UAV data acquisition and analysis for a Cultural Landscape Heritage: the emergency area of the Vallone d’Elva.

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## ABSTRACT
In the last decades, the technology progress in the cultural and environmental field has had a loud growth. The authors applied drone and terrestrial photogrammetric techniques for a complete survey on a complex Cultural Landscape Heritage, requiring protection and promoting actions. These technologies were used to obtain even more detailed 3D point clouds, terrain models, orthophotos (also new quasi-vertical product) with a centimetre accuracy, for tourism development and landslide hazard prevention on road and villages, also reducing survey costs in a complex and limited orography site.

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## 1. Introduction

In recent years, the study of Cultural Heritage (CH) in Italy has undergone a considerable increase. In this perspective, different detection technologies have been developed and used for mapping and monitoring artificial and environmental issues, such as image-based UAV (Unmanned Aerial Vehicle) technology and terrestrial photogrammetry (Watts 2012; Balletti 2019; Barba 2019), associated with traditional topographic techniques.

The article aims to enhance the environment-territory system from a tourist and safety point of view (Parrinello 2018), using a multi-sensor approach to rebuild the landscape heritage of the Vallone d'Elva in Piedmont (Italy), investigating the persistent rocky slopes vulnerability along SP104 road, still closed to traffic, leading to Elva hamlets. In the literature, monitoring and documenting of landslides case studies in complex and inaccessible environments using geomatics technologies are manifold, testifying the importance of this issue. With this in mind, classical topographic techniques such as TLS (Terrestrial Laser Scanning) (Artese 2015 & Kaspersky 2010) for monitoring the large impact landslides were employed, associated with UAV (Lindner 2016) and terrestrial photogrammetric techniques, as well as global satellite technology (Gili 2000) in orographically complex environments subject to landslide events at different scales. Given this orography complexity, an "*ad hoc*" acquisition and processing methodologies have been developed (Fissore 2017), to generate the 3D model.

Nadiral and oblique images (Lingua 2017) have been acquired, in order to obtain a more exhaustive and correct 3D model (complete, accurate, precise) for the greater landslide hazard as witnessed by the event occurred in 2014 which led to the definitive closure of the route. As performed in a similar case (Bassani 2019), a specific Mobile Mapping System (MMS) with LiDAR, GNSS and other synchronized sensors mounted on a car could allow the extraction of detailed 3D model of the sub-vertical rock walls. Here, this investigation could not be carried out due the poor GNSS satellite visibility for kinematic applications caused by complex orography. To overcome this, high resolution terrestrial photogrammetric survey of the whole road has been performed, obtaining dense point clouds and vertical orthophotos, useful for geostructural analysis and tourism landscape purposes. High-resolution images by UAV and terrestrial photogrammetry were analysed using photogrammetric software (Agisoft Metashape Professional), generating surface data at different survey scales with a multiscale approach (Bemis 2014), obtaining 3D models at different levels of detail along the road axis, or focusing on the landslide event. The models obtained enabled the generation of the DSM (Digital Surface Model) and orthophotos (Li 2004); further analyses were carried out to classify the vegetation on rocky slopes, generating a high-resolution DTM (Digital Terrain Model) useful for the planning and landslide risk analysis. Data obtained through the SfM (Structure for Motion) computation of UAV images, allows also to calculate the rock volume possibly subject to collapse, in continuity with field analysis (Tucci 2019).

