Opportunities for UAV mapping to support unplanned settlement upgrading

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***Abstract*—The effort to improve sub-standard living conditions in unplanned settlements is often hindered due to a lack of adequate spatial information describing the baseline situation and changes occurring during and after the upgrading process. Low-cost Unmanned Aerial Vehicles (UAVs) could provide very detailed, up-to-date spatial information for small unplanned areas as and when required. To investigate the utility of such platforms in settlement upgrading, UAV flights were conducted over approximately 150 ha of unplanned settlements in the City of Kigali in May and June 2015. These activities were supplemented by an analysis of the spatial information needs of various stakeholders involved in the upgrading project. The UAV imagery could replace the 2008 25 cm ortho-imagery by up-to-date 3 cm imagery in current workflows for map updating. Moreover, it also enables the extraction of additional information which was previously unavailable, such as detailed elevation data to support surface water runoff analysis and drainage capacity calculations.**

When using UAVs it is also important to take many practical considerations and the societal context into account. The lack of a legislative framework, the requirement for specialized knowledge, and heavy computing requirements of data processing are factors to be addressed when using UAV technologies in this setting. First experiences in Kigali have indicated that while not generally perceived as a problem by the local population, fear of forced displacement and expropriation may raise concerns amongst the residents. Communication with the population before and during flights, and sharing the benefits of the acquired information are important to mitigate these fears.

***Keywords*—Unmanned Aerial Vehicles (UAV), unplanned settlements, housing upgrading projects, spatial information requirements.**

I. INTRODUCTION

Spatial data is considered essential for unplanned settlement upgrading projects (Kohli et al., 2013, Abbott, 2002, Taubenböck and Kraff, 2013). Obtaining an accurate base map of these areas provide a sound basis for designing technical interventions (Paar and Rekittke, 2011, UN-Habitat, 2012), as well as improving the communication between stakeholders (Barry and Rüther, 2005), and empowering local authorities and communities (Abbott, 2003).

Remotely sensed imagery is a key source of spatial information, as it can provide an objective, up-to-date overview of the physical situation in the settlement (Taubenböck and Kraff, 2013). Mason and Fraser (1998) identified seven important roles of satellite imagery for unplanned settlement management: identification of unplanned settlements, identifying changes in the boundaries of these settlements over time, generation of surface data, land use classification, extraction of buildings and other objects for mapping purposes, and reconnaissance. However, small buildings and narrow footpaths characteristic of unplanned settlements may hinder the interpretation of commercial satellite imagery with half-meter resolution (e.g. Kuffer et al., 2014).

UAVs, also known as Unmanned Aerial Systems (UAS) or Remotely Piloted Aircraft Systems (RPAS), are defined as small aircraft operated without an onboard pilot (Nex and Remondino, 2014). Similar to traditional aerial image acquisition, a UAV is mounted with a camera which takes images of a study area as it flies over. The individual images can be stitched together to create a 3D model in the form of a point cloud, as well as obtain a high-resolution Digital Surface Model (DSM) and ortho-mosaic. The ortho-mosaics obtained from the UAV imagery can reach a resolution of a few centimeters (Nebiker et al., 2008). Although this is similar to the resolution which can be obtained by aerial photography, UAVs cost less and are more flexible in acquiring data (Nex and Remondino, 2014). As such, this possibility of obtaining high-resolution spatial data in a relatively cheap and dynamic manner could be a practical approach to fill the information gap in unplanned settlement upgrading projects.

However, for a UAV to be useful for unplanned settlement mapping, the workflow must not only meet the technical requirements of the user, but the new technology must fit into the local context (Pannell et al., 2011). It is therefore important to analyze the spatial information requirements of the potential end-users as well as the social context. The main users of UAVs for unplanned settlement mapping are likely to be governmental institutions. Unfortunately, studies from cities in six different developing countries indicated that spatial data collection and products are often restrained to experts in the governing body and private sectors and that data sharing is limited (Baud et al., 2014). Dependency on spatial technology may therefore increase social exclusion (Pfeffer et al., 2013). It is important to analyze how the benefits of the UAV imagery may not only serve the governing bodies, but also how they may be distributed amongst stakeholders such as the local population.

