DOI: https://doi.org/10.5592/CO/EUROENGEO.2024.189

THREE-DIMENSIONAL MODELLING FOR THE DELINEATION OF HAZARD ZONES ON ROCKY SLOPES IN AREAS OF ARCHAEOLOGICAL INTEREST

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Abstract

With the development of technology and the ever-increasing needs in infrastructure projects, the application of new technology in all technical branches, as well as in the field of Engineering Geology and Rock slope engineering, is becoming more and more imperative. The use of drones for mapping large areas and slopes is now imperative and particularly useful. Also, the creation of a 3-d terrain model in the form of a point cloud data set is particularly useful for a large number of geotechnical analyses. This paper analyzes the process and parameters for the creation of a high-resolution 3-d terrain model, with the use of highly sophisticated programs (UgCS and ArcGIS-Drone2Map), which can be used for the delineation of hazard zones on rocky slopes and discontinuity kinematic analysis in sites of particular interest. Towards this scope several programs can be used (e.g. DSE and Rocscience's dips and rocfall3) to assess the quality of the rock-mass and its discontinuities, as well as the probability of rock falls. The process of performing all the above is not complex but requires familiarity. The study area of assessing this type of modelling is Acrocorinth, one of the most important archaeological sites in Greece, at which is necessary to analyse its vulnerability to rockfalls and design hazard zones.

Key words

Rockfalls, 3D terrain model, slope, disconinuities, rock mass.

1 Introduction

Acrocorinth is a 575 meter high cliff that dominates the plain of the modern and ancient city of Korinthos in Greece and is the largest and oldest fortress in the Peloponnese peninsula. It was constructed during the classical years and it played an important role through the ages due to its strategic position. The entrance area of the archaeological site is located at the entrance point of the Castle, where for defensive reasons it was originally built in a position particularly exposed to all kinds of natural hazards. It was continuously occupied from archaic times to the early nineteenth century (Athanasoulis, 2014). Today it is one of the most important archaeological sites in Greece, with many visitors and it is very important to analyse its vulnerability to rockfalls.

The current research analyzes the potentiality of rockfalls at the entrance of the archaeological site, the footbridge and the visitor access road and examines the wider area which is an active geomorphological field, where rockfalls have been occurring for centuries (Fig1). The phenomenon of rocks and boulders falling from the steep slopes of Acrocorinth is considered diachronic, while evidence of rockfalls already exists since ancient times. In the present research, due to the steep morphology and the difficulty of recording all discontinuities that prevail along the site's slopes, a drone with rtk and high-definition camera was used to survey the high and steep slopes. Purpose of this, was to create a high-resolution 3D terrain model that can clarify in detail the geometric features of the discontinuities of the rock mass as they have been described by Bieniawski (1989) as well as to detect rockfall seeders and characterise them based on the work of Volkwein et al (2011). Similar works, but not on archaeological sites, have been carried out by Saro et al (2018), Guzzetti et al (2002) and others.

