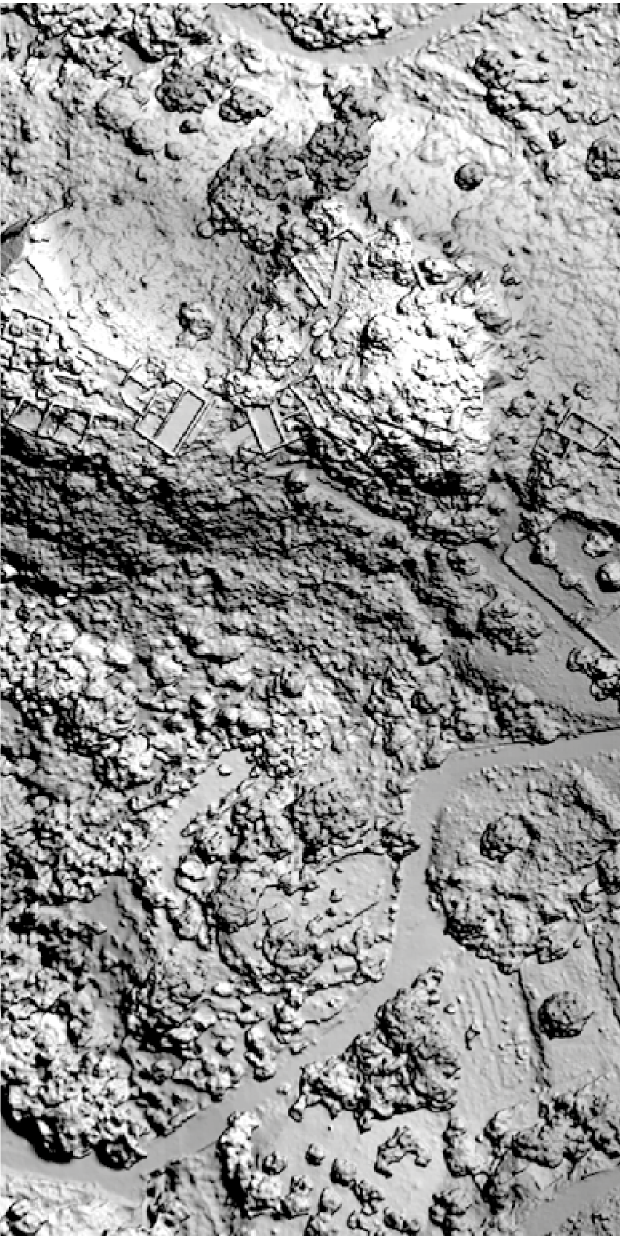
LOST AND FOUND
Processes of abandonment of the architectural and urban heritage
in inner areas. Causes, effects, and narratives (Italy, Albania, Romania)

Edited by Annunziata Maria Oteri



Mappatura da drone in aree interne. Potenzialità e limiti

Luigi Barazzetti (Politecnico di Milano)

Una documentazione metrica precisa e completa degli insediamenti in aree interne presenta sfide uniche per via delle specifiche caratteristiche e delle variabilità che tali aree presentano. Se è vero che una raccolta digitale completa richiede l'uso di vari strumenti, non esclusivamente limitati alla mappatura in sito ma che includa anche l'integrazione delle risorse cartografiche esistenti, uno strumento relativamente nuovo per acquisire e processare immagini con tecniche fotogrammetriche è il drone. Il drone si è rilevato di particolare utilità in quei progetti o studi tra una mappatura a scala territoriale e la documentazione del singolo edificio. Questo articolo riguarda gli aspetti sia normativi che operativi relativi all'uso del drone per catturare immagini e processarle con tecniche fotogrammetriche, in particolare nel caso di piccoli insediamenti in aree interne, a supporto della creazione di archivi digitali, con particolare attenzione al contesto italiano nell'ambito di una ricerca sulle aree interne della Calabria meridionale. L'articolo discute inoltre il dialogo necessario tra il pilota, che qui si intende anche un esperto di fotogrammetria, con gli altri specialisti che utilizzeranno i dati raccolti e processati; ciò anche nell'intenzione di mettere in luce limiti e sfide che questo strumento possiede anche sul piano tecnico. Se confrontato con mappature cartografiche più tradizionali, sia che interessino un progetto a scala territoriale o il restauro di un edificio storico, la mappatura delle aree interne con l'uso del drone occupa una sorta di livello intermedio in cui manca ancora di un flusso di lavoro ben definito.

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Drone Mapping in Inner Areas: Strengths and Limitations

Luigi Barazzetti

In the last ten years, drones have had a significant impact on 3D digital documentation projects at environmental and local levels, including the digital reconstruction of individual buildings. Drones have established a new level of detail and intermediate metric scales between aerial and terrestrial (close-range) photogrammetric applications. This manuscript focuses primarily on the use of drones for documenting architectural heritage within inner areas, examining single buildings, and the digital reconstruction of entire urban spaces. Notably, a strong interplay exists between images or other data collected by drones and the subsequent photogrammetric processing, which also extends from basic visual inspection to advanced remote sensing applications.

The metric processing of drone-captured images relies on photogrammetry, a field that has seen development and experimentation spanning several decades. More recently, the combined use of photogrammetric approaches and methods from the computer vision community has provided advancements in automated processing solutions[1]. Concurrently, drone technology has progressed rapidly, allowing for the integration of cartographic mapping and documentation at the territorial level and at the level of individual buildings[2].

