

REMOTE SENSING FROM UNMANNED AERIAL VEHICLES FOR 3D URBAN MODELLING: CASE STUDY OF LOULÉ, PORTUGAL

José António Tenedório

Professor at Faculdade de Ciências Sociais e Humanas, Universidade NOVA de Lisboa | Centro Interdisciplinar de Ciências Sociais CICS.NOVA - Faculdade de Ciências Sociais e Humanas - Universidade NOVA de Lisboa (CICS.NOVA.FCSH/UNL), Portugal

Avenida de Berna, 26 C, Lisboa, 1069-061, Portugal

ja.tenedorio@fcsch.unl.pt

+351 966110536

Rossana Estanqueiro

Professor at Faculdade de Ciências Sociais e Humanas, Universidade NOVA de Lisboa | Centro Interdisciplinar de Ciências Sociais CICS.NOVA - Faculdade de Ciências Sociais e Humanas - Universidade NOVA de Lisboa (CICS.NOVA.FCSH/UNL), Portugal

Avenida de Berna, 26 C, Lisboa, 1069-061, Portugal

rossana.estanqueiro@fcsch.unl.pt

+351 967090695

Ana Matos Lima

GIS Coordinator at Planning, Geographical Information and Cadastre Division

Municipal Council of Loulé

Praça da República, 8104-001 Loulé

ana.matoslima@cm-loule.pt

+351 966850623

João Marques

Geodrone

Postal Address: Rua Palmira Bastos, n7, Almada, 2810-268, Portugal

geral@geodrone.pt

+351 912616502

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Abstract

Data acquisition using Unmanned Aerial Vehicles (UAVs) is currently a fast and low-cost Remote Sensing approach. UAVs have become standard platforms for applications in photogrammetric data capture. This capture is still only feasible for small areas, around dozens of hectares. In view of our description, we can say that the data obtained using UAVs are useful for 3D urban modelling, i.e., buildings and urban areas, with a view to support large scale urbanism and urban planning studies.

The data were gathered from RGB UAV imagery at a height of 100 meters covering the city centre of Loulé, Portugal. To conduct the UAV survey the following steps were followed from data acquisition through processing 3D urban models: a) establishing flight plan parameters (height, overlapping, time, focal distance, camera data, spatial resolution) and collecting data survey (regarding preparation

aspects such as safety, interferences, and calibration); b) loading photos; inspecting loaded images and removing unnecessary images; c) aligning photos; d) building dense point clouds; e) building a mesh; building a 3D polygonal model; f) texturing the 3D model; g) calculating DEM and DTM; h) creating an orthoimage; and i) exporting results. After processing the data, we arrived at two highly accurate 3D urban models. Taking these results into consideration, we have integrated them into urban plans in order to show their usability in the planning process of a city.

Introduction

The history of cities follows cycles. Sometimes these cycles imply progress, and sometimes they imply decline, considering only the extremes. Each cycle reflects — in different scales and dimensions, and at different rhythms — the importance of local political decisions when it comes to city planning. Planning a city is an established practice that should result in the desired evolution models. As a general rule, those models correspond to urban plans that are created mostly based on qualitative assumptions. Those models embody the dominant ideas that result from the interpretation of the spirit of the Law, the debate around technical solutions, and public participation.

However, in light of the recent theories on urban dynamics, we can employ quantitative models that disclose the self-organization of systems, cities, and territories. These models make extensive use of spatial modelling in a Geographic Information Systems environment and rely on the simulation of future urban growth based on the historical information provided by the observed geographical changes. When, for example, any changes in land use are quantified and subsequently confronted with the changes that had been foreseen in the plans, quantitative modelling conditions are created, thus promoting the dialectic between those models. Therefore, it is not a matter of confronting qualitative and quantitative models to eliminate the relevance and/or the excessive weight of one type over the other. On the contrary, what is at stake here is assessing the potential of each type of model and use the outcome of that assessment for improved technical efficiency at the time territorial management tools are created, monitored, and evaluated.