## 2. The case study: Vallone d'Elva road

The case study is the road of Vallone d'Elva. The village of Elva is sited in Maira Valley in the province of Cuneo (CN). The historical small centre is the 10th municipality for altitude in Italy, 1700 m a.s.l., it is composed by 22 hamlets (mostly abandoned) and it is famous for its richness of artworks. The church contains paintings of the 14th century realized by "Maestro d'Elva" Hans Klemer, a baptistery of XIV century and a wooden crucifix of XV century. For all these reasons the connections with other valleys have always been important for this area. The local people have tried to design a road in order to easily connect Elva to the lower Valle Maira main road. Some documents reported the necessity of an easier route and in 1838 a municipal resolution declared to design a path between Maira and Varaita Valleys, opened in 1934 as mule-track and suitable for vehicles in 1950. The road is composed of 10 km of paved road, enclosed by walls of living rock, flanked by twelve tunnels dug into the rock. From the beginning, it was characterised by landslides and rock falls events causing long periods of isolation for Elva villages. After a huge landslide event in 2014 the road was declared closed due to its dangerousness (Figure 1). Today, the inhabitants of Elva are claiming the re-opening of the road for its cultural and historical value and for its attractiveness. For these reasons and due to its history, the road could be considered a CLH (Cultural Landscape Heritage) to take in consideration for different type of analysis (spatial, morphological, geological,...).

In the UNESCO definition and classification, it is possible to consider as CH "monuments, group of building and sites and as natural heritage (NS) natural features, geological and physiographical formations and natural sites" (eg. Convention Concerning the protection of the World Cultural and Natural Heritage 1972). Afterwards, a more recent definition in the UNESCO documents of 1992 add the Cultural Landscape definition to the previous one, in order to identify combined works of nature and humankind (WHC-92/CONF.002/12 point IV).

Figure 1. 2014 landslide's event which closed the SP 104.

The cultural value of the road could also be underline by the fact that Maira Valley is included into many projects and objectives of the RLP (Regional Landscape Plan), which represents the main tool for establishing the quality of landscape and the sustainable development of the entire regional area. The RLP places within its main strategies the "Revitalization of the mountain and of the hills" that can be reached contrasting the abandonment of the territory, the redevelopment of the Alpine landscapes and the enhancement and re-functionalization of the itineraries historical and scenic routes. Moreover, the Maira Valley has considered as strategic guidelines the protection of elements of geomorphological interest, land monitoring and tourist enhancement of the typical landscapes.

## 3. Data acquisition

The Vallone d'Elva route is a complex environment which characteristics require a careful flight planning. Using standard criteria of terrain resolution and accuracy of photogrammetric products (Piras et al. 2017), it has been chosen to perform manual flights with skilled UAV pilots to guarantee a higher level of safety. To guarantee a rigorous approach in terms of accuracy and precision, a crucial step involved the realization of a topographic network by using both GNSS (Global Navigation Satellite System) and traditional topographic techniques.

The coordinates of 22 vertices have been measured through a geodetic GNSS receiver in static mode (1 hour for each point). The coordinates have been estimated considering a multi-base solution (through the Leica Geo Office® software v.8.4) with the Ostana and Demonte permanent stations of CORSs (Continuous Operating Reference Stations) network by Piedmont district (Figure 2), obtaining a high level of accuracy (σmax=3 mm in vertical direction).

Starting from the reference vertices with RTK GNSS survey, some photogrammetric control points has been acquired on markers, both on horizontal street surface and on vertical rock facades (Figure 3).

The coordinates were estimated with a precision of few centimetres (σmax= 3 cm) with fixed-phase ambiguities for all points.

Finally, the positions of 54 vertical markers (Figure 3c) and 120 natural target points were measured by a total station (Leica Image Station) located on the reference vertices. All measurements were subsequently adjusted with the MicroSurvey StarNet v.9.0 software tool, in order to obtain the final coordinates: the RMSE (Root Mean Square Error) of the estimated coordinates was less than 1 cm.