1. Granshaw, Fraser 2015.
2. Pepe, Alfio, Costantino 2022.

It is important to note that the acquisition of images from airplanes and subsequent photogrammetric processing remains the base of modern cartographic mapping. This approach provides essential outputs such as digital orthophotos, point clouds, digital elevation models, and spatial databases, among others. However, two critical factors come into play when using aerial photogrammetry products: the level of detail, which typically aligns with cartographic requirements, and the acquisition date of the images. This means that recent aerial imagery may not always be available for the area under consideration, which poses challenges when aiming to represent current conditions. Nevertheless, past imagery can be invaluable for understanding changes in specific areas.

Terrestrial images captured with consumer-grade cameras enable specialists to acquire high-resolution imagery, which can subsequently be processed using photogrammetric methods to generate various 3D deliverables. Typically, these images offer higher resolution compared to those obtained from airplanes. Nonetheless, challenges persist, especially when capturing tall vertical surfaces or inaccessible areas. In addition, certain parts of buildings often remain out of reach.

An intermediate level was achieved using images captured from helicopters, albeit at a higher cost and with several limitations, particularly in urban settings. Drones bridge this intermediate level, enabling users to capture fine details that typically require direct inspection with safety measures in place to prevent falls. This applies to scenarios involving work at heights, necessitating specialized operator training and the installation of safety equipment such as lifelines or scaffolding.

Drones are not confined to single buildings; they can survey relatively large areas, elevating the level of detail to a mapping scale surpassing traditional cartographic products from airplanes. Although the overall coverage area may be smaller than aerial acquisitions, drones offer the flexibility of operating at low flying heights. This makes drone-based photogrammetry a potent multi-scale 3D reconstruction method, capable of achieving resolutions ranging from millimeters to centimeters. For these reasons, drones prove immensely valuable for mapping applications in inner areas, especially those characterized by irregular topography and diverse documentation requirements.

This contribution primarily discusses drone-based metric documentation in inner areas, while acknowledging the potential utility of drones in various other applications within this context. Effective collaboration between a photogrammetry specialist and other project stakeholders, such as architects, engineers, conservators, geologists, and archaeologists, becomes indispensable for ensuring accurate plan acquisition and processing that align with the project's objectives.

Numerous drones are available on the commercial market today, with prices varying based on several parameters. Some drones can be programmed to follow predefined flight plans, capturing images with the required overlap for photogrammetric processing. Drones designed for photogrammetry are equipped with navigation sensors (e.g., GNSS) and digital image acquisition sensors, which extend beyond traditional RGB cameras. Some drones even feature thermal or multispectral cameras, making them versatile tools for remote sensing.

Operating drones in the Italian context necessitates a thorough understanding of European and Italian drone regulations. Pilots must meet specific requirements, including certifications and insurance, and adhere to designated operating zones and restrictions. Consulting the maps available on d-flight (fig. 1) is crucial before each flight. Additionally, comparing this map with the Italian map of inner areas may prove insightful, though it would require access to GIS files for direct comparison, as well as consideration of different feature layers.

In summary, the following parameters must be carefully considered before planning, executing, and processing a photogrammetric acquisition using drones:

• Legislative considerations: comply with EU Regulations 2019/947 and 2019/945 for drone operations in Europe. In the Italian context, adhere to the UAS-IT Regulation published by ENAC[3];

• Operational factors: ensure the capability to conduct manual or automated flights with suitable geometry for photogrammetric processing and perform the necessary operations to generate photogrammetric deliverables with metric integrity and sufficient detail. This may involve ground surveying operations, such as setting up and measuring ground control points.

1. Drone operation and photogrammetric processing, some considerations

1.1. Photogrammetric processing of drone images

Readers may wonder why we introduce photogrammetric processing before discussing flight planning. The reason is straightforward: images must possess suitable spatial geometry to extract 3D information. Image geometry also plays a pivotal role in achieving specific metric precision. In the context of a typical aerial photogrammetric project, images depict a geometry structured in multiple strips, featuring longitudinal and transversal overlaps of at least 60% and 20%, respectively. The author often prefers to increase both values, for instance, to 80% and 60%.

3. UAS-IT Regulation. Edition 1, 4 January 2021. https://www.enac.gov.it/la-normativa/normativa-enac/regolamenti/regolamenti-ad-hoc/regolamento-uas-it (last accessed December 2023).

