New geo-tools for urban studies

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ABSTRACT: One of the biggest challenges in urban research is to obtain spatial data with high enough spatial and temporal resolution. New tools based on mobile devices, Unmanned Aerial Vehicles (UAVs) and Web services allow the creations of platforms for collecting georeferenced information to study the complexity and dynamism of urban environments with a resolution, cost and frequency hardly reachable with traditional techniques. This paper presents methods and results obtained within the research group LlactaLAB – Sustainable Cities using three of these tools for three cases. The first case presents the use of low-cost UAVs to produce 2D and 3D geographical information to study urban morphology and visual integration. The second case shows the application of mobile devices to collect data to analyse spatial behaviour of people on public spaces. Finally, the third case explains the use of Google Street View to produce land use information for urban analysis. These cases demonstrate the advantages of such tools in terms of time, effort and cost for producing information for urban studies. Some limitations and lessons learned are also reported.

Keywords *Public space, spatial behaviour, UAVs, Mobile data collection, GIS.*

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1. INTRODUCTION

There is a growing interest for studying the relation between the built environment and people's behaviour. A key aspect in urban studies is the urban form as a physical consequence of the interaction between inhabitants and their environment in a constant transformation process. Many aspects of the city's reality can be read and understood by studying their physical confirmation (Moudon, 1997). Likewise, it is important to understand the degree to which the physical setting affects human behaviour and how the built environment may promote community–building. Public and collective spaces enable social interactions, which are crucial to maintain community cohesion and social capital (Ngesan et al., 2012). Architects and designers face several challenges when it comes to create new urban spaces, especially when there is no empirical base over which to make design choices (Forsyth, 2007; Frick, 2007). In order to design, build and transform public space, it is useful and appropriate studying life in the city, observing and understanding its inhabitant's activities and behaviour, and use this knowledge to improve design practices to promote high quality urban life (Gehl, 2010).

This kind of research requires detailed geospatial information with a space and time coverage high enough to capture the heterogeneity and dynamism of the urban system. This challenge was extremely hard to face until a few years ago due to the scarcity of data sources, the elevated cost to obtain them, and a relatively limited access to specialized tools. However, during the last decade we have witnessed the creation of a plethora of platforms, techniques and tools for spatial data analysis, allowing researchers to obtain and analyse information with a spatial and temporal resolution unimaginable until a few years ago at a relatively low cost. These new opportunities emerged thanks, in part, to the explosive popularisation of mobile devices with geo-positioning capacity along with a growing access to information and communication technologies, including smartphones with integrated sensors and geo-positioning devices, Unmanned Aerial Vehicles (UAV) and collaborative on-line platforms, among others.

Although many of these tools and techniques existed for several years, its use and mastering has not been widely generalized among research groups in urban studies yet, or it has been limited to groups staffed with trained experts experienced in geographical information systems and sciences. This is especially true in emergent countries, where the adoption of new technologies is delayed in relation to high-developed economies. However, this delay is progressively reducing (Pew Research Center, 2014), which reaffirms the need of reviewing the potential of these techniques for urban research.

This paper aims to report the experiences, challenges and lessons learned while using and implementing new tools for obtaining and analysing geospatial data by LlactaLAB – Sustainable Cities research group. We expect that sharing our experience enable other researchers to consider and evaluate the suitability of these new technologies for their own research processes, and that the lessons we learn and the limitations we found allow other groups to overcome obstacles more quickly.

The remaining of this paper is structured as follows: Section 2 explains three selected techniques to produce geo-information about urban environment based on new technologies. Section 3 exposes three cases where the methodologies have been applied to

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study spatial behaviour of people and its relation with the built environment, and presents the advantages and disadvantages of the applied methodology or technique. Finally, Section 4, provides conclusions lessons learned.

2. NEW TECHNIQUES AND TOOLS FOR URBAN STUDIES

During the last few years, the amount and diversity of techniques for producing information about the city has grown exponentially. In this section, three techniques based on new technologies are described to collect geospatial data and produce information about human spatial behaviour and built environment: a) Mobile platforms to collect georeferenced field data; b) UAV systems to produce 2D and 3D urban geo-data; c) On-line photography platforms as an information source about urban land use.

2.1 Geo-information with mobile devices

The collection of geospatial information about built environment is the base of urban studies. Traditionally, paper–based forms and sketch drawings were used to collect data in the field that were later digitalized and processed using computers. This approach implied huge logistical efforts and problems with quality, geographical precision and data integration were quite common. Nowadays, data collection can be easily automated and improved by using mobile devices such as smart phones and tablets, whose flexibility and connectivity make them powerful research tools for both professional studies and citizens' science initiatives (Kim et al., 2013).