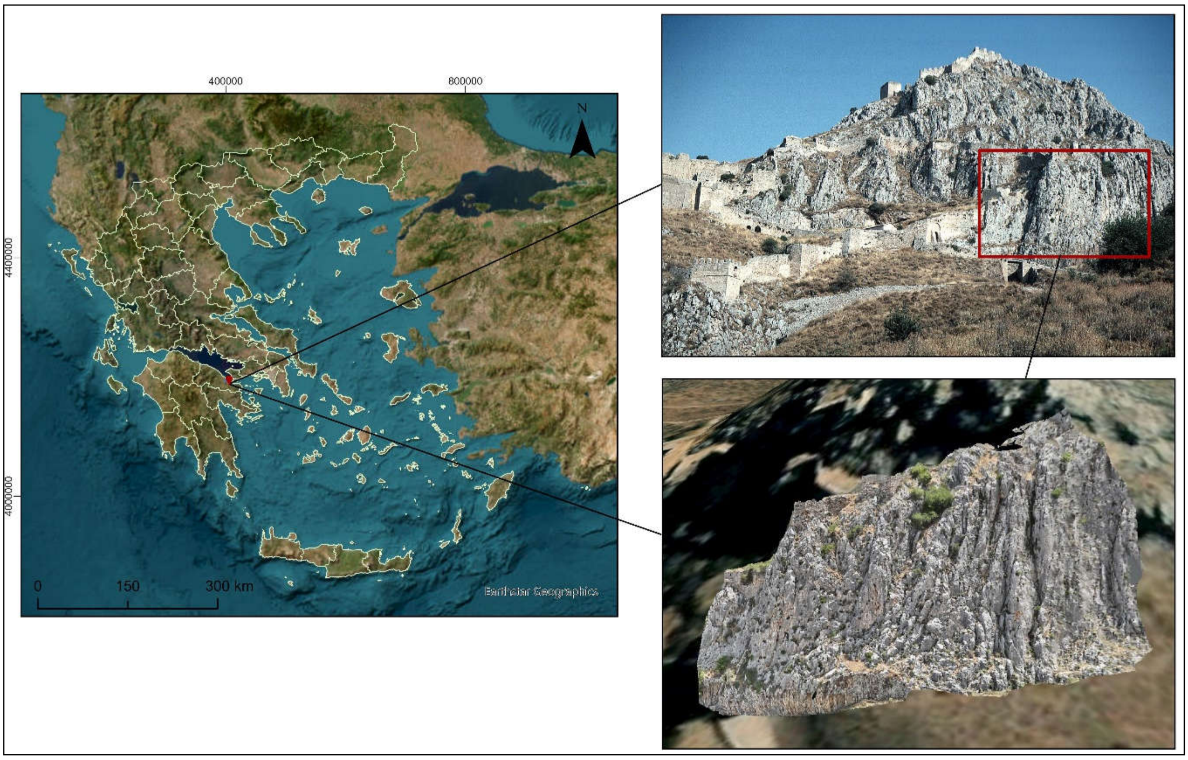

Figure 1. The steep rocky slopes of Acrocorinth in Greece and the area of study

2 Methods

2.1 Synopsis

The methodology used in the curerent reserach is based on the creation of a high-resolution terrain model from which all necessary information is derived for further analyses. This results in fewer file conversions, using core programs rather than using intermediate programs to convert files where errors occur and data reliability is lost. To achieve this, a planned drone flight is carried out through UgCS with flight data that give a GSD value<0.5cm, then the 3d terrain model is created with ESRI's ArcGIS-Drone2Map software, which is directly connected to ArcGISPro for further processing and filling in data without conversions. Having the high-resolution 3D model, the data is imported into the DSE software (Riquelme et al, 2015) to extract the rock mass characteristics (slope inclination and dip/dip direction of discontinuities). Data extracted from DSE are compared with measurements derived in the field with conventional methods (geological compass) and assessed with the use of Rocscience Dips program (licensed academic version 8.027) to check if further improvements are necessary in the digital proposed methodology. Moreover, the 3d terrain model is imported into the Rocscience RocFall3 program (licensec academic version 1.014) to determine the kinetic energy and bounce heigth of potential rockfalls in the entire area. Therefore, a complete digitized method is created to assess all potential risks arising from rock masses and their discontinuities, regardless of their accessibility.

2.2 Geological setting of the study area

Acrocorinth is a prominent tectonic structure, located WSW of the canal of Corinth representing a typical horst. The exposed alpine formations are believed to belong to the Pelagonian zone (Internal Hellenides). The stratigraphy includes Middle Jurassic limestones and various-colored shales with cherts (Collier et al, 1991). These shales either intercalate or lie on top of Middle Triassic-Lower Jurassic limestones. The alpine formations have been initially deformed by thrust faulting that was active in the

Pelagonian zone during Eocene – Latest Cretaceous. A north – south trending thrust fault, bounds the Acrocorinth to the west. Shales and Jurassic limestones occupied respectively the footwall and the hanging wall of this thrust. Generally, east-dipping low-angle thrust faults affect the Middle Jurassic limestones. Due to the latest extensional phase, high- angle normal faults were formed, affecting the pre-existing alpine structures. As a result, a series of neotectonic structures, such as horsts and grabens have been formed. A typical example of the above-mentioned structures is the Acrocorinth horst (Fig.2). This structure is bounded by two west – east trending normal faults downthrown to the north and to the south respectively. Thick Upper Pliocene-Pleistocene to Quaternary clastic sediments cover uncomfortably the alpine formations in the adjacent areas.