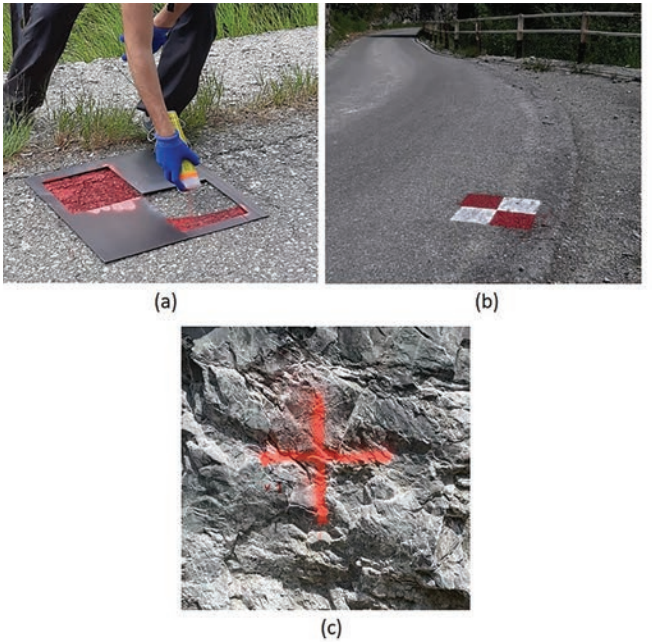


Figure 3. Control points materialization: (a) colouring of highly visible markers (30x30 cm) along the street, using a specially made template; (b) a horizontal marker; (c) a vertical marker.

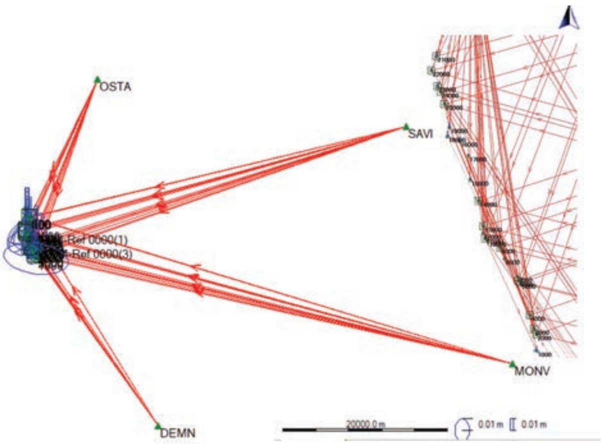


Figure 2. CORSs permanent stations network used as reference.

Figure 4 shows the final topographic network. The image acquisition has required two days considering winds and weather conditions, for 11 flights (Table 1).

The "almost vertical" rock facades suggested the use of a mixed approach for the block geometry, combining nadiral images, about 100 meters far from the street level, and oblique images with a mean distance of about 50 m from rockfaces. Two commercial UAVs have been used (DJI Phantom 4, with a FC6310 camera, 20 MP CMOS sensor, focal length of 8.8 mm).

In order to cover all ten kilometres of the road, the survey was divided in three different areas, namely "High part of Road (HR)", "Low part of Road (LR)" and "Large Landslide (LL)" (Figure 5).