In the last few years, a number of data collection systems and apps for mobile devices have been generated, with a wide range of characteristics and potential uses. Amongst them are those dedicated to gather information through digital forms, which are later aggregated to a centralized database, such as *EpiCollect* (Aanensen et al., 2009), *OpenDataKit - ODK* (Hartung et al., 2010) and *KoBoToolbox* (Pham et al., 2016). There are also specialized apps oriented to GIS applications such as *ArcGIS Mobile* (ESRI, 2016) or *QField*, a mobile version of the popular open source system QGIS (OpenGIS.ch, 2016).

Browning (2011) performed an analysis of alternatives for mobile data collection, concluding that Android's platform ODK presents advantages over other apps. ODK has three components: *ODK Build*, an on-line application to design digital form templates that support several data types, including multimedia and geolocation; *ODK Collect*, the Android mobile client application to collect information; and *ODK Aggregate*, the server component to manage blank forms and add data coming from *ODK Collect* (Jeffrey-Coker et al., 2010).

2.2 UAV Systems to produce 2D and 3D geo-information

The explosive development and popularization of low-cost Unmanned Aerial Vehicles (UAVs) allows to capture aerial photographs economically and flexibly. These photographs, combined with new digital image analysis algorithms, present a new opportunity for 2D and 3D geo-information production, at a very low cost compared to traditional techniques (Nex & Remondino, 2014; Remondino et al., 2011). The general process of geo-information production from aerial imagery implies five main phases*: a) planning, b) data capturing, c) processing* and *d) exportation and analysis*. The main products include three-dimensional point clouds, Digital Surface Models (DSMs), land use and land coverage maps, volumetric models, amongst others.

UAV photogrammetry allows diverse applications for urban studies, like vegetation mapping in urban landscape (Feng et al., 2015), automated detection of the main components of the urban environment (buildings, streets, trees, cars, grass and water) (Zhang et al., 2015) or monitoring and evaluating damage produces by natural catastrophes (Candigliota et al., 2012).

2.3 On–line platforms for geo–referenced photographs.

Web services that provide street-level georeferenced photographs have existed for several years. These services allow users to explore places from a computer's screen and to extract metadata to generate spatial and temporal information in ways that were not possible before (Zheng et al., 2011). The most outstanding example is Google Street View (GSV), which gathers pictures with a specialized equipment, compound by a set of cameras with a sensor system that generate omnidirectional panoramic images, referenced to a geographical location. The cameras can be set over motorized vehicles, bikes or backpacks, which has allowed Google to generate images of cities and rural areas in all the six continents and make them available to the general public through on-line maps and digital globes (Anguelov et al., 2010). This platform provides an immersive experience, enabling the user to explore in detail the characteristics of geographical settings. Another platform dedicated to Street-level georeferenced photographs is Mapillary, which uses a crowdsourcing strategy, providing users with a mobile application to collaborate with their photographs to the platform. Mapillary authorizes the use of images under open license, making it easier to use their information for several purposes, while Google Street View has a much more restrictive license, provoking frustrations in many users (Neubauer, 2015).

The potential of these platforms as an information source for researchers about urban environment is of great interest. For example, Kelly et al., (2013) used Google Street View for assessing elements of the built environment, like land use, streets and sidewalks characteristics and public transport infrastructure. The authors used the PABAK (*Prevalence – Adjusted Bias – Adjusted Kappa*) index to evaluate the reliability of the method, and found that a 95% of the analysed items had a "substantial" or "almost perfect" matching degree, with certain variations of reliability between them.

3. APPLICATIONS

The applicability of the mentioned tools and techniques has been explored in the context of the research project "*Urban design as a resilient cities construction tool. Uses, perceptions and possibilities in the margins of Tomebamba River in the city of Cuenca – RIOURBANO*". This project aims to understand the relation between urban environment and uses, perceptions and human behaviour in the Tomebamba river banks, in Cuenca, Ecuador. For this purpose, five zones have been defined for analysis (Figure 1). The objectives of the project require the detailed collection of different features of the urban setting, from which three have been selected to examine the application of the techniques explained in section 2. These features are: a) land use, b) human spatial behaviour and c) spatial morphology. In the following paragraphs the applied techniques, results and lessons learned are explained for each of the three mentioned features.