Taking into consideration what was just said, we would like to highlight the following aspects that are important for this analysis and for city planning purposes: i) these plans are designed based on geographic information; ii) this geographic information supports the 2D and 3D representations of cities; and iii) these 2D and 3D representations require fast and low-cost information acquisition methods (Tenedório et al., 2014) taking into consideration the speed at which the city's functions and morphology change. Theoretically, an urban plan is a formal tool whose aim is the efficiency of a city. Bearing this in mind, two questions might be asked: What is a smart city plan? Is a smart city plan technology-based? The answers to these questions are complex. A smart city corresponds to a vision of urban development that implies the usage of very different technologies. These technologies should promote urban quality of life, i.e., they should aid in the analysis and management of the efficiency of a city's performance through local departments information systems, e.g., in the fields of energy, transport, water, green spaces, heritage, urban revitalization, urban services in general (education, health, culture, public participation in the discussion of city plans, entertainment and leisure, etc.). In no way can technology be seen as a means of dematerializing urban services; there can be no virtual cities without technology (Tenedório et al., 2014).

According to Batty (2014: p.1) «(...) the smart city is the automated city where the goal is to improve the efficiency of how the city functions. These new technologies tend to improve the performance of cities in the short term with respect to how cities function over minutes, hours or days rather than over years or decades». Batty's statement encompasses the notion of speed that currently explains much of the functioning of a city. The short period of time in which events develop is presently one of the main factors that explain urban change. Computation is part of the smart city concept (Batty, 2013). For that reason, we can say that the smart city is the aim and technology is a tool employed to achieve that aim. The role played by computation is of such importance that we cannot talk about the

dematerialization of urban plans or about virtual urban plans without accepting the processes of virtually representing urban metabolism. Let us look at the case of energy performance and the use of solar energy. Mapping photovoltaic potential in urban areas uses the solar model to identify building tops for the installation of solar panels (Brito et al., 2012). We cannot think about applying the solar model without considering the 3D representation of urban buildings made with the information obtained by LiDAR or without considering computation to simulate the photovoltaic potential. This case clearly illustrates the role that data acquisition technology and computation play for the benefit of the smart city.

Technologies used to acquire urban geographical information are an irreplaceable tool for the creation of information on the city. They also feed the computation of urban data as well as the 2D and 3D representations that are necessary to create urban plans. UAVs (Unmanned Aerial Vehicles) are currently a very fast and low-cost information acquisition technology. UAV technology draws from the knowledge provided by previous technologies, such as photogrammetry and information acquisition by LiDAR (Light Detection And Ranging) (Colomina & Molina, 2014). UAV technology allows for a good cost-time relationship, since it combines low cost and fast information acquisition. The little time needed for the survey, as well as the frequency with which we can obtain data are two of the most important capabilities of this technology (Colomina & Molina, 2014; Haala, Cramer, & Rothermel, 2013).