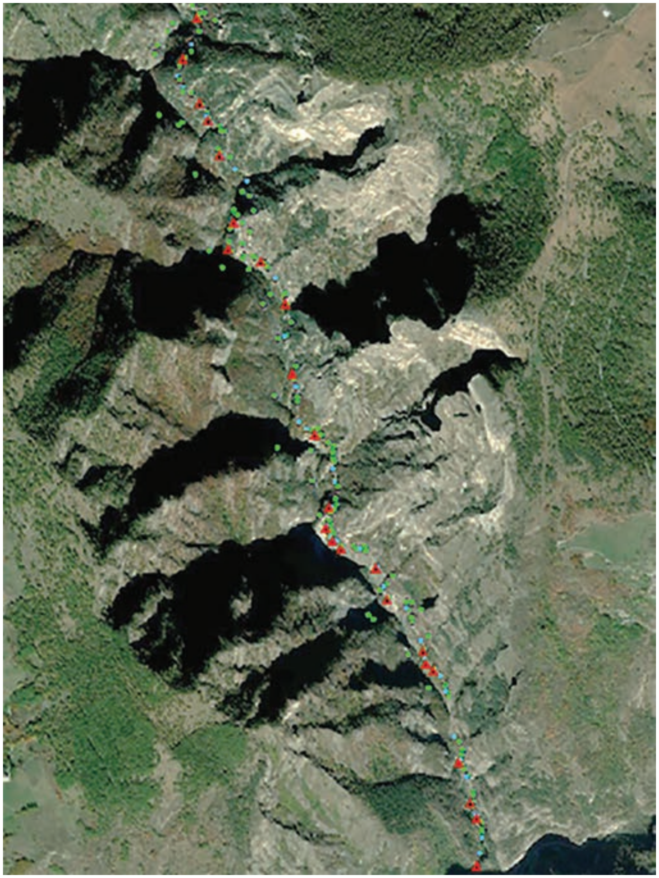

Figure 4. The topographic network with reference vertices (red), horizontal markers (blue), vertical markers and the natural points (green).

| Area | Nadir | Oblique | Total |
|---|---|---|---|
| HR | 3 flights 505 images | 5 flights 395 images | 8 flights 900 images |
| LR | 4 flights 340 images | 3 flights 259 images | 7 flights 599 images |
| LL | 2 flights 48 images | 2 flights 137 images | 4 flights 185 images |

Table 1. Flights and images in different areas. For the location of the HR, LR and LL areas, please refer to Fig. 5.

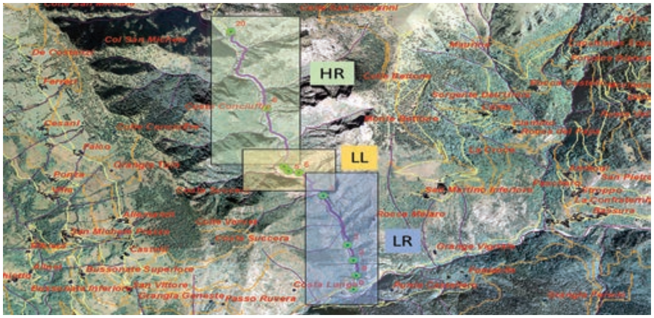


Figure 5. The three different areas of Vallone d'Elva route.

## 4. Photogrammetric data processing

The photogrammetric processing has been carried out with SfM algorithms using the commercial software AMS (Agisoft MetaShape professional), dividing the total amount of the gathered data in 3 different chunks. Nadiral and oblique images have been aligned together, setting up the "high" level of accuracy of AMS (i.e. using the photos at the original size). Then, some GCPs (Ground Control Points) used for georeferencing 3D models, and CPs (Check Points) to validate the obtained precision, have been collimated in all the images, obtaining the results shown in Table 2 and Table 3.

Three 3D dense point clouds have been produced with the "high" details level of AMS (which means that the original images were downscaled by a factor of 4 – i.e. 2 times by each side) in order to obtain some products suitable for a large-scale purpose (1:200), as shown in Table 4.

| | n. GCPs | ΔX [mm] | ΔY [mm] | ΔZ [mm] |
|---|---|---|---|---|
| HR | 17 | 39<br>**16** | 29<br>**13** | 53<br>**17** |
| LL | 9 | 10<br>**5** | 19<br>**9** | 10<br>**5** |
| LR | 13 | 20<br>**10** | 15<br>**7** | 34<br>**14** |

Table 2. Max/mean (bold) residuals on GCPs.

| | n. CPs | ΔX [mm] | ΔY [mm] | ΔZ [mm] |
|---|---|---|---|---|
| HR | 7 | 33<br>**14** | 13<br>**8** | 16<br>**10** |
| LL | 4 | 12<br>**8** | 7<br>**5** | 10<br>**7** |
| LR | 5 | 13<br>**9** | 17<br>**9** | 26<br>**15** |

Table 3. Max/mean (bold) residuals on CPs.

| | N° points [millions] | Processing time [hh:mm] | Density [points/dm$^2$] |
|---|---|---|---|
| LR | 199 | 05:49 | 8 |
| LL | 47 | 00:24 | 10 |
| HR | 268 | 03:46 | 6 |

Table 4. Millions of points, processing times and densities of dense point clouds.