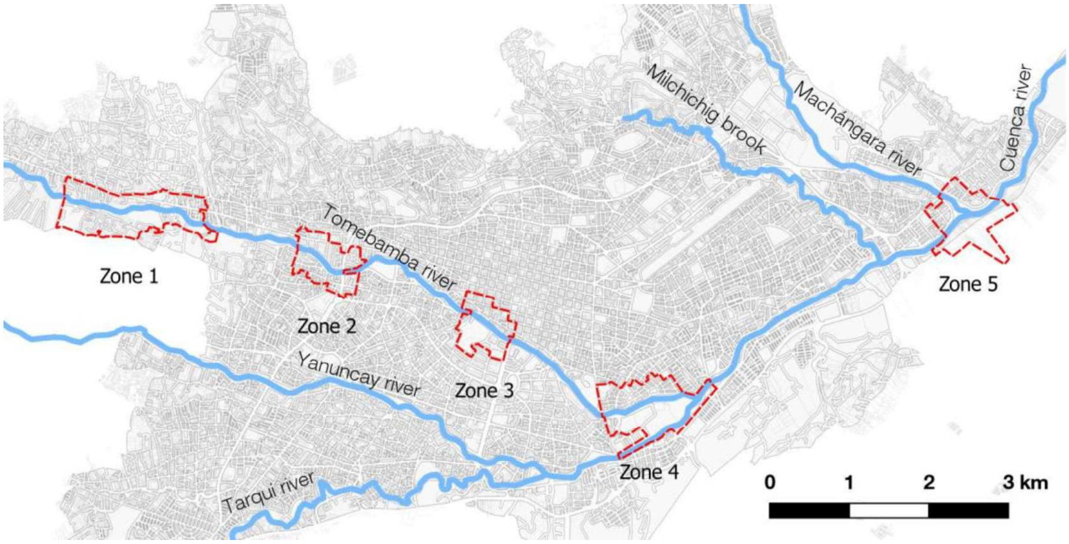

Figure 1. Study area with five zones for data collection in the Tomebamba river banks. Cuenca, Ecuador.

3.1 Land use analysis at parcel scale

Studying land use's diversity and complexity is key to build urban sustainability indicators, intervention criteria and to improve public space design (Hermida et al., 2015).

As a part of the project RIOURBANO a characterization of urban land use was made at a parcel scale. In the first stage, a team of 22 students collected land-use information using ODK Collect in mobile devices. 1922 parcels were registered in 1122 working hours, covering Zone 3 of the study area (Figure 1). The data were uploaded in ODK Aggregate and validated in terms of precision and completeness for an aleatory sample of 55 parcels. Processing and validating data took 20 working hours. In the second stage, a group of 5 students characterized 1753 parcels using Google Street View and registering the data directly in a Geographical Information System. This required a total of 75 working hours. Although geographical coverage of Google Street View images is wide for most of the study area, there are spots with no coverage. Thus, a third stage of field work was necessary in order to register 671 remaining parcels using ODK Collect with a simplified and optimized form. The third stage took 70 working hours to collect data and 40 hours to process and validate them. In total, 4346 parcels were characterized in 1955 hours, with and average efficiency of 2.22 parcels per hour (Table 1). This experience's results show that characterizing parcels with Google Street View is more efficient, reaching an efficiency of 23.37 parcels per hour. Data collecting with ODK was less efficient, but it is still viable as long as the form is well designed and user friendly.

During this process, some difficulties have been identified. As for using ODK, students reported feeling insecure and in danger of robbery at some places when using their mobile devices in plain sight for data collection. For this reason, it was decided to make teams of 2

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people, duplicating the effort in data collection. Also, digital forms with too many options in multiple choice items were difficult to manage. Thus, it is recommended to use assisted free text options or search boxes. As for Google Street View, the main limitation is geographical coverage, that reached 72% of parcels in this study. Also, the date when images were taken might represent a potential limitation, although this was not the case. Finally, some images present obstacles that impede adequate characterization. These problems have been previously identified by other authors (Kelly et al., 2013).

Table 1. Efficiency in characterizing parcels by using ODK and Google Street View

Stage	Method	Time (hours)	Parcels (#)	Efficiency (parcels/ hour)
1	ODK	1142	1922	1.68
2	GSV	75	1753	23.37
3	ODK	110	671	6.10

3.2 Spatial behaviour in Tomebamba river banks.

RIOURBANO research project aims to build an analytical framework to define urban design criteria for river margins. Such framework should incorporate new perspectives based on users' behaviour and perception to reinforce the public dimension of the contemporary city.