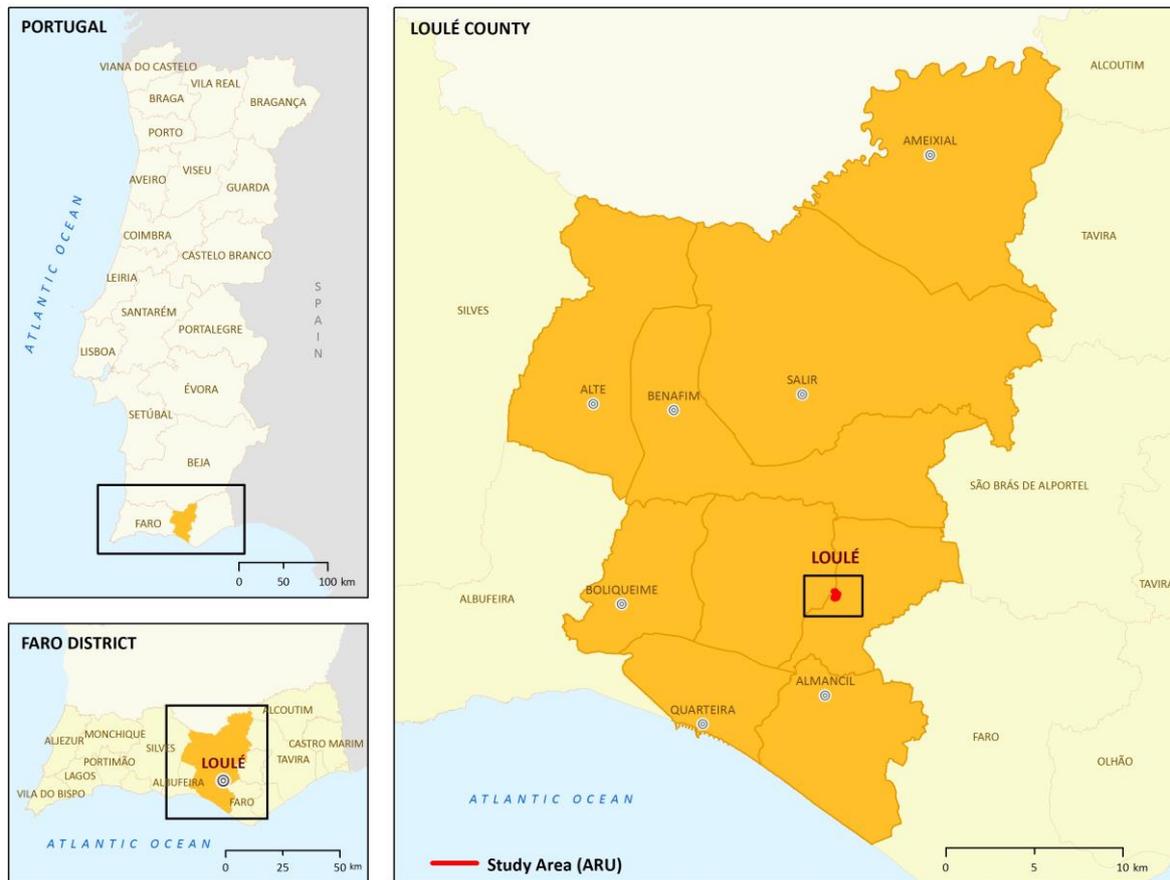
UAV technology is the ultimate technology for urban data acquisition by remote sensing. Data modelling for 3D urban representation is achieved based on photogrammetry principles. That type of data modelling is particularly important for the generation of consistent geographic information, namely for the analysis of urban revitalization areas. Urban revitalization can have many positive effects, namely: reduced urban sprawl, improved quality housing, improved cultural and social amenities, etc.. In Portugal, urban revitalization has been present in the city's policies over the last few years, mostly due to the economic and financial crisis and the consolidation of this new 'paradigm' for the construction of the city. That built heritage is usually associated with the centre of Portuguese cities, and therefore with their urban origin, regardless of their size and relative historical value. This paper summarizes the process of data acquisition using UAV and 3D modelling in an extensive computational environment.

Study area

The case study on which we worked in 2016 corresponds to part of the historical centre of Loulé (Study Area, ARU) in the District of Faro, Southern Portugal (Figure 1). This part of the historical centre is located in the urban revitalization area of Loulé.

The concept of 'Urban Revitalization Area' (ARU) was born in Portugal with Decree-Law no. 307/2009 of 23rd October, which defined the Legal Framework for Urban Rehabilitation (RJRU). Thus, paragraph 2(b) of article 2 states that ARU is 'the territorially delimited area that, due to the insufficiency, disrepair, or obsolescence of the buildings, infrastructures, collective equipment, and collective urban and green spaces, namely regarding their conditions of use, solidity, safety, aesthetics, or salubrity, justify an integrated intervention, which may be delimited in its own instrument or correspond to the area of intervention of a detailed plan for urban rehabilitation.' ARU should then be understood as a parcel of land that belongs to the city and is in need of recovery or revitalization. We would like to highlight that ARUs are areas with great potential in terms of urban dynamics, where intervention is urgent. In order to intervene in those areas, the usage of Geographic Information Technologies (GIT) is significant because it not only facilitates the access of interested citizens to information, but also aids in the promotion of those areas, which are usually uncharacterised and lifeless.

