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Article

Close-Range Photogrammetry for non-intrusive prediction of geohazards: landslides

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Abstract: In recent years, the number of monitoring techniques developed for management of natural and engineered ground systems such as slopes, embankments, and retaining walls has significantly increased. The current study examines a slope stability problem near Kyrenia Castle, a 7th century castle located in Northern Cyprus. The landslide and accompanying reinforced concrete/stone walls, constructed for rehabilitation purposes, are monitored for a period of two years. The current condition of the site is back-analyzed using the finite element method (FEM) as a conventional analysis. To detect changes over time, close-range photogrammetry (CRP) is employed using photographs taken with an unmanned aerial vehicle (UAV) to generate a dense cloud model. The results demonstrate the compatibility of the CRP with FEM, making the technique a viable and efficient option for various engineered and natural ground systems. CRP is proved as an outstanding monitoring technic by being fast, cost-effective, sustainable, and non-destructive compared to conventional methods.

Keywords: Retaining Wall; Unmanned Aerial Vehicle (UAV); Close Range Photogrammetry (CRP); Monitoring; FEM

1. Introduction

Nowadays, a lot of attention is paid to the ecosystem and our surroundings. It is vital for humankind, regardless of where they live, to protect their environment from undesirable natural effects like geohazards. Methods for safeguarding and sustaining geotechnical assets such as slopes, retaining walls, embankments, etc., have improved over the past few decades in conjunction with advancements in construction techniques.

The soil is a natural major system composed of various elements that combine to form a wide range of geologic and biogenic systems. These systems operate autonomously, and the behavior and mode of failure in the soil system vary depending on the type, origin, and quantity of the involved elements [1]. It is essential to maintain geotechnical structures from any kind of failure, particularly those that occur over a long period of time with no obvious signs of rupture. These types of failures are often the result of inadequate design or maintenance, material degradation, the use of inappropriate backfill material, or poor drainage systems [2-5]. Monitoring movements and deformations in geotechnical structures is important because it allows for the detection and correction of anomalies at an early stage, thereby increasing the service life of the structure and preventing potential disasters. There are several methods for monitoring ge-

otechnical structures, including traditional methods such as precise leveling and total station surveying, as well as more advanced techniques that utilize technologies like global positioning system GPS, interferometric synthetic aperture radar (inSAR), and satellite or aerial photogrammetry.

Manual 3D reconstruction using handheld devices can be limited in its ability to produce accurate models of structures due to physical limitations. Using Unmanned Aerial Vehicles (UAVs), optimal scanning methods, and onboard machine learning algorithms may provide a more scalable and effective method for 3D reconstruction [6-9]. The use of UAV technology to investigate geotechnical assets could be important in the creation of safe and cost-effective structures. The advantages of sustainable and non-contact monitoring methods, such as high precision, automation, and artificial intelligence, are becoming increasingly apparent as displacement monitoring systems continue to advance [10].

Photogrammetry involves the reconstruction of objects from different images and perspectives. This method utilizes digital twin technology, which is a virtual copy of a physical object that accurately represents the properties and behaviors of its physical counterpart in the physical space through modeling and real-time data exchange, allowing for learning, reasoning, and dynamic recalibration to improve decision-making [11, 12]. Other studies have also highlighted the potential of photogrammetry in civil engineering applications, particularly in the monitoring and analysis of geotechnical assets such as slopes, embankments, and retaining walls [13]. Additionally, the integration of photogrammetry with other technologies such as laser scanning and GPS can provide more accurate and detailed information for monitoring and analysis [14]. The use of UAVs for photogrammetry has also been shown to be an efficient and cost-effective option for collecting data in remote or hard-to-reach areas [15]. Furthermore, there are studies that compared the use of Photogrammetry and other monitoring techniques such as inclinometer, total station or GPS and showed that photogrammetry is a more efficient and precise method in monitoring land movements and deformations [16, 17].

The integration of photogrammetry with other technologies and the use of UAVs can provide more accurate and detailed information for decision-making and risk management. Therefore, among various types of photogrammetry, the Close-Range Photogrammetry (CRP) is becoming more prevalent in engineering applications as computer processing power, data storage capacity, digital picture capture, and processing devices is improved. The main applications of close-range photogrammetry include measuring the deformation of structures, modeling buildings, documenting artifacts, performing reverse engineering, reconstructing traffic accidents, and criminal investigations. Close-range photogrammetry as a sustainable method has been extensively used since the 1960s, with applications in architecture and archaeology [18]. In 2018, Ekinci and Bazarbek adopted the CRP method to monitor the volume change behavior of small scaled stabilized clay samples. Traditional measuring methods have endorsed the CRP findings while considering the diameter and height of specimens both before and after testing [19]. The accuracy and potential of photogrammetric approaches have also been noted in various works in recent decades [20-24].

