampering the scaled implementation, particularly in countries with corrupt political institutions. In most countries, the surveying profession is highly standardised, which can be both a challenge and an opportunity. Bounded by surveying regulations and standards that do not include UAV-based procedures, the organised profession has little incentive to deviate from business as usual. As outlined by (Hargadon and Douglas, 2001), entrepreneurs should strive to embed their ideas within the set of prevailing understandings that mark the institutional setting yet contrast their innovations to existing solutions. Best practices by entrepreneurs and technology advocates as well as a clear understanding of the cost and time savings of UAV-based workflows are expected to support the uptake of UAV technology as an additional surveying tool – side by side with traditional equipment such as GNSS, total stations or theodolites.

As reported in the findings, a business model including “drone-as-a-service” seems to be the most likely option for early adopters. In addition, responsibility to incept change should also be carried by donor organisations supporting land-related projects in the Global South. Western donors often contract companies from their own countries to get a job done without investing in domestic markets (Cheney, 2019). Instead, tenders should invigorate local partners to incentivise the development of new market segments at the geographical region of the beneficiary.

The Hype Cycle depicts a typical pattern that arises with each innovation showing typical progress through an evolution of over-enthusiasm and disillusionment followed by eventual productivity. With the assessment of the importance of FELA pathways throughout the Hype Cycle, we depict a generalised pattern that evolved from best practices and expert opinions on future developments (i.e. towards the slope of enlightenment). Our findings do not specifically focus on the country level but rather model context-specific dynamics and requirements in the process to reach the plateau of productivity and ultimately foster increased adoption of UAVs in land administration. Following (Linden and Penn, 2003), innovation profiles may be at different positions in different geographical regions. With UAV technology in general and its implementation in land administration contexts, the findings suggest that national policies and infrastructure fundamentally steer innovation dynamics. The firm reliance on infrastructure and regulations, two aspects that need time to evolve, means that UAVs are instead a long-fuse technology showing a slower adoption (c.f. Linden and Penn, 2003). Depending on these inherently different circumstances from one nation to another, some countries may lag behind, and others might be further ahead. Eventually, some countries might even skip early technology development stages. The latter is also referred to as technology leapfrogging (Davison et al., 2000). For UAV technology, this has been reported for the agricultural and medical sector highlighting examples from the Global South (Cheney, 2019; Radovic, 2019; Haula and Agbozo, 2020). However, it is beyond the scope of this investigation to infer on technology leapfrogging in the context of land administration.

Overall, our generalised assessment does not claim to be the ultimate guide to make UAVs succeed in the domain of land administration. Instead, with the nuanced importance of pathways over the process of technology emergence, FELA can be seen as a set of levers that can be utilised or calibrated differently, at different moments, to support innovation.

6. Conclusion

UAVs are increasingly used to aid mapping endeavours worldwide. However, adoption and implementation in the land administration domain remain low. Embedded in the Hype Cycle and FELA concept, this study analysed the emergence of UAV technology in land administration. It assessed the importance of FELA elements from the initial phase of innovation trigger all the way to the plateau of productivity. Nine experts could elaborate on 16 different country contexts. None of the experts reported that the plateau of productivity was reached already. The majority saw respective countries already sliding into or being at the trough of disillusionment. This presents a phase in which the innovation needs to overcome disappointing expectations, and a market is yet to develop, and adoption starts to rise.

Notwithstanding the importance of all FELA pathways throughout the innovation process, it can be concluded that scaling up the use of UAVs from a niche market to a widespread application in land administration contexts is led by alternating top-down and bottom-up dynamics. Enabling laws and policies and supporting governance, accountability and institutions are crucial to creating such a UAV-friendly national ecosystem early on in the process of technology adoption and allay exaggerated expectations. Once this ecosystem has been made, market demand is expected to surge driven by partnerships, adapted standards, tech advocacy and awareness-raising campaigns.
highlighting the superiority of high-resolution data amongst other benefits of UAV technology. The generalised global perspective reported here sheds new light on the dynamics during the innovation process of UAV technology in land administration. The assessment of the importance of FELA pathways can be used as a baseline to direct strategic decisions concerning national policies and guidelines towards the scaled implementation of UAVs in land administration.

The scope of this study was limited to a generalised assessment of the emergence of UAV technology in land administration. Data from the expert interviews did not suffice to conclude country-specific developments or technology adoption rates. Thus, further research should be undertaken to study the impact of UAVs as disruptive technology on existing land administration workflows in a national context. The trajectory of countries that succeed towards the plateau of productivity and eventually adopt UAV technology for land administration could further be compared to the generalised model presented in this article.

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