For this end, users' behaviour in the study area was registered in detail. Each zone was divided in 100m sections. On each section, the location of each person was registered on a paper map, and demographic characteristics, behaviour and activities were collected in a digital form using ODK Collect. Both datasets were later joined using an ID code. 2750 standing people and 5588 pedestrians were registered in the study area. Activities were classified according to their function as *recreational*, *productive* or *quotidian*. This allowed to perform comparative analysis for zones, age groups, and gender groups (Figure 2).

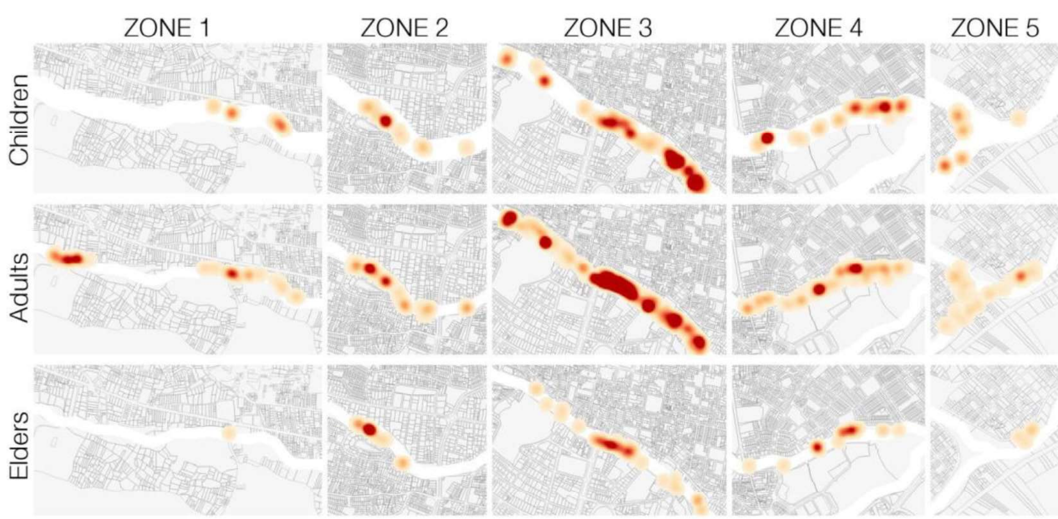

Figure 2. Intensity of use of river margins by age group.

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Results showed that all zones have few users under the age of 15 or above 60. Despite all zones showed similar patterns, the ones closer to residential areas had more presence of children and elders, while the absence of these groups is related to areas with accessibility barriers and lack of infrastructure. There are also differences in activity types between zones. Zones 4 and 5 present a predominance of leisure and recreational activities, while in Zone 1 productive activities are more frequent. Finally, Zone 3 has a larger concertation of people performing quotidian activities. Gender differences are also evident in terms of space use, especially close to peri-urban areas, where public space quality is inferior.

The applied technique presents a series of advantages compared to conventional procedures. Firstly, the combination of digital and paper-based collection produced detailed spatial data on the relation between users and environment configuration, making correlational analysis possible. Processing time was minimal, because it was necessary to digitalize points drawn on paper and join them to the base generated with ODK. However, the time to verify and fix collection errors was considerable. The most common errors were inconsistencies in the number of records between the digital form and paper maps, incomplete records, and wrong values in date and time fields. Paper records presented some lack of location precision, which varies according to the observer's experience. More precise data might be obtained by using mobile devices GPS, but practical difficulties must be considered, since the observer would have to take the GPS near the observed person, disturbing her privacy (Golicknik & Ward Thompson, 2010).

3.3 Urban morphology in Tomebamba river banks

One of the goals of RIOURBANO research project is to assess urban morphological characteristics of river banks and adjacent areas in order to produce guidelines public space quality improvement using a *Research by Design* approach.

For this purpose, aerial imagery was captured using low-cost equipment. The platform configuration included a DJI Phantom II quadcopter, assembled with a GoPro Hero Black 3 camera and a Q-StarZ 1300 GPS for image positioning. Six flights were conducted to capture imagery for the study area. Images of each flight were processed separately, following a semi-automated workflow using Agisoft's software PhotoScan. Resulting products were point clouds, three-dimensional meshes, digital elevation models in raster format and Orto-mosaics. Additionally, point clouds were classified in four categories (ground, vegetation, buildings and water) to produce digital terrain models (DTM) and digital surface models (DSM). These models were later used to calculate building and vegetation volume and to analyse visual integration.