The current study aims to discuss the Close-Range Photogrammetry monitoring process through its application in a case study. The study area is close to Kyrenia castle, a historical place requiring high-level attention to keep it safe from any possible landslide or geohazard. We anticipate that the observations of the case study will indicate that close-range photogrammetry can be considered a routine monitoring method with the advantage of being cost-effective, non-destructive, and precise.

2. Materials and Methods

This study utilized the photogrammetry process which involved several steps, as outlined in Figure 1. A walkover survey and desk study were conducted to gather topographic data for the study area. Target locations were then plotted based on the initial data analysis and printed on laminated A4 paper for durability in various weather conditions. These retroreflective targets were placed on site to facilitate alignment between epochs, with the number of targets varying depending on the morphology of the research area. The targets served as ground control points and their positions were recorded using the Pentax Arrangement G6 GNSS (Global Navigation Satellite System). The utilization of ground control points enhances the precision of the generated point digital elevation model (DEM).

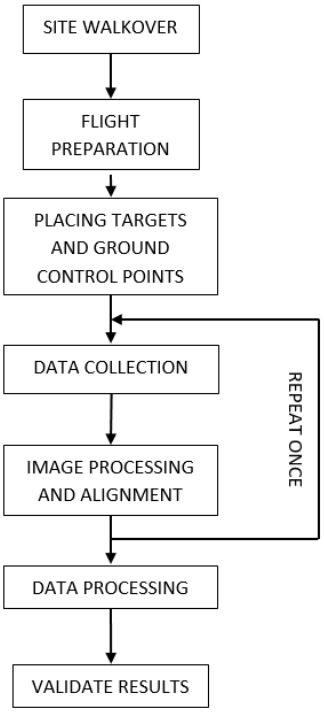

Figure 1. The aerial close-range photogrammetry procedure stages.

2.1. Image collection

Initially in this phase image collection was performed by taking numerous high-quality photos of the study area from various angles in different time lapses within a period of two years. Later, the 3D models were generated for each period of time and were compared to evaluate the displacement in the study area.

The study used a DJI PHANTOM 3 unmanned aerial vehicle (UAV) equipped with a 12-megapixel Sony EXMOR camera. This UAV remotely took 120 overlapping photos (with 70% overlap) at each point in time. The battery life and memory space of the camera were constantly checked during the process.

2.2. Image Processing

The image processing includes a three-step process: creating a 3D cloud, aligning the images to a map, and comparing the point clouds. Creating the 3D point cloud involves multiple steps that can be done using software such as PhotoScan (Agisoft), PhotoModeler, or open-source tools like Photosynth and Bundler [25, 26].

PhotoScan software was used for image processing, as it offers effective solutions for constructing multi-view 3D models. Hyper-scale 3D landform models were extracted using Structure-from-Motion (SfM) photogrammetry, which utilizes overlapping images taken from different angles [27, 28]. To enhance the accuracy of 3D point cloud construction, it is crucial to remove blurry or misaligned images. Using PhotoScan, the photographs are aligned by repeatedly adjusting the camera orientation and position through a least-squares alignment method. In this phase, the program creates a sparse model of point cloud and determines depth information by using calculated camera positions. The user can adjust the point cloud's quality and depth parameters. It has been found that removing noise and points outside the workspace before executing the dense cloud building process can improve the processing time and quality of the final dense cloud.

2.3. Data Processing

The final stage of data processing involved georeferencing and comparing point clouds from various epochs using software packages such as CloudCompare, I-Site Studio, or 3DReshaper. These software tools allow for the alignment of different epochs using reference points in various 3D models and provide the ability to compare point clouds in order to identify changes over time [29-31].

To process and compare the data from two dense 3D point clouds, the clouds from two different points in time were exported to CloudCompare in the (laz) file format. Before comparison, the point clouds were aligned using the Iterative Closed Point Processing algorithm of CloudCompare. It is important to ensure that the point clouds have a close overlap for optimal alignment. In some cases, manual selection of targets may be necessary when automatic alignment is not successful. It is essential to check non-moving targets off-site to properly align the point clouds.

