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editors

D-SITE

Drones - Systems of Information on culTural hEritage. For a spatial and social investigation

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CONFERENCE PAPERS
3D Models from UAVs for the visualization and conservation of Cultural Heritage

Acquisition systems for critical and emergency areas, UAS monitoring and indoor inspection operations. New approaches to fast, low-cost and open sources survey

UAVs remote sensing for the analysis of territorial aspects: geological, agricultural, forestry

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Multirotor drone, architectural heritage, surveying, documentation.

ABSTRACT

The diffusion of multirotor drones, together with Structure from Motion applications, has favoured their use in architectural survey, study and enhancement. In particular, drones allow the free navigation of the space and the observation from new points of view. The movement takes place in a 3D space, perceptively similar to the virtual one. Therefore, the tangible heritage becomes a 1:1 scale model of itself, and as such it is observed, surveyed, modelled and narrated. Similarly, point clouds and 3D models permit analogous experiences that favour interpretation and presentation processes.

The gaze of the flying avatar: multirotor drones experiences for architectural heritage surveying, study and enhancement

1. Introduction

The growth of automatic control technologies has allowed the development of drones, both for recreational purposes and scientific research. In particular, the functions of flight control and planning, stabilization and handling, automatic return, collision prevention, the equipment with cameras, as well as the cost-effectiveness have boosted the diffusion of drones. In heritage fields, photography has always played a leading role. Especially in architectural and archaeological studies, the application of digital photogrammetry to aerial images has been very important, from aerial photogrammetry solutions combined with the use of balloons for surveying at the architectural scale (Angelini et al. 2008; Tsingas et al. 2008).

Therefore, the possibility of providing multirotor drones (from now in this paper simply called "*drones*" for the sake of brevity) – that is small helicopters – with cameras, even with a high resolution, has favoured their use for documentation, survey and monitoring of architectural heritage. In particular, the procedures of Structure from Motion (SFM) have increased the use of drones for the study of historic buildings and of their particulars, their characteristics, and degradation. In fact, the SFM allows the automatic orientation of digital images, even taken from videos, and therefore the generation of point clouds and 3D models.

Based on some case studies related to the use of multirotor drones, aim of the paper is to present a reflection on their use at the architectural scale, both for documentation, historical critical study, and enhancement of historical buildings. The purpose of the paper is not to focus on measurement issues, data processing and accuracy – although they are important aspects –, but to understand how multirotor drones could influence the critical process of architectural study and the approach to built heritage. Therefore, the paper relates to the fields of digital culture (Gere 2002), also in relation to cultural heritage and digital heritage from real contents (Murray 1997; Bolter, Grusin, 2000; Berry, Dieter 2015), and to the line of visual culture studies (Pinotti, Somaini 2016). In particular, the possibility of drones to take images moving freely and with great stability in three-dimensional space, near the facades, even inside the buildings, plays an essential role, and favours a remediation in the mutual relationship between the scholar and the monument.

2. The architectural surveying as critical interpretation

As it is well known, the traditional process of architectural surveying roots on the following phases (Docci, Maestri 2009): the preliminary study of the building; the surveying project (with the realization of sketches to discretize the architectural continuum and to highlight significant elements that will be measured, and defining the surveying methodology); the measurement; the restitution with interpretive drawings and models. The diffusion of laser scanners and of digital photogrammetry software has produced