High density point clouds (about 1 point each 4 cm) and a moderate level of noise have been obtained: some noisy points, caused by vegetation and border effects have been removed manually. The triangulated 3D models have been obtained using the setting "high" of AMS (i.e. using 1/5 of the number of points of the source dense point clouds), generating high resolution meshes in terms of faces and vertices number, as summarized in Table 5.The final steps had regarded the generation of the DSM and the relative orthophotos in the coordinates system WGS84 – UTM 32N using the relative meshes (detailed in Table 6), as shown respectively in Figure 6 and Figure 7.

## 5. DTM generation and multiscale GIS

Although filtering and segmentation of clouds from airborne flights is now a fairly consolidated procedure, the use of such high-detail clouds in complex environments with slopes and irregularities, makes it necessary to experiment "*ad-hoc*" workflow that supports the specific characteristics of the point clouds and the thick vegetation recognizing objects to be extracted, such as trees and buildings (Spanò et al. 2018). In this case, to obtain a DTM (Digital Terrain Model - without vegetation), two different filtering and classification approaches with AMS were tested (one completely automatic and another one semi-automatic). The first approach was not completely successful because of the complex orography of the area.

| | N. faces [millions] | N. vertices [millions] | Proc. time [hh:mm] |
|---|---|---|---|
| LR | 40 | 120 | 02:04 |
| LL | 0,1 | 0,1 | 01:26 |
| HR | 53 | 27 | 02:09 |

Table 5. Numbers of faces and vertices against processing times of the generated meshes.

| | DSM process. time [mm:ss] | Orthophotos process. time [mm:ss] |
|---|---|---|
| LR | 02:44 | 25:58 |
| LL | 00:09 | 00:14 |
| HR | 03:39 | 33:50 |

Table 6. DSM and Orthophotos processing times.

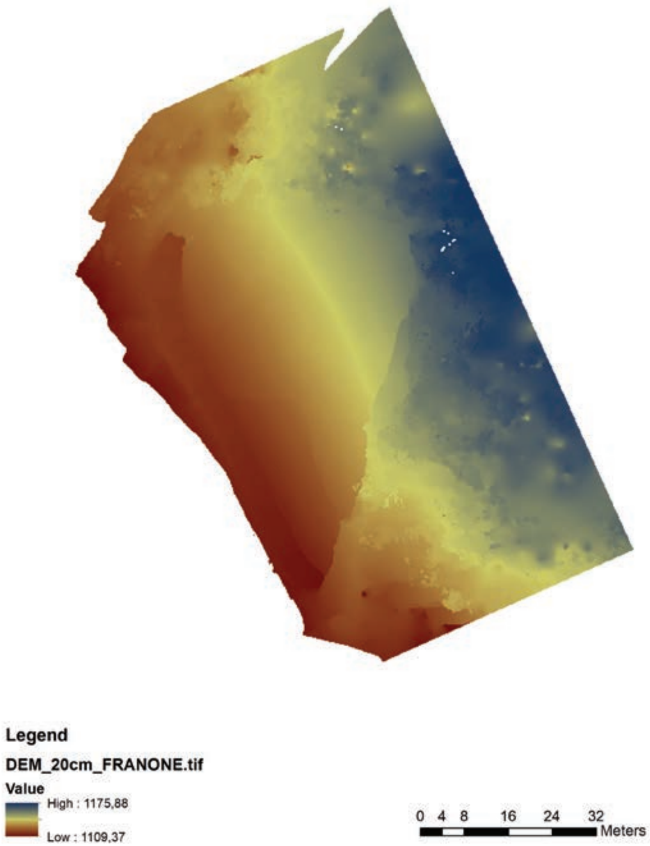


Figure 6. DSM generated on the LL site.


Figure 7. Orthophoto extracted by LL site.