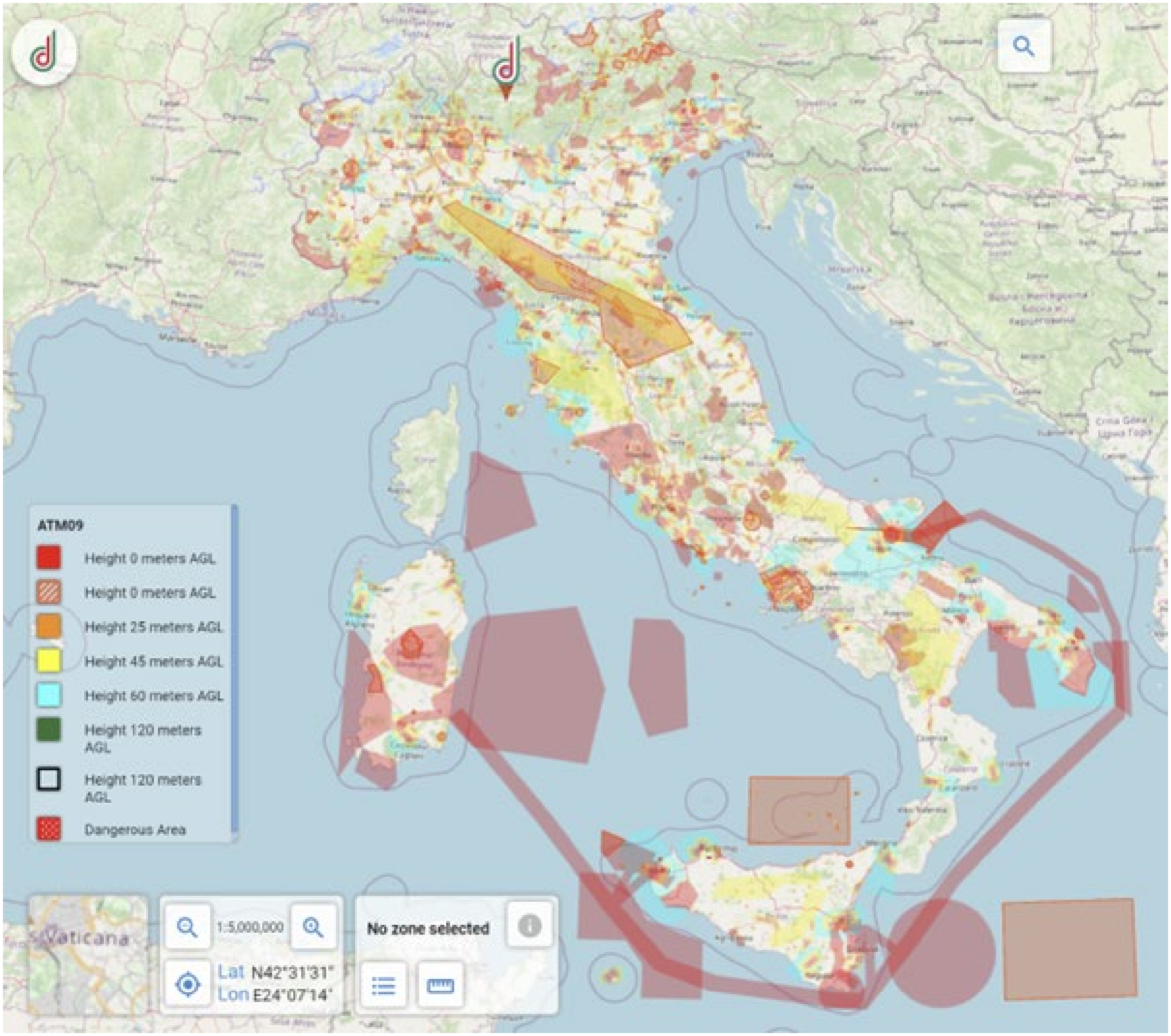

Figure 1. Maps showing flight limitations for drones, available on d-flight; https://www.d-flight.it/new_portal/ (accessed 14 March 2024).

Another essential aspect pertains to camera calibration, specifically the interior orientation parameters (principal distance, principal point position) and distortion coefficients typically based on the Brown's model[4]. It is highly advisable to utilize a precalibrated camera, even though many users today overlook this fundamental step, which can result in potential errors in the photogrammetric reconstruction[5] (fig. 2).

A photogrammetric block designed for camera calibration should consist of convergent images with roll variations (±90°), variable camera-object distances, and a suitable configuration around the object. The recommendation is always to calibrate the camera with a dedicated flight and check the statistics (precision of computed parameters and their correlations). If the calibration project yields satisfactory results, the calibration parameters can be employed as constant values in traditional 3D modeling projects with drones.

Based on the author's experience, individuals lacking a specific background in photogrammetry often estimate interior orientation parameters and calibration coefficients during the processing of images for 3D reconstruction, typically starting with initial values stored in a software database or even proceeding without any initial approximations. In cases involving a non-precalibrated camera, it is advisable to incorporate convergent images with variable camera-object distances because calibration based solely on near-nadir aerial photographs may not always be reliable. Regardless of the situation, the general recommendation is always to perform camera calibration beforehand through a dedicated calibration flight and subsequently utilize the parameters in the 3D reconstruction project.

Photogrammetric processing typically follows a well-established workflow, which typically encompasses the following stages: image matching, image orientation, point cloud and mesh generation, texture mapping, and orthophoto production. The author does not intend to delve into the details of these steps within this contribution. Interested readers are directed to photogrammetric textbooks for a comprehensive understanding. However, the availability of numerous commercial and open-source software tools capable of automating most phases of the photogrammetric pipeline is noteworthy. This automation has become increasingly prevalent in the last 10 years, contributing to the widespread use of photogrammetry. Nevertheless, this has also led to instances where individuals lacking adequate expertise have generated incomplete reconstructions lacking metric integrity.