a partial alteration of the process, anticipating the measurement phase, and postponing the critical-interpretative act in the post-processing (Bianchini 2014; Gaiani 2012).
In a certain way, the spread of drones in the architectural survey has in part brought back the surveyor closer to the building, inviting him/her to look at it closely, forcing him/her to reflect if the shots are useful for documentation and photogrammetric survey, especially of architectural and constructive details.
The first aspect that has favoured the spread of digital photogrammetry applications is the possibility of creating point clouds with SFM processes far cheaper than using laser scanners (Stathopoulou et al. 2019).
Secondly, drones are useful for the surveying of roofs and facades (Carnevali et al. 2018), in particular of buildings with peculiar characteristics, such as for example towers (Centofanti et al. 2018).
The practice highlights the useful combination of drones and laser scanners. For example, in terrestrial laser scanning a recurrent problem is the integration of gaps in the point clouds caused by ledges and cornices. Certainly, the greater precision and certainty of the measurements offered by the laser remains, but drones allow station points that are often impossible for laser scanners (Mateus 2019). Moreover, laser scanners can be useful in the registration of photogrammetric models made in subsequent campaigns, sometimes even at a great distance of time. In the process of architectural surveying, after the phase of taking the measurements, necessarily the "*restitution*" through critical interpretative models follows. They can be 2D drawings, discontinuous or numerical models (point clouds and mesh models), mathematical models (for example CGS or NURBS models), or HBIM models (Migliari 2003; Chiavoni, Filippa 2007; Maiezza 2019; Rodríguez-Gonzálvez et al. 2019; Brusaporci et al. 2019). The role and skills of the user plays a leading role, also in taking images (De Luca 2011). 3D modeling requires a critical work, made by expert connoisseur of traditional geometries and construction systems.

Figure 2. Facade of the Basilica of Collemaggio. View of the point cloud inside the Agisoft software.

Figure 3. Comparison between the point cloud acquired by laser scanner to the left and by drone to the right.

Certainly, the question concerning the relationship between the architectural characteristics, the scale of restitution and the purpose of the knowledge remains essential (Docci, Maestri 2009). Last but not least, 3D models – through their visualization – can play an important role in telling the story of architectural heritage and therefore in enhancing cultural heritage (Brusaporci et al. 2017).

3. Documentation, Communication, Enhancement

The spread of digital photography has favoured, also in the field of drones, the use of images for the documentation of cultural heritage. More and more are the videos made with drones for the enhancement and publicity of places and architectural heritage. This goes hand in hand with the diffusion of digital photography using smartphones, which allows anyone at any time to acquire photos, tag, georeferenced, and share them on social media. In general, it is a process of "democratization" of documentation, survey and modeling, boosted by economic applications and repositories such as Sketchfab (https://sketchfab.com/) o Potree (http://potree.org/) which allow the diffusion and sharing of 3D models in the form of point clouds or meshes (Brusaporci et al. 2018).

Project as "*Google Arts & Culture*", "*Open Heritage*", or "*Google Earth*" – even considering the opportunity to insert pictures by users – support processes of Participatory Heritage (Roued-Cunliffe, Japzon 2017): "*The innovation that is digital photography, and its spinouts, in the realm of social media operate not only in the service of heritage, but are complicit in its definition*" (Coyne 2012). Point clouds – if sufficiently dense – can be intended as discontinuous digital models and represent the buildings as if they are a spatial picture, providing a navigable three-dimensional cast. An issue is related to the colour of the points, heavily influenced by lighting conditions, especially for indoor images, where HDR can greatly support the post-processing (Trizio et al. 2019). Photorealistic meshes with a high degree of detail can offer extremely interesting Virtual Reality experiences, with the vision at close range and from unthinkable points of view of complex architectural details, and favoring the narrative and understanding of architectural heritage.

4. The case studies

For some time now, our research group from L'Aquila University, also within the INCIPICT project (http://incipict.univaq.it), experiments the use of drones for

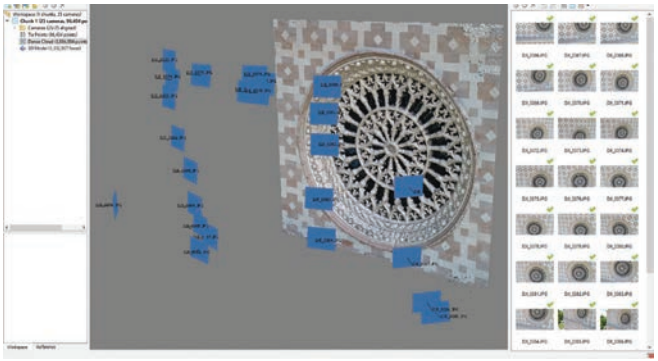

Figure 4. Point cloud screenshot of the Collemaggio rose window obtained by drone photogrammetry.