3. Case Study

In this case study, the retaining walls of a slope located beside the Kyrenia Castle in the northern part of Cyprus were monitored (Figure 2) in over a two-year period. The retaining walls are located adjacent to the historical Kyrenia castle and the seashore-line, and therefore, the stability of them are of great importance from both archeological and environmental points of view. Additionally, it was important to secure the carpark and sports hall at the top of the slope. The walls seen on Figure 2 were constructed at different times and consists of reinforced concreate wall and gravity retaining wall combinations. Using the CRP method for this kind of situation helps preserving the areas in a sustainable way through saving working hours and cost [32].

Figure 2. The retaining walls in the adjacent Kyrenia Castle in Northern Cyprus.

3.1. Photogrammetry

In the photogrammetry process, the satellite photos of the area from 2008 to 2020 were obtained from google earth. As it is shown in Figure 3, in 2008 there were no significant problems with the slope; however, in 2010 the tip of the landslide, erosion area, started to appear. After three years when the destructive process of the landslide was continuing, the Kyrenia Municipality decided to construct retaining walls to protect the slope in 2013, as shown in Figure 3. Due to the lack of proper design, the footing of the walls is embedded over the slide instead of passing through it. Therefore, these walls not only fail to reinforce the slope from sliding but also aggravated it with their undesirable excess load. Based on the last photo taken in 2020, the landslide process has led to destruction of the half of car park in the picture in comparison with the photo taken in 2008.

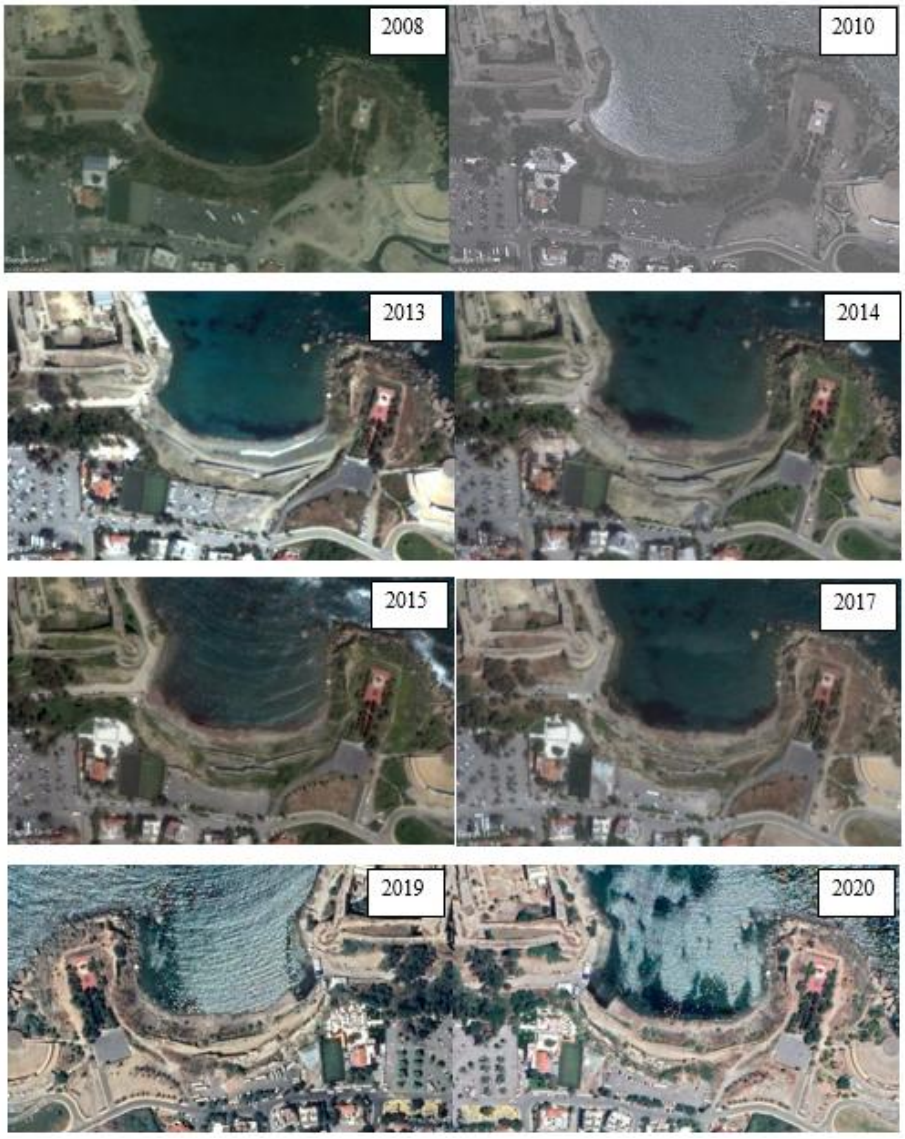

Figure 3. The satellite photos of the study area in different years.