4. Roncella, Forlani, 2021.

5. *Ibidem.*

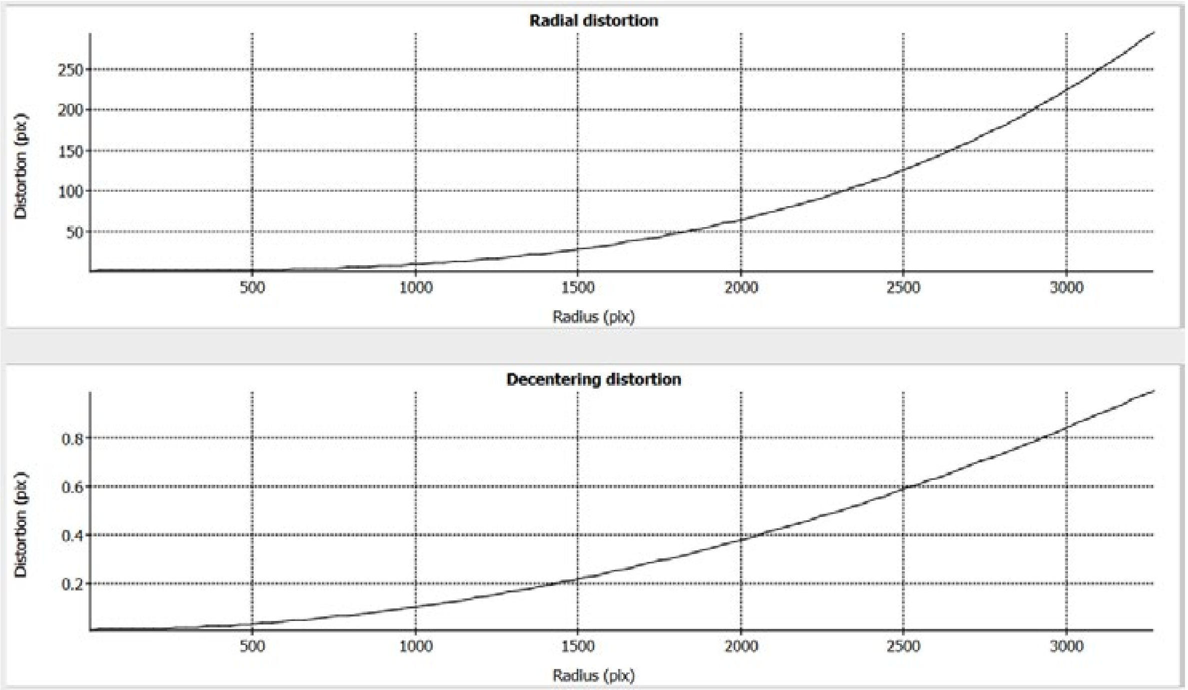

Figure 2. Radial and decentering distortion curves after a calibration project. The drone is a Mavic 3 Enterprise (elaboration by L. Barazzetti.

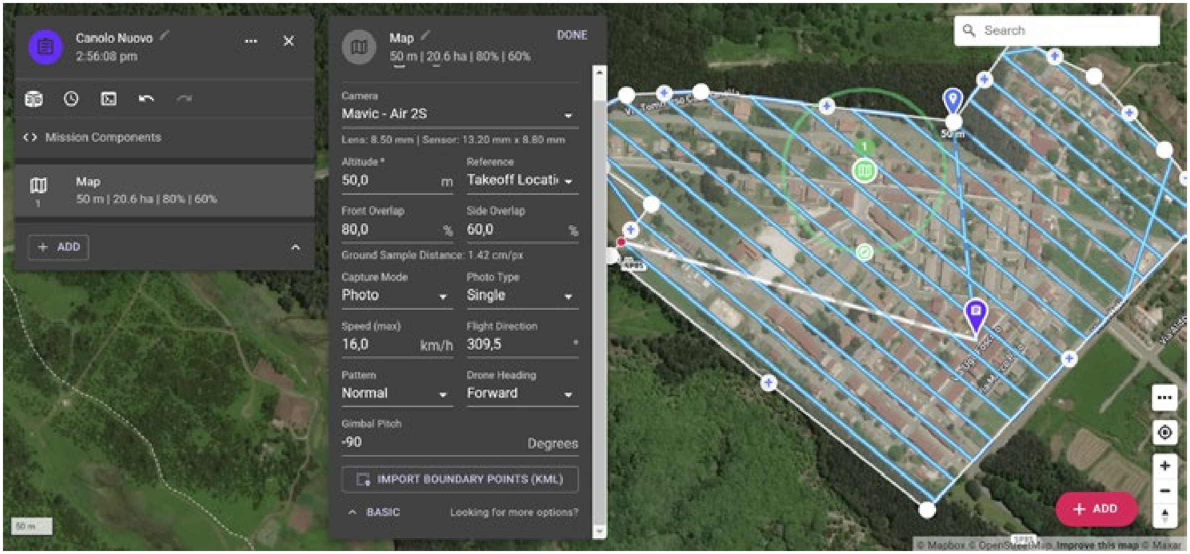

Figure 3. Example of a "traditional" photogrammetric flight structured in several parallel strips planned before reaching the site (photo and elaboration by L. Barazzetti 2023).

1.2. Flight planning and image acquisition

One of the primary advantages of drone technology and photogrammetry is the ability to automate the data acquisition phase (fig. 3). While not all drone-based photogrammetric projects can make use of automated flight planning options, applications requiring traditional aerial orthophotos or more complex geometries can benefit from these options to expedite data collection and establish a more consistent image block structure with predefined overlap, as well as convergent images.