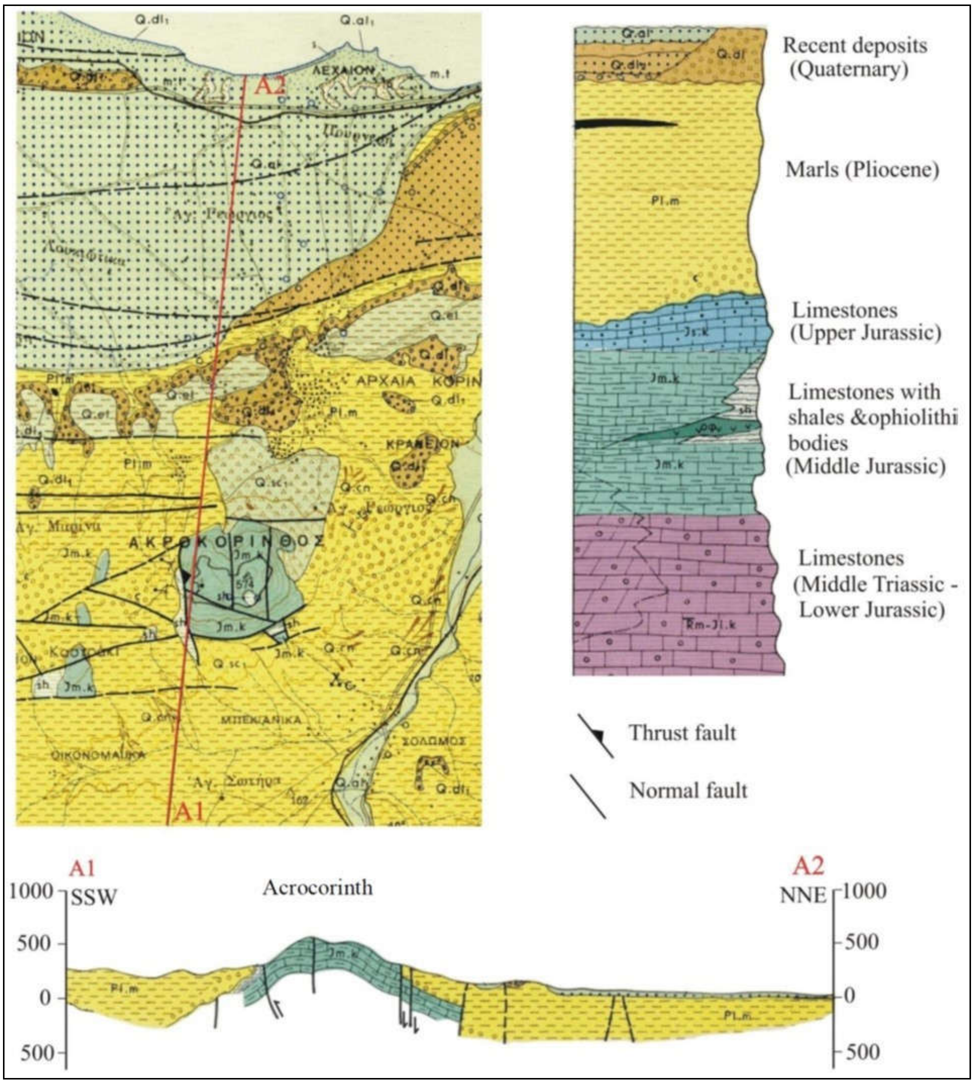

Figure 2. Geological setting of the Acrocorinth horst accompanied with a cross-section based on the Korinthos geological sheet (I.G.M.E, 1971)

2.3 Drone setting and flight planning

In order to achieve a correct and accurate 3D terrain model, some preparation is required in the field. Especially in this case, where through the terrain model conclusions and evidence about the discontinuities of the rock mass are exploited, it is very important to create a high-resolution terrain model with aerial photographs. With the rtk module that exists in the drone and the use of the UgCS program the flight is planned with the correct paths to ensure the necessary overlap between the photos, constant distance between drone and slope, accuracy in shooting position, and constant shooting angle.