Figure 1. Location of the study area in Loulé, Portugal

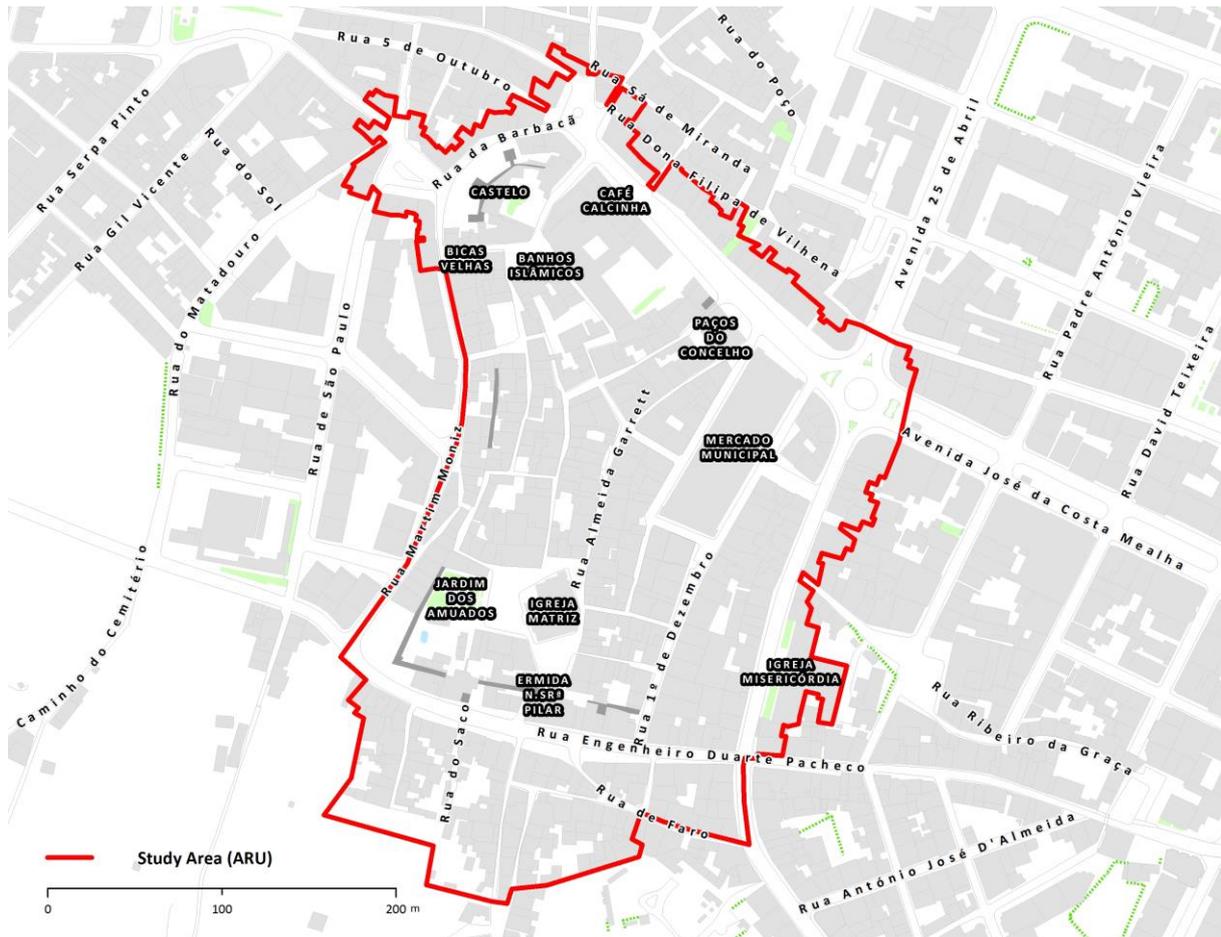


Source: Authors. 2016

The intervention area (Figure 2) of the urban revitalization of Loulé (named 'Urban Revitalization Area', or *Área de Reabilitação Urbana* — ARU — in Portuguese) corresponds to the historical centre of the city and is located in the parish of São Clemente, which is the seat of the municipality with that same name. It encompasses a total of 10 hectares, with 27 blocks, around 438 buildings, and a resident population of 440 thousand inhabitants, composed of 229 families, according to the Population Census of 2011. This area includes the whole perimeter inside the city walls, the Mouraria (old Moorish quarter), and the surrounding public space that includes Praça da República, Largo Gago Coutinho, Avenida Marçal Pacheco, Praça D. Afonso III, Rua da Barbacã, and Largo Dr. Bernardo Lopes.

In terms of historical heritage, this area also includes a number of buildings classified as National Monuments, such as, for example, Igreja Matriz (the main church of the parish), the castle, and the portal and stone cross of Igreja da Misericórdia (another church). The Ermida Nossa Sr.^a da Conceição (a chapel) is a Public Interest Building. And the Café Calcinha (a café) is a Municipal Interest Building. Besides these classified buildings, other places have a historical and heritage value, such as the Mercado Municipal (the municipal market), the Jardim dos Amuados (a park), the Convento Espírito Santo (a convent) and the Cerca do Convento (the fence of the convent), the Alcaidaria (the old city governor's house), the Ermida da Nossa Sr.^a do Pilar (a chapel), the Paços do Concelho (Council buildings), the Bicas Velhas (old water pipes), and the Banhos Islâmicos (old Muslim baths).

Figure 2. Location of the study area in Loulé, Portugal



Source: Authors. 2016