In highly complex geometries, an approximate 3D model of the object can be employed to create a comprehensive 3D flight plan, incorporating convergent images at various heights. Pilots must pay attention to obstacles during on-site work. A fully manual flight remains a valid choice for drones lacking automatic flight capabilities and areas characterized by intricate geometries and obstacles.

A crucial parameter for planning drone acquisitions is the Ground Sampling Distance (GSD), which corresponds to the projection of the image pixel onto the object. In simple terms, a camera with a pixel size of p×p mm² will capture an area of P×P mm² on the object, dependent on factors such as the camera-object distance and the camera's focal length.

Typical values for drone projects range from a few millimeters to several centimeters. Importantly, the GSD is inconsistent throughout the project due to variations in the camera-object distance caused by the object's geometry. Utilizing drones with "terrain follow" capabilities can be helpful in maintaining a more consistent GSD in areas with significant changes in elevation. However, pilots must also consider the Digital Surface Model (DSM) used to plan image acquisition. When using DSMs downloaded from the internet, the resolution is often limited (several meters), potentially affecting the flight trajectory.

The GSD also plays a crucial role in establishing a connection between the acquisition phase and the requirements of the final deliverables. It can be used to calculate the metric scale (1:m) for traditional orthophotos, which can then be used to generate 2D drawings such as plans, sections, and elevations. The GSD serves as a fundamental parameter in the communication between the pilot and the specialists who will utilize the products of the photogrammetric acquisition following the final delivery.

2. Drones and photogrammetry. Some general considerations

2.1. GCPs, RTK, PPK: georeferencing the project

Photogrammetric projects, including those involving drones, require "3D external information" for georeferencing. These projects inherently encounter ambiguity and need to undergo scaling, rotation, and translation to align with a specific reference system. The term "external" implies that the image content alone cannot resolve this ambiguity.

One viable solution involves measuring well-distributed points in the area or on the object. Among the various options available, utilizing a GNSS receiver in Real-Time Kinematic (RTK) mode enables operators to record precise positions of distinguishable ground points (such as corners, manholes or targets) that can be subsequently measured within the images. The accuracy of these methods can reach approximately ±2-5 cm.

Alternatively, drones equipped with GNSS receivers capable of operating in RTK or Post Processed Kinematic (PPK) mode can be employed to determine image locations instead of capturing control points on the ground. Additionally, drones typically enjoy superior sky visibility compared to terrestrial locations. The primary practical distinction between RTK and PPK lies in the calculation of precise

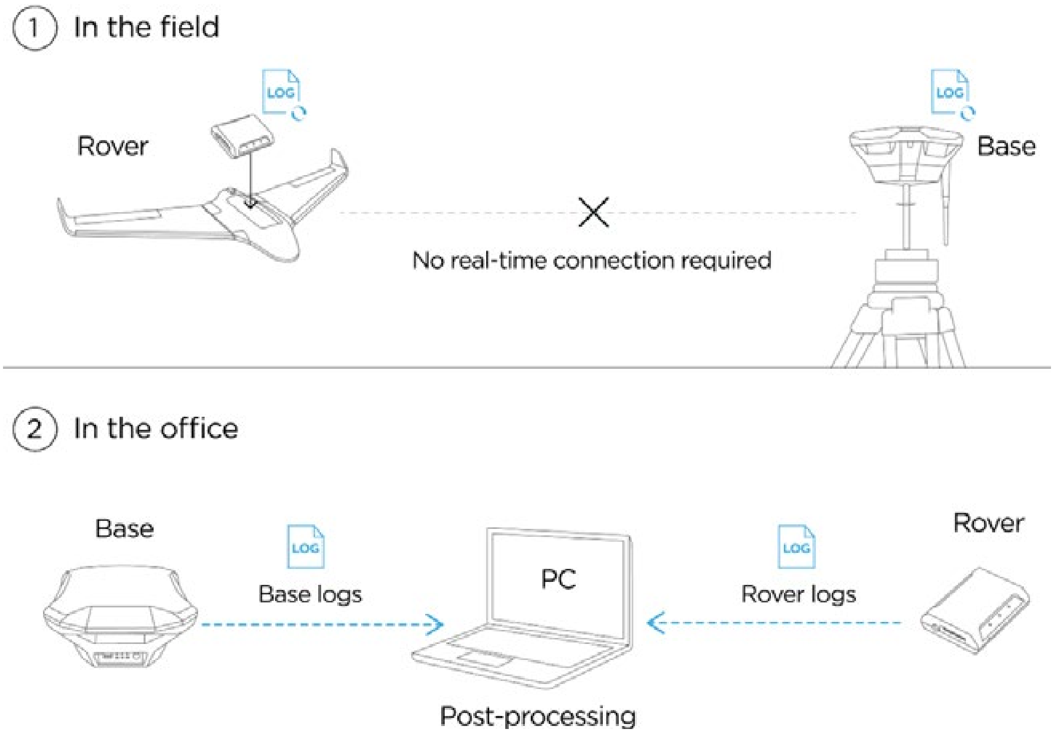

Figure 4. Difference between RTK (top) and PPK (bottom) (https://emlid.com, accessed 14 March 2024).

camera locations; RTK offers real-time corrections, while PPK involves the computation of accurate camera positions later in an office setting (fig. 4).