All the above parameters contribute to the small value of the GSD index, which concerns the sharpness of the photos. It is worth noting that DJI provides a program for horizontal flight planning, but in this case, due to the existing steep slopes, a vertical flight was performed. Overall, through programming with the UgSC software the flight time was minimized and the minimum possible value of GSD for the accuracy of the 3d terrain model was achieved. Figure 3 shows the planned flight with the calculated data, flight time, number of photos, GSD, and area covered.

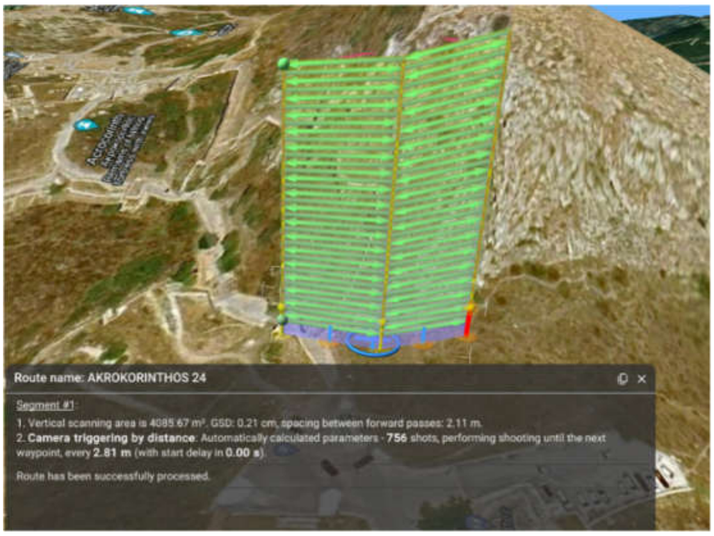

Figure 3. Scheduled flight with calculated data, flight time, number of photos, GSD, and area covered

2.4 3D terrain model

Agisoft Metashape and cloud compare programs are used in many corresponding tasks for similar works. However, in this research ESRI's drone2map software was used for two main reasons. Initially, it is a similar program to Agisoft Metashape but it communicates directly with Arcgis Pro where an advanced analysis can be carried out using directly additional data from other sources, such as cartographic, geological, climatic data, etc. Also, the type of file that is generated can be directly imported into other software programs related to discontinuity analysis like the DSE and Rocfall3, that are used for further stability and rockfall analysis.

After completing the flight all the aerial photos and flight data are imported into the drone2map software and the 3d terrain model is created having a high resolution and clarity for further extraction of the discontinuity characteristics of the examined rock mass. Because of the original flight design, there is no need for a higher resolution or sharpness than the existing, so that time and computing power is saved. Figure 4 shows the generated 3d terrain model of Acrocorinth, the drone's flight path and shooting locations and Table 1 presents the types of files created by the drone2map software.

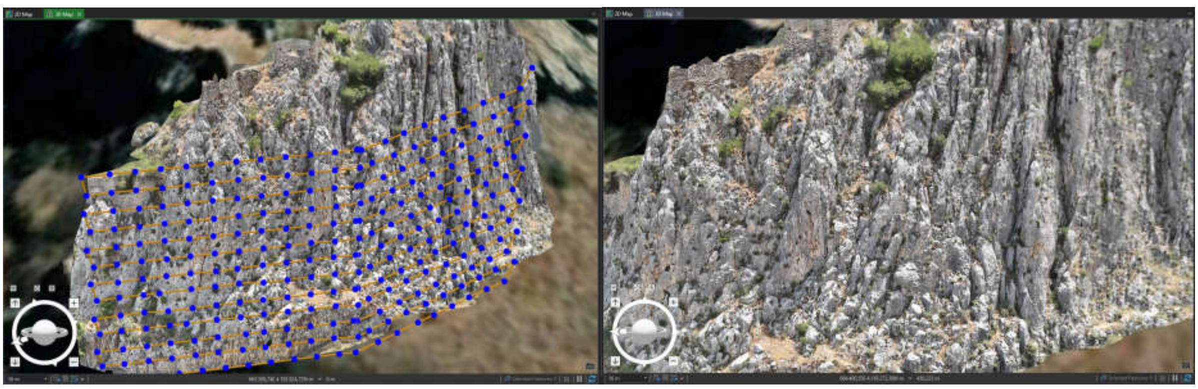

Figure 4. 3D terrain model of Acrocorinth with the drone's flight path and shooting locations