In respect to steps given on Figure 1, the photogrammetry process was performed by using an UAV. A dense cloud was created, which can be seen in Figure 4. The photogrammetry process has been done in over a period of 2 years.

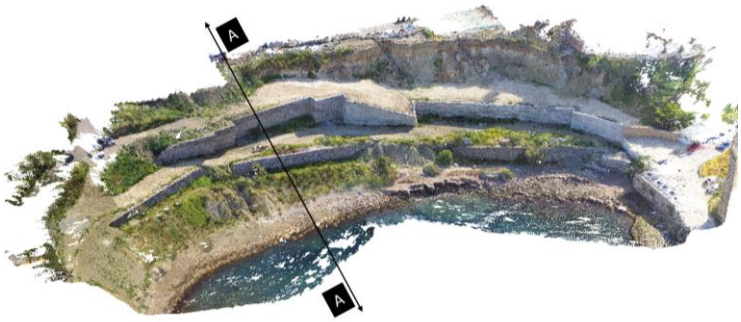

Figure 4. The study area's point cloud and the position of the section chosen for comparison with the FEM.

Each pixel of the photo in Figure 4 contains geometric data, the results of comparing these data in different epochs reveals the movement process of the wall in the section A-A (Figure 4).

As it is demonstrated in Figure 5, a significant displacement of about 40 cm has occurred between epoch-1 and epoch-2 in the wall from January 2018 to December 2019 period.

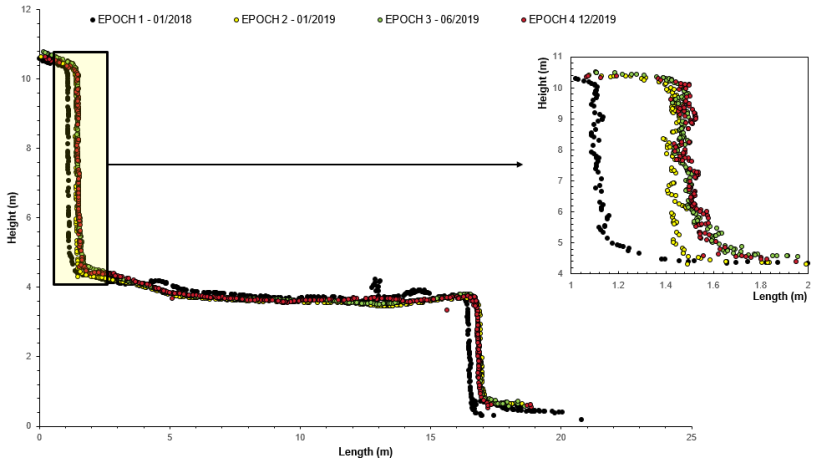

Figure 5. Comparison of epochs at section A-A with close-range photogrammetry method.

3.2. Numerical Analyses

In order to determine the current condition of the site and validate the results obtained from the photogrammetry study Finite Element Method (FEM) software packages, namely Geo5 and Plaxis 2D, were used in this study to analyze the area in the 2D. It is essential to give the most accurate soil parameters to the software as input to achieve a successful numerical model. In this respect site investigation was performed on the area. Standard penetration test was performed, and undisturbed samples were taken to preform laboratory test. Sieve analysis, consistency limit tests, consolidation and consolidated drained tests were performed on undisturbed samples. As a result of all site and lab tests an ideal soil profile was formed so that it can be imputed to numerical analyses. It is also important to use accurate topographical data in slope stability analysis. In this respect A-A section seen on Figure 4 was exported to the numerical analysis software as a surface geometry. Therefor the photogrammetric study aided the topography requirements of the study as well. The Figure 6 shows that the observed slide has both rotational and transitional features. The other main part revealed in the investigation via the FEM tools was the presence of the toe of the slide in the sea. The movement vectors in the photo express the direction of the slide and there is no force to resist the movement.

These findings are in agreement with the photogrammetry study. As it can be seen in Figure 6. the toe is displayed below the sea level and this observation is of great importance for the design process of any future support structure.