The advantage of having precise camera locations lies in the ability to georeference photogrammetric projects directly. This approach proves particularly beneficial in areas where measuring control points with sufficient ground distribution is challenging. In general practice, capturing some control points and employing a combination of both methods is advisable. Additionally, including some points as check points—points not directly used in photogrammetric processing—allows for evaluating metric accuracy through their 3D coordinates.

Considerations on the Italian Reference System

Based on the author's experience, the results of the digital documentation phase are typically generated within either a local Cartesian or a cartographic reference system. The use of a cartographic system often leads to confusion among the various stakeholders involved in the project. A simple question like, "Which reference system will we use for the project?" often produces diverse and incomplete responses, including terms like UTM, ROMA 40, WGS84, RDN, ETRF89, ETRF2000, and more. Occasionally, the choice of a reference system remains a complex issue for several specialists involved in the project. Professionals working with GIS data accessible through geoportals frequently encounter different reference systems, further adding to the confusion. Additionally, changes in reference systems are not entirely clear to various specialists dealing with georeferenced information.

The *Nota per il corretto utilizzo dei sistemi geodetici di riferimento all'interno dei software GIS aggiornata a Gennaio 2022*[6], issued by the Istituto Geografico Militare (IGM), offers clarity on some of these concerns.

One solution to address these challenges is the utilization of a GNSS permanent network registered within the current Italian reference system. Data acquisition through methods like RTK or other forms of differential measurements, with the master receiver featuring coordinates in the correct system, directly provides the desired coordinates. These are typically presented in the format of latitude-longitude-ellipsoid elevation or North-East-ellipsoid elevation. To calculate orthometric elevation, the user can refer to the geoid model provided by IGM rather than relying on global geoid models available in photogrammetric packages (such as EGM96 or EGM2008).

3. Some examples

We consider the case of five areas in Calabria acquired with a drone, using automated flight pre-planned before reaching the site (fig. 5). The areas include the municipalities of Ferruzzano, Canolo (both old and new areas) and Bruzzano (both old and new).

The aim of the acquisition was the production of detailed orthophotos showing the areas with sufficient level of detail. The GSD was planned considering the requirements of the architects involved in the project, flight restrictions, and the time necessary to operate the drone and recharge the

6. The document is accessible at the following link: The reader can access this note via the following link: https://www.igmi.org/++theme++igm/pdf/nuova_nota_EPSG.pdf, last accessed December 2023

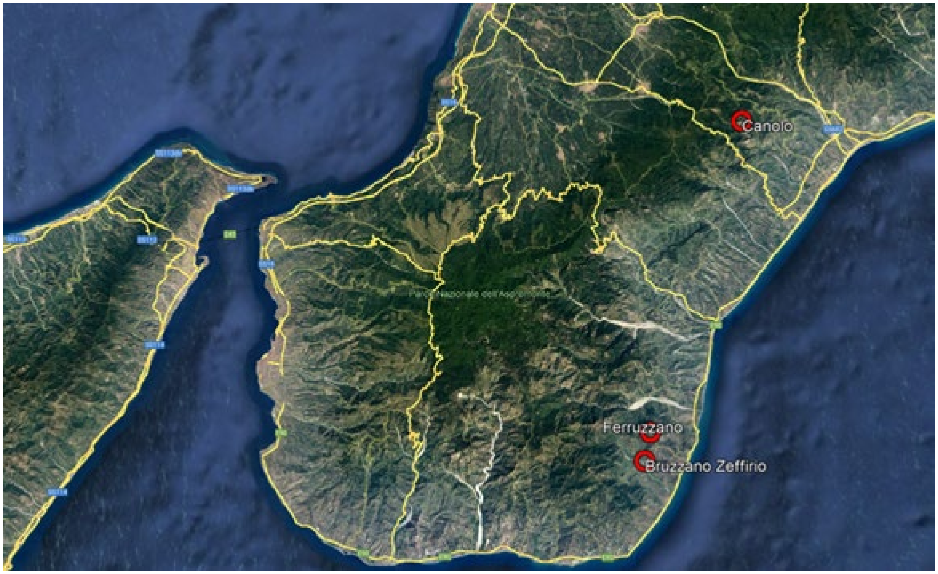

Figure 5. The five surveyed areas distributed in three municipalities (elaboration by L. Barazzetti 2023).

batteries (6 batteries were available, offering an expected flight time of more than 1h30m). The camera was also precalibrated, and the flights included both normal (camera oriented 90°) and convergent images. The aim of tilted images was not the reconstruction of vertical surfaces (facades) but mainly to acquire additional images to be used in bundle adjustment, strengthening block geometry.

Image acquisition was carried out in two working days, including the time to move from the different places. Processing was carried out with the main aim of extracting high-resolution orthoimages, which could show the details with a level of detail higher than traditional aerial orthophotos. Figure 6 shows an example of an orthomosaic for Ferruzzano. The image is also georeferenced to be imported into GIS software and overlapped with other geospatial datasets. As can be seen, the resolution allows the identification of conditions, with multiple buildings having major damages.