ARU integrates part of the Special Area of Protection and has an urban morphology where the line of the walls, distinguishable from some remaining parts, defines the limit of the expansion of the old town to the North, West, and South. We can see that only to the East did the construction of the market (in beginning of the 20th century) trigger the renovation of the Medieval urban fabric and the subsequent development of that area.

Data acquisition by UAV remote sensing

The UAV flight (Table 1) was planned to survey ARU's data. A quadcopter micro drone equipped with a Sony A5100 camera, an RGB sensor, and a 16 mm focal length camera were used.

Table 1 Summary of the UAV flight characteristics

Flight characteristics	
Data	15/10/2015
Number of photos	252
Altitude	138 m
Spatial resolution	3.42 cm
Longitudinal overlapping	90%
Transversal overlapping	40%

Source: Authors. 2016

The flight resulted in 252 photos with 90% longitudinal overlapping and 40% transversal overlapping. Spatial resolution was 3.41 cm, which was therefore adequate to model urban data for the creation of 3D models for the extraction of detailed information (Tenedório et al., 2014; Haala, Cramer, & Rothermel, 2013). From the total of 252 aerial photos obtained, 51 were used to model a sample area (Figure 3) focused on the castle of the city of Loulé (a very important urban landmark for the configuration of the original urban morphology).

3D data modelling

The smart city urban plan requires high-quality information based on computational processing. This may originate two types of products: 2D ortho-images and 3D urban models. Using those products we can then measure and extract urban parameters, such as building façade height, building volume, solar exposure, public spaces, green areas, urban sustainability indicators, among other pieces of quantitative information that are useful for the plan. Besides the extraction of the abovementioned parameters, 3D visualization is fundamental for the promotion of the plan at different stages of the planning process, for example, at the time of public participation in the debate on urban revitalization proposals. In this section, we show that it is possible to model UAV-obtained data assessing their quality.