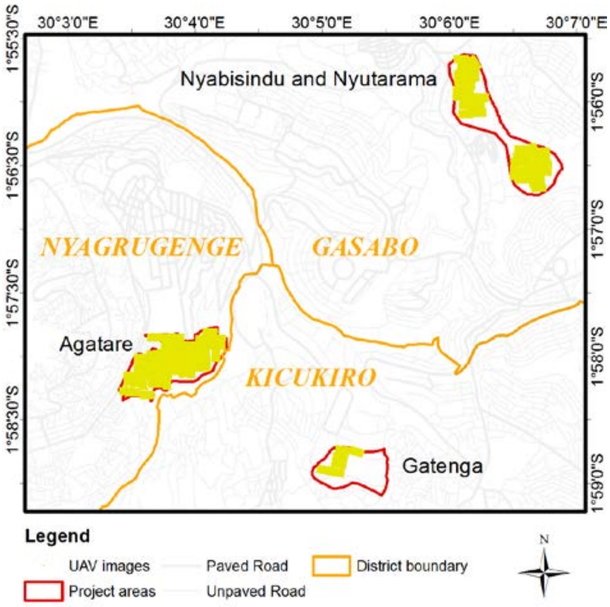
The objective of this paper is to analyze the potential of UAVs to support unplanned settlement upgrading projects, identify the first perceptions of various stakeholders, and to identify important factors which should be taken into account for the diffusion of this technology and its benefits amongst stakeholders. It is based on the results of UAV image acquisition in the context of upgrading projects in the City of Kigali, Rwanda in May/June, 2015. First, this paper provides an overview of the context of the case study, the background of upgrading projects in Kigali, Rwanda, the upgrading project in question, and the activities carried out with a UAV in the area. Second, the spatial data requirements of upgrading projects are analyzed, and specific points are analyzed where a UAV could be of added value. Third, the practical considerations and social context are analyzed. Finally, a discussion leads to the identification of key factors which should be taken into account to support the diffusion of UAVs and their related information extraction techniques, for unplanned settlement upgrading.

II. Study Area

In 2000, the Government of Rwanda established the Rwanda Vision 2020 (Rwanda, 2000). Kigali played a key role in this plan, which aimed to modernize the city and transform it into an important global city. A Conceptual Master Plan for the City of Kigali was developed in 2007 and updated by a detailed Kigali City Master Plan (KCMP) in 2013. In this plan, some unplanned settlements must be moved to make space for business districts, while others should be improved to meet the Kigali City Master Plan guidelines. A partnership was formed between the Rwanda Housing Authority (RHA), Affordable Housing Unit of the City of Kigali One Stop Center (CoK-OSC), and the Nyarugenge District One Stop Centers to conduct an upgrading project in Nyarugenge District. It is a pilot project which aims to not only identify infrastructure improvements in the area, but also to develop successful strategies for participatory engagement and designing slum upgrading projects in Kigali and the Secondary Cities of Rwanda. The study area covers parts of Agatare, Rwampara, Biryogo and Kiyovu cells of the Nyarugenge District in Kigali. The project targets issues including: storm water drainage, sewerage, drinking water supply, roads, electricity and public lighting, and housing improvement.

The project area is roughly 86 ha in size, with an estimated 3,977 households and 18,914 individuals (GISTech Consultants LTD, 2015). The houses are generally made of mud and wood with corrugated iron roofs. A few localized improvements have previously been made regarding access and drainage, but the current project aims to provide a more comprehensive improvement. The project started on in December 2014 and the detailed design and cost plans were provided at the end of June, 2015.

Figure 1: The project areas covered by UAV flights over the three districts of Kigali in May 2015.



In May 2015, a number of UAV flights were conducted by the University of Twente – Faculty ITC with the support of City of Kigali – One Stop Center (CoK-OSC), the Rwanda Civil Aviation Authority (RCAA), and village representatives. The UAV was a DJI Phantom 2 Vision+ quadrocopter with a 14 Megapixel RGB camera with a fish-eye lens (FOV = 110°). Eighty-nine flights were made in total, taking more than 15,000 images to cover approximately 150 ha of unplanned settlements (Figure 1). Examples of some derived products, the dense point cloud and ortho-image, are given in Figures 2 and 3 respectively.

Interviews were also conducted with both institutional and local stakeholders to identify important spatial information requirements for the upgrading projects, the perceived use of UAV for these activities, and to assess the attitudes of the local population towards the usage of UAV.