While orthophotos are often regarded as a standard output of the digital documentation phase, a single drone flight can yield a multitude of other valuable products. For example, a Digital Surface Model (DSM) can provide the missing third dimension that orthomosaics lack (fig. 7). When contour lines are necessary, filtering the DSM or point cloud to retain only the terrain can pose not only technical challenges (as automated algorithms may require extensive manual correction) but also

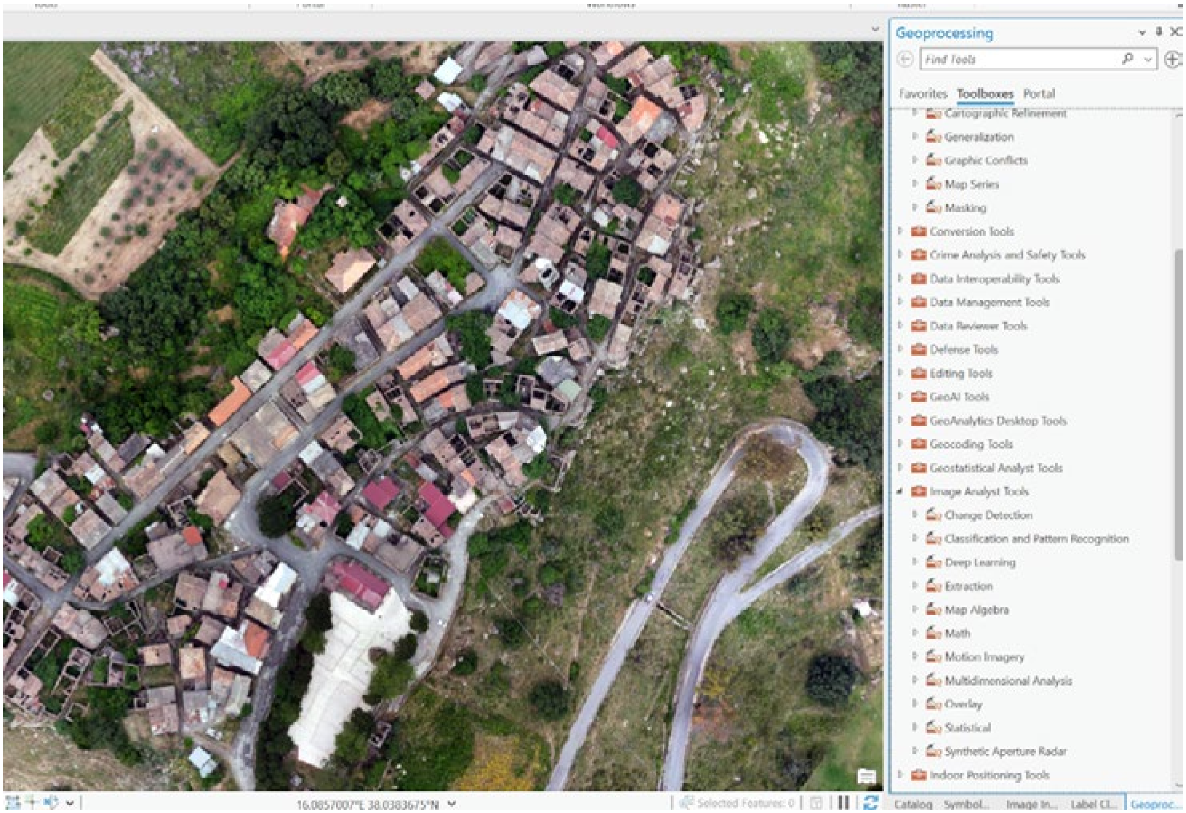

Figure 6a. Ferruzzano superiore, Reggio Calabria. The overall ortho-mosaic of the village (photo and elaboration by L. Barazzetti 2023).

Figure 6b. Ferruzzano superiore, Reggio Calabria. A zoom showing the achieved level of detail (photo and elaboration by L. Barazzetti 2023).