The results of semi-automatic classification were acceptable: 75 % of the vegetation points were correctly detected, while were wrongly classified ground about 11 %, and the rest was unclassified; besides, 85 % of rock wall were correctly detected as ground, while 9 % were wrongly classified like buildings in "*quasi*" vertical parts. In the following (Figure 8) are reported the different between them and the critical issues found.
Starting from the ground classify points obtained, 3D surfaces have been generated to compute a DTM with a GSD of 20 cm. Analyses and post-processing phases have been developed using a multiscale approach, optimizing gradually the elaborations according to the operative aims. Specifically, we started with a regional analysis of the cultural and geological features of

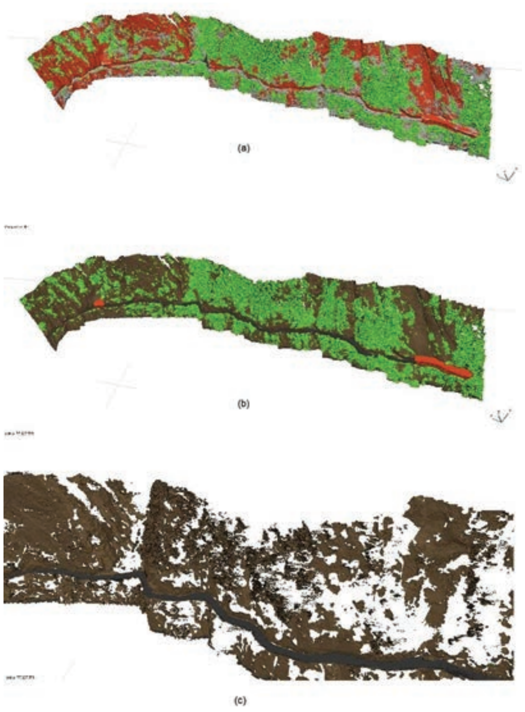


Figure 8. Classification map reporting classifying results: a) Automatic classification by "Classify Points" tools; b) Semi-automatic classification in AMS; c) Critical issues found cause of complex and steep geography. Red, green, brown and black points represent building, vegetation, ground and road respectively.

the entire valley of the Elva stream, establishing a GIS platform, show in (Figure 9). Finally, they allow an enhancement of all the landscape aspects of the Vallone d'Elva in order to create virtual tours (Bronzino et al. 2019).

## 6. A new product: the side road orthophoto

The larger scale data have been produced using terrestrial photogrammetry to obtain even more detailed 3D results, with a resolution in order to perform geological analyses on individual fractures/rock-walls

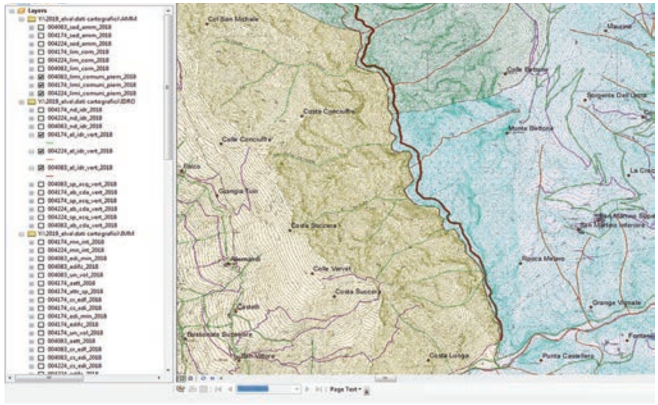

Figure 9. GIS platform for multiscale data visualization and analysis approach.

for landslides hazard and for touristic purposes and valorisation of this CLH. For an easier representation of geostructural features (such as sliding mechanisms, rock-wall fracture analysis, etc.) some vertical orthophotos were performed, as shown in (Figure 10). These orthophotos constitute an important aid in the design phase for feasibility studies, general and executive planning.