The complete sequence of the processing and modelling procedure consists in the following stages: 1) loading photos; inspecting loaded images and removing unnecessary images; 2) aligning photos; 3) building dense point clouds; 4) building a mesh; building a 3D polygonal model; 5) texturing the 3D model; 6) calculating the Digital Surface Model (DSM) and the Digital Terrain Model (DTM); and 7) creating an ortho-image. The software Agisoft PhotoScan was used for computational processing.

The essential stages of the creation of this model are:

- Aligning photos: at this stage, matching points between photos are searched, creating the first scattered point cloud, which enables the calculation of pitch angles and the relative position of the photos. After this stage, Ground Control Points are associated by identifying them in the photos.
- Building point clouds: this is made after photo calibration and the creation of a point cloud in the previous stage; the software creates a point cloud that may vary in terms of density according to the selected parameters and that enables the subsequent construction of a polygonal mesh that is representative of the covered area.
- Creating the DSM: this is made from the polygonal mesh of the point cloud, and may become a DTM in case the points of the point cloud that correspond to a building or vegetation are filtered.
- Creating an ortho-image based on the DSM or on the polygonal mesh.

All these stages were subject to quantitative assessment based on the technical report produced by the software. For the error analysis (Table 2), 14 Ground Control Points (GCP) of the whole area were used, covered by 252 photos. The results of the error analysis are in compliance with the reference values for the production of very high resolution ortho-images. A visual comparison between the geometry of the ortho-image and a vectorial map (Figure 3) was also carried out. This vectorial map was produced according to standards issued by the body that regulates national cartography (General-Directorate of the Treasury) to integrate the national cartographic series on a 1:2000 scale (SCN2k). The aerial coverage that originated that vectorial map was performed in 2008, in the Hayford-Gauss Datum 73 Reference System, replaced by the PT-TM06-ETRS89 System. The conversion between the Hayford-Gauss Datum 73 Reference system and the ETRS89-TM06 System was carried out through a polynomial transformation.

Table 2 Ground Control Points (GCP) and error analysis

GPC ID	XY error (cm)	Z error (cm)	Error (cm)	Projections	Error (pixel)
2	0.883367	0.15217	0.896378	12	0.065
4	0.296492	-0.0176378	0.297016	13	0.062
5	0.175913	0.0310803	0.178637	11	0.069
8	1.67871	0.671731	1.80811	8	0.086
9	0.261196	-0.222981	0.34343	14	0.057
10	3.52824	-0.490272	3.56214	15	0.152
11	3.92666	0.634293	3.97756	22	0.138
15	1.49882	-0.121902	1.50377	4	0.053
16	1.34727	-0.0350472	1.34772	12	0.055
21	0.869971	0.0865473	0.874265	8	0.046
24	1.2787	0.249891	1.30289	15	0.063
26	1.05798	-0.557513	1.19588	14	0.154
29	1.03796	-0.223301	1.06171	9	0.121
30	0.981831	-5.93E-03	0.981849	17	0.090
Total	1.71687	0.339623	1.75013		0.1

Source: Authors. 2016

Figure 3 Ortho-image with overlapping of the vectorial map



Source: Authors. 2016

A visual observation shows a very high correlation between the vectorial map and the urban objects represented by the ortho-image. In fact, this observation confirms what had been determined by the error analysis (Table 2). Taking this assessment into consideration, this product can be used in an urban setting, namely for morphological analysis.

Building on the DTM we can explore information that might be interesting for urban analysis, such as the extraction of polylines (Figure 4) and consequently the calculation of profiles (Figures 5 e 6).