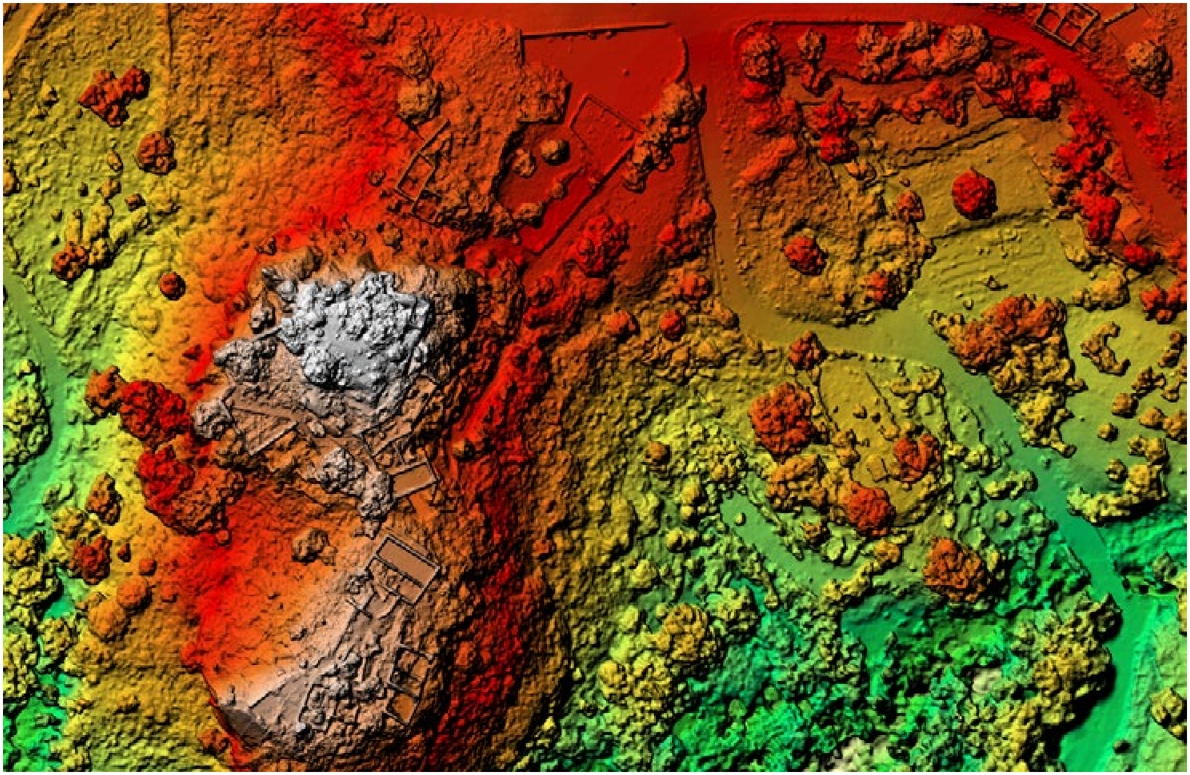

Figure 7. Bruzzano Vecchio, Reggio Calabria. The DSM (as hillshade) (elaboration by L. Barazzetti 2023).

necessitate decisions on what to exclude, particularly in models with higher resolution than traditional cartographic products. These decisions are closely tied to the project's objectives.

It would be a mistake to categorize orthophotos and DSMs as true 3D deliverables. They can be better described as 2.5D products, providing a single RGB or elevation value for specific cartographic locations. In other words, for a comprehensive 3D representation, the image block's geometry must possess different characteristics to capture vertical surfaces, such as building facades. This becomes particularly challenging when guaranteeing the same ground sampling distance (GSD) for the lowest parts of buildings, which may be difficult or impossible to capture in narrow streets. Integrating ground data with more traditional methods like terrestrial photogrammetry and laser scanning would complement the project despite the challenges of registering all the products within a unified environment and the increased on-site workload.

The range of potential applications and products is, therefore, vast and highly dependent on the unique characteristics of inner areas. Therefore, a preliminary inspection, meticulous planning, and ongoing dialogue between the pilot (also considered a photogrammetry expert) and the other specialists involved in the project are always essential.

Considerations and conclusions

Planning the acquisition of images for the metric documentation of inner areas with drones is not only a photogrammetric problem. It can only be executed effectively when various aspects are carefully considered, including the project's specific requirements, which necessitate a close dialogue between the pilot/photogrammetry specialist and other personnel involved in the project. It also involves adherence to legislative aspects related to drone operations and data quality aspects during acquisition and processing. Equally important is contemplating the future use of the photogrammetric outputs, as they constitute input data for subsequent work undertaken by professionals in the field.

The paper also described some experiences conducted in five areas in Calabria, employing a drone equipped with automated pre-planned flight routines executed before reaching the actual survey site. The primary goal of this data collection was to generate highly detailed orthophotos that could depict these areas with sufficient precision. The research is specifically focused on comprehending how a history-based approach can clarify the reasons behind the abandonment of these small settlements (specifically Canolo Vecchio, Ferruzzano Superiore, and Bruzzano Vecchio in the province of Reggio

Calabria) and direct potential strategies for reuse, the utility of obtaining high-resolution images has proven particularly valuable for gathering data otherwise inaccessible at various scales.

At the urban scale, for instance, orthophotos enable a comparison with other historical cartography (especially aerial photos) to understand the speed at which the phenomenon of settlement ruination, or the abandonment of specific parts, is advancing. In the case of Calabria, this task is further complicated by the limited documentation of the territory since the post-World War II era and the numerous natural disasters that have often resulted in the destruction of historical archives. At the architectural scale, orthophotos prove especially useful for analyzing damage to inaccessible parts (such as roofs or high zones of buildings). Of course, there remain challenging aspects to address. In cases of not recent abandonments that have led to the complete ruination of settlements and surrounding territories, the use of drones, in many instances, is inconclusive. In the specific instance of this research, for example, the possibility of obtaining a high-resolution orthophoto of the Africo site had to be abandoned. This is because the complete coverage of ruins by vegetation would have yielded unsatisfactory results, with the added risk of damaging the instrument.

For these reasons, the planning of the Ground Sampling Distance (GSD) considered specific requirements by the specialists involved in the project. It also factored in flight restrictions and the operational time required for the drone, including battery recharging intervals. Furthermore, the camera utilized for this endeavor had been precalibrated, and the flight routes were meticulously designed to encompass both nadir images (where the camera was oriented at 90 degrees) and oblique images. The inclusion of oblique images served a distinct purpose: it wasn't primarily intended for reconstructing vertical surfaces, such as building facades, but rather to acquire additional images that would enhance the bundle adjustment process and the overall block geometry.

While the photogrammetry specialist may not be directly engaged in the future application of the data, establishing a dialogue and comprehending how these outputs will be utilized can prevent the production of deliverables that do not align with the end users' expectations.

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