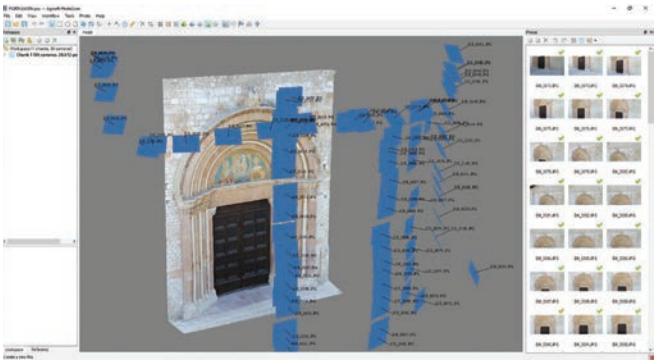

Figure 5. Point cloud screenshot of the Collemaggio Holy Entrance obtained by drone photogrammetry.

Figure 6. Mesh models of the rose window and Holy Entrances of the Basilica.

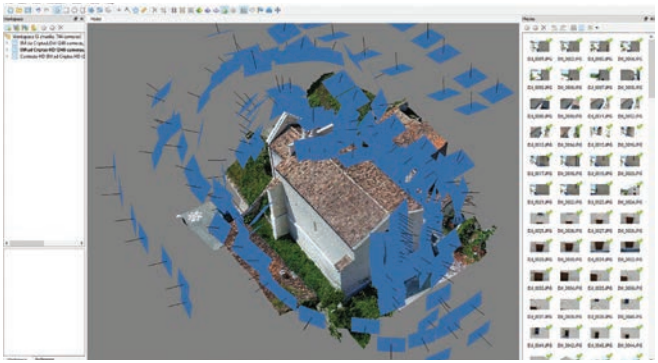

Figure 7. Point cloud of St. Maria ad Cryptas in Fossa (L'Aquila). Screenshot of the Agisoft software.

the study, survey and enhancement of architectural heritage. The reflections presented in the previous paragraphs and in conclusions rises from these works. In particular, in this paper we refer to two case studies: the survey of St. Maria ad Cryptas church in Fossa, near L'Aquila (IT), and of the Collemaggio Basilica in L'Aquila. In both cases, drones and laser scanner were used. St. Maria ad Cryptas (14th century) is a Cistercian church with one-nave and a less width square presbytery. The photogrammetric survey of the building was carried out with the help of the DJI Phantom 4 drone. The 248 photographs acquired by the integrated camera were processed with Agisoft PhotoScan Professional 1.4.3 software, thus obtaining the point cloud and the textured mesh of the exterior of the church. Moreover, the digital survey was performed by integrating drone photogrammetry applications and laser scans. In particular, the Faro Focus S70 laser scanner was used to realize 17 scans, of which: 6 outside the church, with a resolution corresponding to a distance between the points of 6.1 mm at 10 meters; 9 scans inside, with a resolution of 3.1 mm at 10 meters; 2 in the crypt, with a resolution level of 6.1 mm at 10 meters. For the acquisition of photographic images, necessary to associate the RGB value to the points, the HDR mode was set, choosing three exposures for the exterior and the crypt, and 5 for the interior of the church.