III. GIS requirements for upgrading projects

As it was a pilot upgrading project, there is not yet a well-established methodology regarding spatial data norms for upgrading projects in the City of Kigali. The spatial data requirements were therefore not clearly defined at the start of the project. Rather, they were based on the recommendations of a World Bank consultant (Banes, 2015), and were further specified in an interactive manner during the project execution by the contracting authorities (RHA, CoK-OSC, Nyarugenge District) and consultants. Table 1 lists the spatial data collected by the consultants, which could be equated to the current spatial data requirements. The spatial information was mainly either: (i) provided by authorities, (ii) digitized from the 2008 ortho-imagery, or (iii) collected in field with a GPS. The collection of the spatial information was supported by

TABLE 1: SPATIAL INFORMATION COLLECTED BY GIS CONSULTANTS FOR THE NYARUGENGE DISTRICT UPGRADING PROJECT

Spatial Layer	Source
Aerial imagery / Elevation	A 25 cm orthophoto from 2008 and DTM points at 10 m intervals provided by Rwanda Natural Resources Authority (RNRA)
Building Footprints	Footprints were digitized from satellite imagery and roof material was obtained by sampled questionnaires with the support of Rapid Planning,
Roads (type and material)	Digitized from satellite imagery, GPS in field
Drainage	Digitized from satellite imagery, GPS in field
Power lines	Provided by the power company, GPS in field
Water pipelines	Provided by the water utility company
Land use	Digitized from aerial photos, field survey
Services	GPS in field
Parcels	Provided by RNRA
Administrative boundaries	Provided by National Institute of Statistics Rwanda (NISR)

Figure 3: Sample of the 3D model (mesh) obtained from the UAV data over the Nyarugenge project area.

Rapid Planning, a project supported by the German Federal Ministry for Education and Research and UN-Habitat to develop a trans-sectoral urban infrastructure planning methodology, for which Kigali is one of the three case cities (Rapid Planning Consortium, 2015).

The imagery obtained from UAVs could be used to replace satellite imagery in the existing spatial data workflows of the upgrading project. In this way, rather than relying on an ortho-photo from 2008 with a 25 cm resolution, an up-to-date ortho-mosaic with a resolution of a few centimeters could be used to digitize the objects of interest. This was perceived by the consultants to be a large benefit for the existing workflow by reducing the time and cost of subsequent field verification.

However, the UAV information products also open a gateway to obtaining additional information regarding the area. For example, the drainage in the Agatare project area

Figure 2: Sample of the ortho-image obtained from the UAV data over the Nyarugenge project area.

was mapped by GPS points in-field and measuring the width of the drain at regular intervals. Using the Digital Terrain Model (DTM) extracted from UAV imagery, the drainage capacity could be calculated more accurately (though still concealed in some areas by trees etc.), facilitating the design of more adequate interventions. Attributes of each individual building, such as size and roof material and condition could also be extracted to help monitor the implementation of the KCMP. Other perceived uses of the UAV imagery mentioned by institutional stakeholders include: visualization, valuation for tax collection purposes, and inspection for the monitoring of illegal construction.

IV. Utility of UAV for upgrading projects

A. *Practical considerations*

Although, from a scientific perspective, UAVs seem like a promising method for spatial data collection, there are also practical limitations regarding legislation, flight execution, data processing, and specialized knowledge. Flight permission falls under the domain of the Rwanda Civil Aviation Authority (RCAA). Although there is currently no legislation regarding the use of UAVs within the country, the RCAA has noticed UAV activities and expresses concerns similar to those exhibited by Civil Aviation Authorities around the world. There are three main concerns: safety of the flight operations, security of the data collected, and privacy of the tenants of land being flown over. The lack of legislation, in Rwanda as well as many other countries, makes it complicated to obtain flight permission which affects the reliability of UAV as a data collection instrument.

The technological characteristics of the UAV platform also affect the utility of UAVs as a data acquisition platform. Firstly, imagery cannot be acquired during rainy or windy weather conditions. Secondly, the range of the platform limits the extent of area covered per flight, and requires the take-off location to be close to the flight area. This may be difficult in unplanned settlements, where dense construction, narrow footpaths and overhanging power lines or vegetation make it difficult to find adequate take-off locations and which may slow down data acquisition.