Figure 4 Ortho-image with polylines extracted from the DTM



Source: Authors. 2016

Figure 5 North-South profile obtained from polylines extracted from the DTM

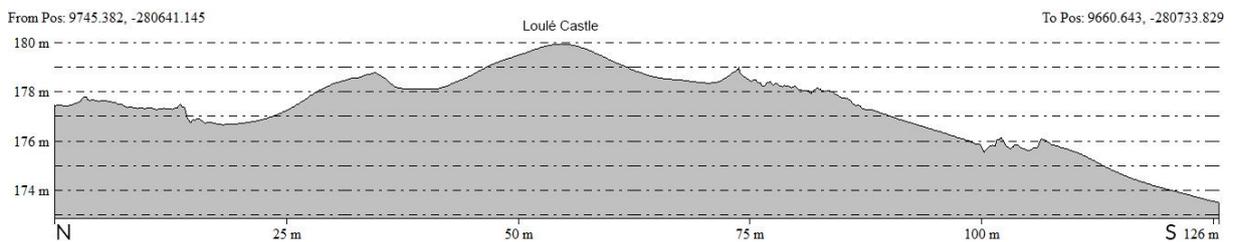
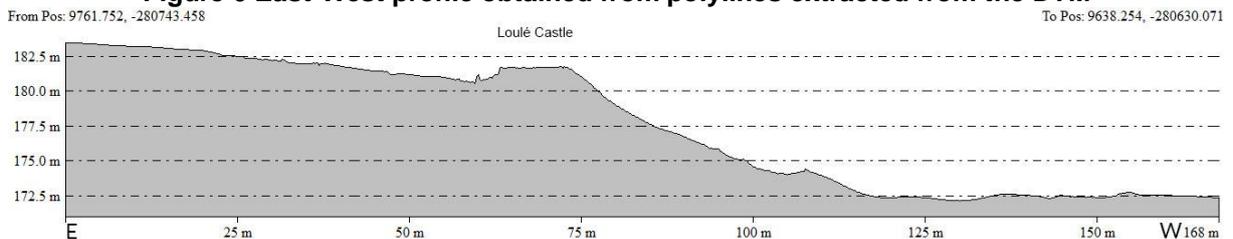


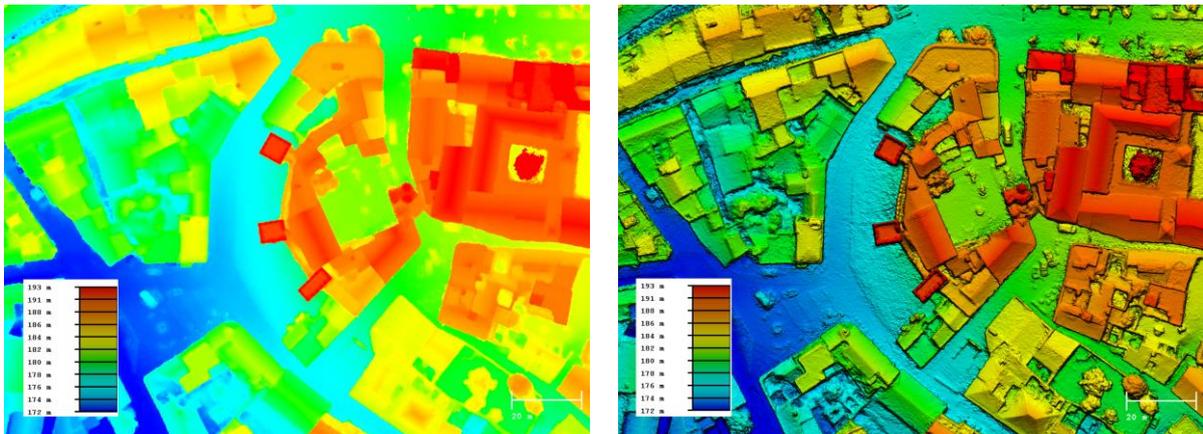
Figure 6 East-West profile obtained from polylines extracted from the DTM



Source: Authors. 2016

Three-dimensional models, such as the DSM, with geometry and surface texture, enable the study of urban roughness and are very important for planning and heritage conservation purposes (El Garouani, Alobeid & El Garouani: 2014). The DSM is particularly important for urban analysis, namely in terms of: intervisibility mapping, identifying the skyline, calculating urban volumes, building orientation, urban risk modelling, flood risk mapping, architectural visualization, among other applications. The analysis of the shape and morphology of the city, namely its historical centres, frequently uses three-dimensional information with DSM. Figure 7 shows a part of ARU of Loulé modelled based on 3D data obtained by UAV.