## 7. Conclusions and perspectives

For the CH study and validation regarding the Vallone d'Elva road, the most recent and current 3D detection technologies have played a significant role. The use of nadiral and oblique images from UAV was employed on a complex orography with a limited accessibility allowing to reduce survey costs in respect to more traditional survey technologies. Moreover, a terrestrial photogrammetric approach was used to exploit the pre-existent dense point clouds, obtaining an even more detailed feature of the landscape and cultural value of Vallone d'Elva, allowing to obtain an high level of detail and providing consistent and valuable material and results for the study of landslide hazards

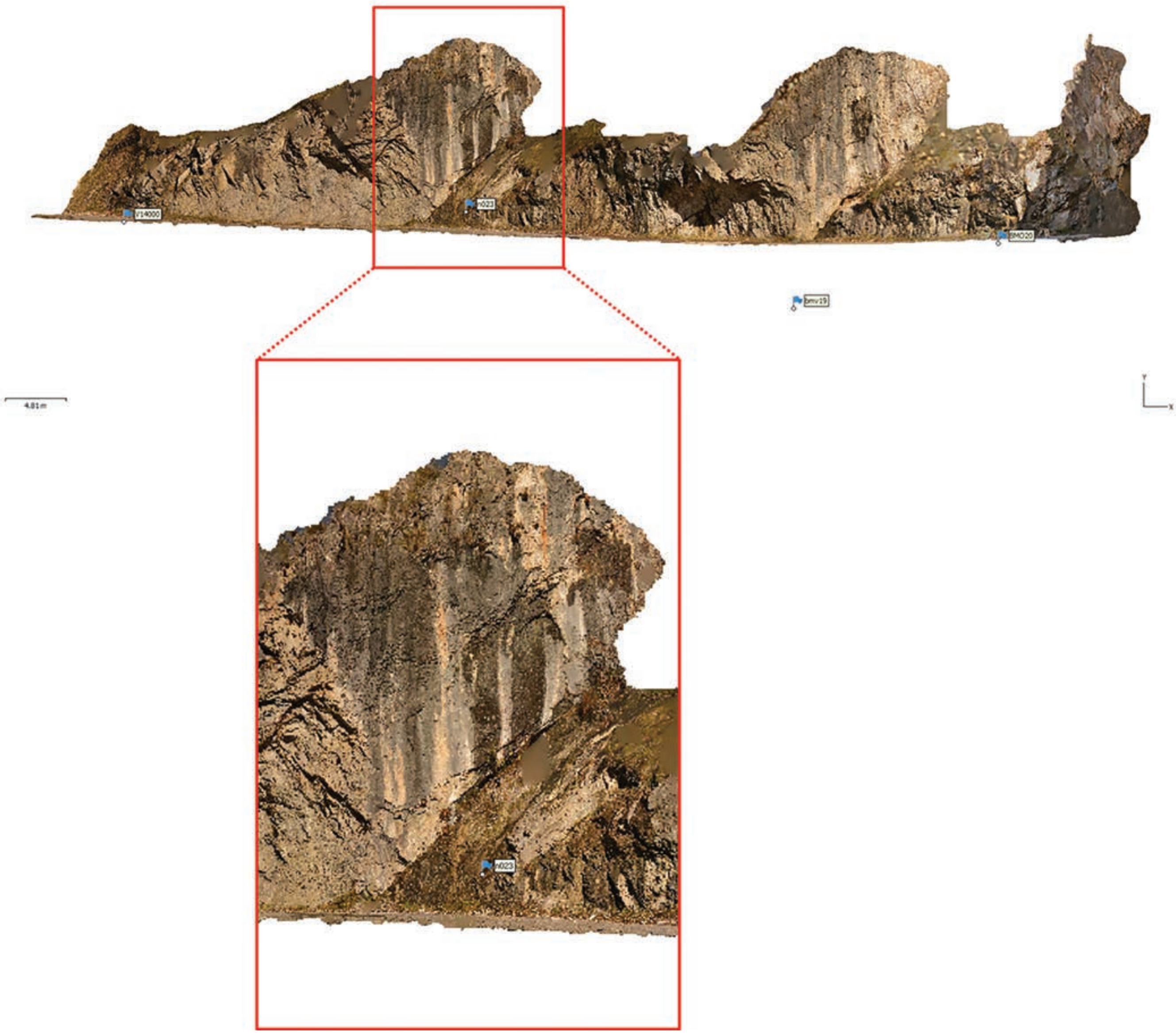

Figure 10. Vertical orthophoto on a particular side of SP104 rock-wall. Note the even more detail on the rock wall (red box).

and tourist valorisation of the road, the hamlets and the villages. The multiscale approach supply an effective representation of this complex object, useful for the aforementioned different purposes.