Table 2. Types of files created by the drone2map software

3D Products of Drone2Map		
Create point clouds	**Create DSM Texture Meshes**	**Create 3D Texture Meshes**
SLPK	SLPK	SLPK
LAS	DAE	DAE
Merge LAS Tiles	OBJ	OBJ
	OSGB	OSGB
	3D Tiles	3D Tiles

3 Results

3.1 Discontinuity analysis from field data

As mentioned before field measurements were took place in the research area of Acrocorinth with a detailed recording of 65 discontinuity planes along with their features (orientation in dip/dip direction, aperture, spacing, continuity, etc). All the recorded data were imported into the Rocscience Dips program (version 8.027) for further analysis. From the analysis perfromed the resulting stereodiagram was produced in which it is obvious that one major (1m: 79/189) and two minor discontinuity set planes (2m: 75/28 and 3m: 86/216) seem to prevail in the entire area (Fig 5).

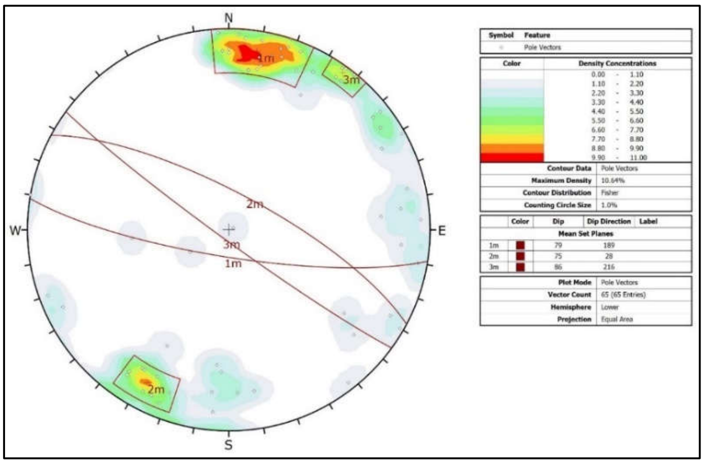

Figure 5. Stereodiagram of the discontinuity pole vectors (1m, 2m, 3m) and the major planes in the study area

3.2 Discontinuity analysis from digital data

As mentioned before the 3d terrain model created with ESRI's ArcGIS-Drone2Map software was imported into the DSE software (Riquelme et al, 2015) to extract the slope inclination and the dip/dip direction of discontinuities. The density and the percentage of the principal poles extraction from DSE are presented in Table 2. By comparing the field (Fig.5) and digital data (Table 2) it seems that there is a coincidence among the discontinuities 1m and J1, 2m and J6, 3m and J2. However, the major plane from both sets (1m and J1) gives a significant difference in the dip direction of 57^0, so that a further analysis of the digital data set is necessary to understand the reason of this difference.

Table 3. Density and principal poles extraction fron DSE

No	Dip⁰	Dip Dir⁰	Density	%
J1	76	246	2.09	48
J2	82	224	1.23	12
J3	56	318	0.55	14
J4	59	102	0.21	1
J5	89	339	0.20	3
J6	88	31	0.12	10
J7	89	92	0.11	10

3.3 Rock fall simulation

In the Acrocorinth cliff the three systems of discontinuities, as examined before, are the main factor in potential failures, with overturns and falls of rectangular pieces of small-medium size that can reach a size of 1-1.3 m^3. For this reason, the 3d terrain model that was created was particularly useful to simulate rockfalls in the entire research area (Fig 6).

Figure 6. Panoramic view of the Acrocorinth cliff in which the 3d terrain model was created

For this purpose, the Rocscience RocFall3 program (version 1.014) was used with several trajectories simulating the travelling of the detached rock blocks along the steep slopes of the research area. The results of the simulation were converted into raster-geotiff format files and imported into the ArcGIS Pro software for further processing and rendering of the required information (kinetic energies and rock bounce heights) at all points of the research area (Fig 7).