Back in the office, there are also practical challenges to obtain the required information from the raw UAV images. Firstly, from a data quality perspective, a high image overlap, or redundancy, increases the quality of the 3D model. However, the large number of images may also incur data storage problems (Baiocchi et al., 2014). Furthermore, processing the imagery currently requires specialized software and advanced hardware requirements.

B. Social considerations

Such practical problems of obtaining permission, flight operation and data processing may be overcome. However, they overlook one of the most important stakeholders involved in UAV data acquisition – the inhabitants of the settlements being flown over and their privacy. Based on the experiences of flying the UAV in Kigali, the first observation was the interest of the inhabitants during the flights. Many people were curious, crowding around to watch the flights, taking pictures and asking questions. However, a number of people were also concerned. Most concerns were based on the fear that the UAV was being used to survey the area and plan for expropriation. An effort was made to mitigate these fears by answering questions and explaining the purpose of the activities during the flight acquisition. Furthermore, the village leaders were notified about the flight activities beforehand so they could communicate this to the local population and mitigate concerns.

The utility of UAV data products, in the form of printed images, for the local residents was also analyzed through interviews. When shown some sample UAV images, a number of residents ‘recognized’ the images from previous land administration activities or the activities of the consultants involved in the Agatare project. Others indicated that it was very important to provide the users with some kind of training or explanation regarding how to interpret the images.

The images were mainly considered to be useful for the village leaders. The general population mentioned uses such as giving a friend directions how to find their house, or as a memory to show their grandchildren how the neighborhood used to look like. Others mentioned that you could compare your house to your neighbor’s house. This was also the most recurring theme in the utility of the images for village leaders. The UAV imagery was considered to be useful to identify which aspects (e.g. house typology) needed to be changed in order to comply with the KCMP. Village leaders also mentioned that they could use the images to help explain the government plans to the population.

V. Discussion

Although there is a great enthusiasm regarding the detail of the imagery obtained from a UAV, practical aspects must be taken into account to determine which applications could maximally benefit from the UAV imagery. In the case of upgrading projects, the size of project areas and required level of detail appear to make it suitable for UAV image acquisition. However, the limited extent covered by the current UAV platform makes it less suitable for tasks which require covering large areas in a limited amount of time. Such applications could consider obtaining a UAV platform more suitable for the task in question, or smart sampling strategies.

The potential use of the DSM obtained from the imagery should also be further investigated. Comparing the quality of DSMs extracted from UAV imagery to traditional surveying methods are a hot topic of research (e.g. Harwin and Lucieer, 2012, Haarbrink and Eisenbeiss, 2008). If the quality is sufficient, it could provide an enormous benefit to the upgrading project in the terms of surface water drainage analyses and the detailed design of infrastructure.

The utility and adoption of UAVs in this context is limited by external factors. There is no definite legislation due to the recent emergence of this technology, causing difficulties and ambiguities regarding flight permission and may make it difficult to rely on UAVs for data collection. To resolve this issue, it is important to develop clear policies, guidelines and standards regarding flight regulations. The UAV pilots should operate safely and in compliance with these standards to help establish trust and transparency between the various parties. This could ensure UAV users have the freedom to conduct flights and extract high-quality information to support urban planning activities, while guaranteeing responsible flights and respecting public safety.

VI. Conclusions and recommendations

To conclude, a UAV has the potential to be a valuable tool in spatial information acquisition for urban upgrading projects. The provision of highly-accurate and up-to-date information allows for the mapping of the current situation in the area, including the identification of buildings, roads, land use, drainage, and other points of interest which are vital for upgrading projects. The increased detail of the UAV imagery versus conventional satellite (or aerial) imagery may save time in field verification. UAV data products also have the potential to provide spatial information to the upgrading project which isn’t available through conventional techniques, such as providing high-resolution elevation information for detailed drainage calculations and design of implementation measures. Further analysis should investigate methods to obtain useful spatial information from the data, which fit the needs of the stakeholders while taking local constraints into account.

The practical aspects of UAV data collection must be contemplated when considering the adoption of UAVs as a data acquisition platform. It is therefore recommended to take the societal context into account when considering the implementation of UAVs. Communication with aviation agencies should create a setting which allows UAV pilots to operate easily when operating safely. An effort should be made to communicate the purpose of UAV image acquisition to the local population, as well as methods to share the benefits of the information obtained through the flights.

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