Figure 7 DSM of an urban historical area surrounding Loulé castle



Source: Authors. 2016

Ultimately, 3D modelling of UAV data serves the three-dimensional representation of urban objects both inside the urban fabric (Figure 8) and isolated.

Figure 8 3D model of Loulé castle and its urban surroundings



Source: Authors. 2016

The creation of a 3D model of Loulé castle and its urban surroundings (Figure 8) made use of 51 aerial photos as mentioned before. From those aerial photos with 90% longitudinal overlapping and 40% transversal overlapping, a cloud with 23116106 points, 2311901 vertices, and 4616659 faces was created.

Conclusions: modelling UAV data for analysis and urban planning

The importance of 3D data obtained by UAV for urban analysis, and consequently for the design of urban plans, was made evident in the previous sections although it has some limitations. On the one hand, data obtained by UAV may support urban databases with low-cost 3D information albeit confined to small geographic areas. Computation is still limited when it comes to dealing with large volumes of data, which would be required for wider areas. On the other hand, UAV technology that is affordable to local administrations has also very specific limitations: low UAV autonomy to cover vast areas, and heavy computational processing.

In spite of the limitations we have identified, we would like to stress the advantages of modelling UAV data for urban analysis and for the creation of city plans: i) low cost; ii) undemanding in terms of human resources; iii) possibility of creating 3D urban models to make measurements and extract interesting parameters; iv) permanently updateable; v) monitoring extreme weather events with urban impact (floods); vi) creating and maintaining digital archives of urban evolution.

Data acquisition and modelling technology promotes the implementation of the idea of smart cities. In fact, UAV for surveying and mapping may contribute to generate data and information that will serve the dimensions of city smartness.

References

- Batty, M.** (2013). *The New Science of Cities* (pp. 1-518). Cambridge MA: The MIT Press.
- Batty, M.** (2014). *Deconstructing Smart Cities*. In N. Pinto, J. Tenedório, A. Antunes, & J. Cladera (Eds.) *Technologies for Urban and Spatial Planning: Virtual Cities and Territories* (pp. 1-13). Hershey, PA: Information Science Reference.
- Brito C., Gomes N., Santos T., Tenedório J. A.** (2012). Photovoltaic Potential in a Lisbon Suburb Using LiDAR Data. *Solar Energy*, 86, 283-288.
- Colomina, I., Molina, P.** (2014). Unmanned Aerial Systems for Photogrammetry and Remote Sensing: A Review. *ISPRS Journal of Photogrammetry and Remote Sensing*, 92, 79–97.
- El Garouani, A., Alobeid, A., El Garouani, S.** (2014). Digital Surface Model Based on Aerial Image Stereo Pairs for 3D Building. *International Journal of Sustainable Built Environment*, 3: 119–126
- Haala, N., Cramer, M., Rothermel, M.** (2013). Quality of 3D Point Clouds From Highly Overlapping UAV Imagery. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL (September), 4–6.
- Pinto, N. N., Tenedório, J. A., Antunes, A. P., & Cladera, J. R.** (2014). *Technologies for Urban and Spatial Planning: Virtual Cities and Territories* (pp. 1-349). Hershey, PA: IGI Global.
- Tenedório, J. A., Rebelo, C., Estanqueiro, R., Henriques, C. D., Marques, L., & Gonçalves, J. A.** (2014). *New Developments in Geographical Information Technology for Urban and Spatial Planning*. In N. Pinto, J. Tenedório, A. Antunes, & J. Cladera (Eds.) *Technologies for Urban and Spatial Planning: Virtual Cities and Territories* (pp. 196-227). Hershey, PA: Information Science Reference.

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