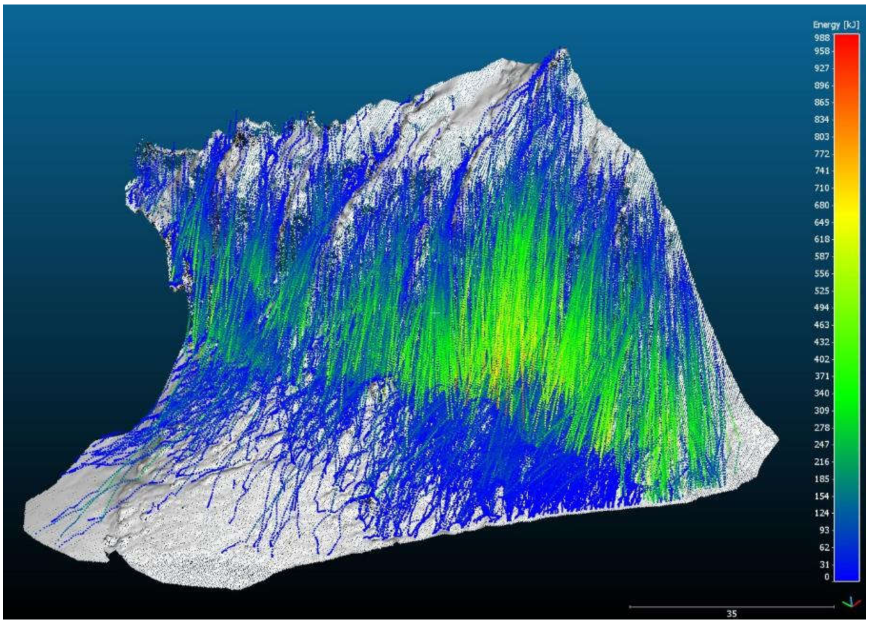

Figure 7. Image fragment (raster) of the distribution of kinetic energy in various trajectories of the rocks because of the simulations

The generated data in asci format can be processed as raster files and used as overlay information in 2D and 3D models of the topography across the survey area (Fig 8), so that it is possible to determine the kinetic energy and rock bounce height values for the selection of the most appropriate rock fall protective system at the most suitable location.

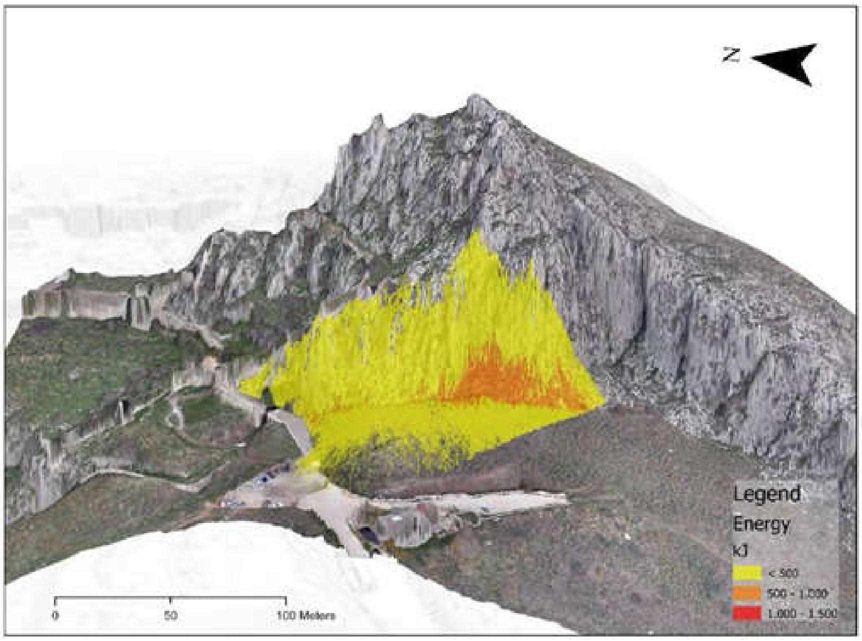

Figure 8. Distribution of the rockfall kinetic energy in the survey area with three zones of kinetic energy

The simulation discussed can be extended to the entire area of Acrocorinth, so that it is possible to identify hazard and risk zones and decide on the most appropriate protection measures in each zone, saving valuable time and money.