The point cloud was then used to allow the virtual visit of the church that, damaged by the 2009 earthquake, remained closed until April 2019. In particular, the use of a VR viewer, combined with the point cloud processing software Scene, offered the possibility to virtually explore the church, allowing an immersive visit experience in which the user has the perception of moving within the scanned architectural space.
The Collemaggio *Basilica* has a medieval settlement and a Renaissance facade. It has three-naves, transept in line with the fabric, flat terminated apses. The architectural surveying of the *Basilica* was realized with the integration of Leica BLK360 laser scanner and digital photogrammetry applied to pictures taken by a DJI Phantom 4 drone. The laser scanning campaign was realized with 37 station points into the church and 13 outside. The instrumental resolution between two points at 10 meters is of 20 mm. The 50 scans have been recorded by using Autodesk ReCap software. UAV technology have been necessary to realize the point cloud of the external parts of the building that cannot be measured by the terrestrial scanner, such as the roofs, the façade and the related architectural details. By using the drone, 4 datasets of photos were acquired, consisting of 159 images for the exterior of the *Basilica*, 86 images for the so-called Holy Entrance, 219 for the main façade and 25 for the main rose window.

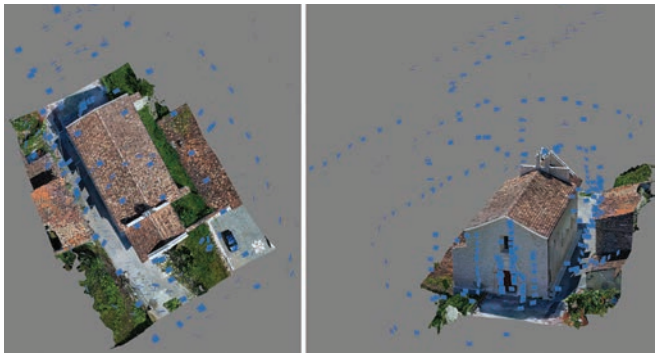

Figure 8. Maria ad Cryptas: point cloud obtained by drone with indication of the photos position.

Figure 9. Navigation of the point cloud of St. Maria ad Cryptas through the use of a VR viewer and Scene software.

According to Structure from Motion technology, the images have been elaborated with the Agisoft PhotoScan Professional 1.4.3 software, realizing a point cloud and a textured mesh.
In order to allow the navigation of the numerical model, the mesh of the exterior of the *Basilica* was exported in.obj format, for the surfaces, and.jpg for the texture; subsequently, the exported model was loaded on the website Sketchfab.
This web platform, also available on mobile devices, makes it possible to enjoy the asset in a completely original way compared to the traditional visit. In fact, the architectural elements placed even at high altitudes, such as the rose window, can be observed from privileged points of view and at close range, thus promoting their knowledge and the understanding of their architectural values.

5. Conclusion: The space of the observer

The stability and handling of drone movement in the internal and external space of buildings, and the possibility of viewing in real time what is framed make these tools a sort of avatar of the observer: through the digital screen, he/she can freely navigate the real space and look at the monument from new points of view. With specific reference to the scale and spaces of build ings, from a perceptive point of view, the scholar was traditionally confined into an anthropometric and anthropocentric perspective space. Certainly, with stairs, scaffolding, and elevators different and closer points of view are possible, but these systems are extraordinary, and the points of view exceptional but static.
The drone allows you to change the viewing and perception modes, because the eye of the viewer – through the drone camera – is able to see like the one of a bird, or rather of a bee, assuming positions allowed both by a free flight ability and by small drone size.
The movement of the drone takes place in a three-dimensional space controlled by the user, in many ways similar, also in perceptive characteristics, to the virtual one to which surveyors and modelers are used in the digital age. Conceptually, the real building immerses into a sort of digital space – in the sense of a space that is experienced with digital tools and in the manners of digitality –, where the drone takes on the role of user's physical avatar.
In this way, the tangible heritage becomes a 1:1 scale model of itself, and as such it is observed, detected, modeled and narrated. Similarly, but in the virtuality, point clouds and 3D models allow similar experiences that favor interpretation and enhancement processes (ICOMOS 2008) In the post-digital age, there is a union between real architectural heritage and digital heritage (from real content), overcoming the traditional

opposition, with an explicit and reciprocal possibility of favoring the study and enhancement of historic buildings (Brusaporci 2017).

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