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## Bibliography

Artese G. (2015). *Geomatics Activities For Monitoring The Large Landslide Of Maierato, Italy. Applied Geomatics*, 7.3, 2015, pp. 171-188.

Balletti C. (2019). *Geomatics Techniques For The Enhancement And Preservation Of Cultural Heritage. International Archives Of The Photogrammetry, Remote Sensing & Spatial Information Sciences*.

Barba S. (2019). *Accuracy Assessment Of 3d Photogrammetric Models From An Unmanned Aerial Vehicle. Drones*, 3.4, 2019, pp. 79.

Bassani M. (2019). *Estimating The Available Sight Distance In The Urban Environment By Gis And Numerical Computing Codes. Isprs International Journal Of Geo-information*, 8.2, 2019, pp. 69.

Bemis S. P. (2014). *Ground-based And Uav-based Photogrammetry: A Multi-scale, High-resolution Mapping Tool For Structural Geology And Paleoseismology. Journal Of Structural Geology*, 69, 2014, pp. 163-178.

Bronzino G.p.c., (2019). *Laser-visual-inertial Odometry Based Solution For 3d Heritage Modeling: The Sanctuary Of The Blessed Virgin Of Trompone. International Archives Of The Photogrammetry, Remote Sensing & Spatial Information Sciences*.

Fissore F. (2017). *Digital Model Of Walls Of Padua Lowrelief. The International Archives Of Photogrammetry, Remote Sensing And Spatial Information Sciences*, 42, 2017, pp. 95.

Gili, J. A., (2000). *Using Global Positioning System Techniques In Landslide Monitoring. Engineering Geology*, 55.3, 2000, pp.167-192.

Kasperski, J., (2010). *Application Of A Terrestrial Laser Scanner (Tls) To The Study Of The Séchilienne Landslide (Isère, France). Remote Sensing*, 2.12, 2010, pp. 2785-2802.

Li Z., Zhu C., Gold C. (2004). *Digital Terrain Modeling: Principles And Methodology*. Crc Press.

Lindner G. (2016). *Uav Monitoring And Documentation Of A Large Landslide. Applied Geomatics*, 8.1, 2016, pp. 1-11.

Lingua A., (2017). *3d Model Generation Using Oblique Images Acquired By Uav. International Archives Of The Photogrammetry, Remote Sensing & Spatial Information Sciences*, 42, 2017.

Parrinello S., Picchio F., Dell'Amico A. (2018). *When The Future Is The Past. Digital Databases For The Virtualization Of Museum Collection. International And Interdisciplinary Conference On Digital Environments For Education, Arts And Heritage*. Cham: Springer, pp. 212-222.

Piras M., Di Pietra V., Visintini D. (2017). *3d Modeling Of Industrial Heritage Building Using Cotss System: Test, Limits And Performances. The International Archives Of Photogrammetry, Remote Sensing And Spatial Information Sciences*, 42, 2017, pp. 281.

Spanò A. (2018). *Gis-based Detection Of Terraced Landscape Heritage: Comparative Tests Using Regional Dems And Uav Data. Applied Geomatics*, 10.2, 2018, pp. 77-97.

Tucci G. (2019). *Monitoring And Computation Of The Volumes Of Stockpiles Of Bulk Material By Means Of Uav Photogrammetric Surveying. Remote Sensing*, 11.12, 2019, pp. 1471.

Watts A. C., Ambrosia V. G., Hinkley, Everett A. (2012). *Unmanned Aircraft Systems. Remote Sensing And Scientific Research: Classification And Considerations Of Use. Remote Sensing*, 4.6, 2012, pp. 1671-1692.