4 Conclusion

The classic process of discontinuity measurements through the geological compass is particularly time-consuming and requires direct access to the slope, which in many cases is not possible. Through the process of drone flight and the extraction of the characteristics of rock mass discontinuities, work time is significantly reduced, and data are obtained from hard-to-reach areas. In this procedure flight preparation and planning plays an important role, because it gives high-precision data that is useful in the later digital processing. Moreover, not many programs are used, so there is no need for many file conversions and the resulting data is considered highly reliable and useful for many purposes. The methodology presented in this paper was applied to the Acrocorinth cliff in Greece, an area of particular archaeological interest and the data collected in the field provided important information regarding the discontinuity features that control the kinetics of the cliff.

With reference to the discussed methodology, a 3D terrain model of high definition and precision was created with the correct use of photogrammetry methods, equipment and programs, to obtain reliable data for the discontinuities of the rock mass in question. The orientations (dip/dip direction) of three discontinuity planes extracted by the DSE software program through the specific high-resolution 3D terrain model were like those derived by the geological compass, but with a significant difference in the value of the dip direction in on one of the three discontinuity planes. It is a fact that the discontinuity data extracted from the proposed procedure need further investigation to minimize any errors, as well as the fact that the proposed procedure is promising and will solve many problems of rockmass kinetic analysis in areas where access is not feasible.

This method has all the necessary properties to be applied to various rocky slopes and infrastructure projects and to create hazard zones, as Depountis et al (2019) did on a major road in western Greece. This can be achieved by delineating different hazard zones in the 3D model created with the rockfall simulations performed in the entire study area, which distinguish the distribution of rock kinematics across the surface of the relief in different categories.

References

Athanasoulis, D. The castle of Acrocorinth and its enhancement project (2006-2009), Greece. *Hellenic Ministry of Culture and Tourism/ 25th Ephorate of Byzantine Antiquities*, 2014, 9-16.

Bieniawski, Z.T. Engineering Rock Mass Classifications: A Complete Manual for Engineers and Geologists in Mining, Civil, and Petroleum Engineering. *JohnWiley & Sons: Hoboken, NJ, USA*, 1989.

Collier, R.; Dart, C. Neogene to Quaternary rifting, sedimentation and uplift in the Corinth Basin, Greece. *Journal of the Geological Society of London*, 1991, 148, 1049-1065.

Depountis, N.; Nikolakopoulos, K.; Kavoura, K.; Sabatakakis, N. Description of a GIS-based rockfall hazard assessment methodology and its application in mountainous sites. *Bulleting of Engineering Geology and the Environment,* 2020, 79, 645–658

Guzzetti, F.; Crosta, G.; Detti, R.; Agliardi, F. STONE: A computer programm for the three-dimensional simulation of rock-falls. *Computers and Geosciences*, 2002, 28, 1079–1093.

I.G.M.E., Geological map of Korinthos, 1971.

Riquelme, A.J.; Abellán, A.; Tomàs, R. Discontinuity spacing analysis in rock masses using 3D point clouds. *Engineering Geology*, 2015, 195, 185–195.

Rocscience Inc., Toronto, Canada. *Academic Bundle License Software No.:21832-001*, 2024, issued to the Laboratory of Engineering Geology, University of Patras, Greece.

Sarro, R.; Riquelme, A.; García-Davalillo, J.C.; Mateos, R.M.; Tomás, R.; Pastor, J.L.; Cano, M.; Herrera, G. Rockfall simulation based on UAV photogrammetry data obtained during an emergency declaration: Application at a cultural heritage site. *Remote Sensing*, 2018, 10, 1923.

Scavia, C.; Barbero, M.; Castelli, M.; Marchelli, M.; Peila, D.; Torsello, G.; Vallero, G. Evaluating Rockfall Risk: Some Critical Aspects. Geosciences 2020, 10, 98.

Volkwein, A.; Schellenberg, K.; Labiouse, V.; Agliardi, F.; Berger, F.; Bourrier, F.; Dorren, L.K.A.; Gerber, V.; Jaboyedo, M. Rockfall characterisation and structural protection—A review. *Natural Hazards and Earth Systems Sciences, 2011*, 11, 2617–2651.