A surface of 820,312m2 was mapped with an average pixel resolution of 0.5m. Volume analysis showed a 4:1 relation between vegetation (492,441m3) and buildings (125,127m3). Average compactness (relation between built volume and surface) in the area is 0.15 m3/m2. Visual integration analysis from 34 points of observation showed that 15.9% of the study area can be seen from these points, while visual connectivity to a reference line on the opposite bank are have 10.4m of average length. The most visually integrated points are on the eastern side of the analysed area (Figure 3).

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Aerial photogrammetry with low-cost UAVs proved to be an economic, viable and effective technique for producing information on urban morphology. Platform's versatility and ease of use (DJI Phantom II quadcopter) allowed good operation flexibility. Integration of location data from GPS to individual pictures was successful but cumbersome, so we recommend to use low-weight, GPS-enabled cameras that are able to save geographical coordinates directly to picture's EXIF metadata.

The main limitation for low-cost UAV photogrammetry is linked to the relation between the surveying area, flight time (determined by battery duration) and the desired resolution of final products. Therefore, a multirotor UAV is suitable for small areas with good visibility and where landing tracks are unavailable. However, for larger surfaces fixed wing UAV are recommended, as they allow longer flight times and higher altitudes, although they are more expensive and complex to operate. Weather is another limitation for UAV operation, since they must be only used under good weather conditions and without electromagnetic interference that could degrade remote control signal and on–board sensors. Also, geographical and geometrical accuracy of final products is severely affected by GPS precision, and therefore adding ground control points with a differential GPS is recommended to obtain high precision products. Lastly, security and privacy, as well as national and local legislation must be taken into account. Legal status of UAVs operation varies in different countries, and is changing and evolving, which implies serious limitations in some places.

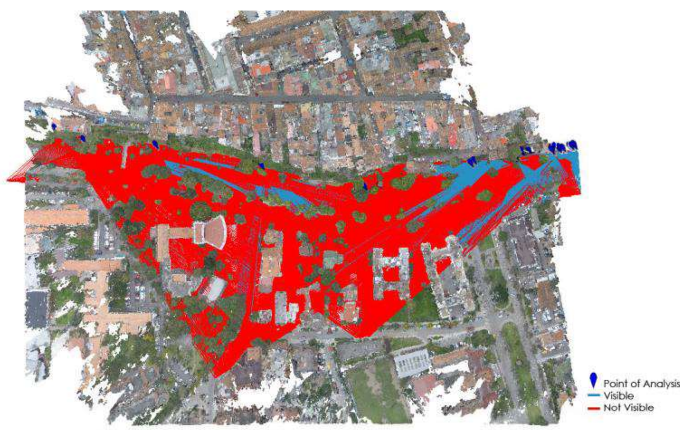

Figure 3. Visual connection for project's Zone 3.

4. CONCLUSIONS

This paper presented three new technologies applied to urban studies, specifically related to built environment and human spatial behaviour. The presented techniques include georeferenced field data collection with mobile devices, information derivation from on-line georeferenced photography, and cartographic surveying with unmanned aerial vehicles. These techniques were applied in the context of a research project about use, perception and behaviour at Tomebamba river banks in Cuenca, Ecuador. The techniques proved to be effective to produce detailed information on land use at parcel level, human spatial behaviour and urban environment's morphological characteristics.

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Our experience indicates that these techniques improve information production's efficiency when compared with traditional methods, since data collection is performed directly on digital support with geo-referencing capacities, integrating geographical position directly and, at times, replacing field visits and avoiding digitalization errors. These features reduced cost and time for data collection and pre-processing and are accessible to non–specialized users with only basic training.

Nonetheless, the techniques have limitations. In one hand, even when they are sufficiently intuitive and easy to operate, some of them might require more experience and qualification to exploit their whole potential and to avoid implementation problems. On the other hand, legislation for UAV use is highly variable and unstable in different countries, which makes difficult and sometimes impossible to implement this technology. Finally, as for using Google Street View, the main limitations are their restrictive license, geographical coverage and the rate of photographs updating. Is at this point where platforms as Mapillary can be used as a proper complement.

It is of our interest that our experience and the lessons we learnt with these techniques are useful for other researchers, who might share their experiences as well, enriching the toolbox for urban research.

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