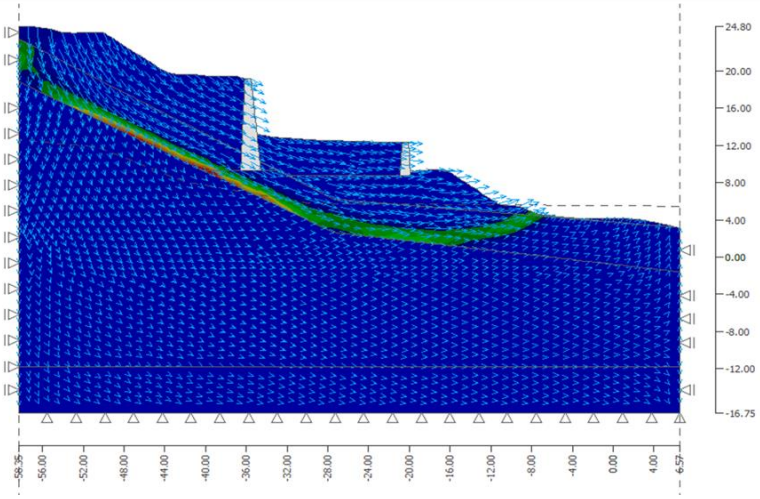

Figure 6. The schematic picture of the slide was generated with the geo5 software.

To clarify that toe of the slide extended into the sea, at the mentioned point, a bathymetric survey was adopted. The bulge area was surveyed by a GNSS equipment, and the topography results proved that the toe of the slide was located in the water as shown in Figure 7.

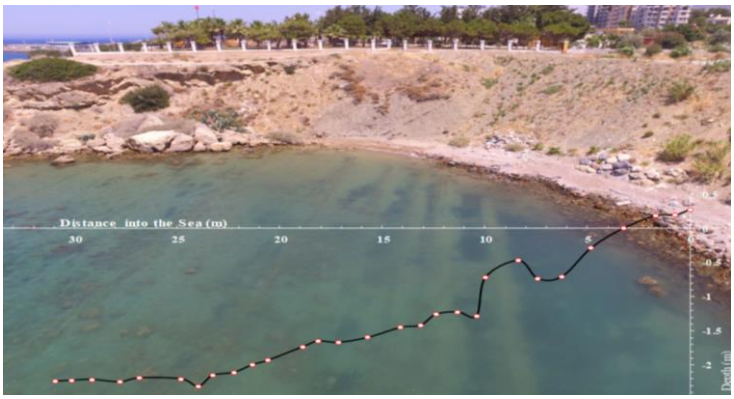

Figure 7. The bathymetric survey of the slide's toe in the sea with the GNSS.

4. Conclusions

In this study, close-range photogrammetry was used to monitor the slope adjacent to the historical Kyrenia Castle. The results of this method were validated through numerical analyses with numerical software packages. The study compared the movement of the slope over a two-year period, from January 2018 to December 2019, and found that the slope moved more in the first year than it did in the whole two years. It was also observed that the slope can still experience significant movement after sliding for 8 years. The study concludes that the retaining walls built on the slope have actually accelerated the sliding process, and that the toe of the slide was located in the sea, as confirmed through depth measurement using GNSS. This indicates that the retaining walls are not effective in preventing the slide, even if they are designed properly. The findings in the mentioned case study demonstrate that close-range photogrammetry is a reliable, cost-effective, non-destructive, and accurate method for monitoring slopes and retaining walls and can be a valuable tool in geotechnical engineering helping to prevent sudden failures and further maintenance expenses. It also indicates that the slope stability of

critical assets should be continuously monitored and evaluated, and the design and maintenance of the retaining walls should be reconsidered and reviewed to avoid further damage or collapse.

Author Contributions: All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Abdullah Ekinci. The first draft of the manuscript was written by Mehrdad Nategh and Anoosheh Iravanian and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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References

1. Assadi-Langroudi A, O'Kelly BC, Barreto D, Cotecchia F, Dicks H, Ekinci A, Garcia FE, Harbottle M, Tagarelli V, Jefferson I, Maghoul P. Recent advances in nature-inspired solutions for ground engineering (NiSE). International Journal of Geosynthetics and Ground Engineering. 2022 Feb;8(1):3. **https://doi.org/10.1007/s40891-021-00349-9**
2. Anderson SA, Rivers BS. Capturing the impacts of geotechnical features on transportation system performance. InGeo-Congress 2013: Stability and Performance of Slopes and Embankments III 2013 (pp. 1633-1642). **https://doi.org/10.1061/9780784412787.164**
3. Budhu, M. Soil mechanics & foundations. Hoboken: John Wiley & Sons Inc. (2000).
4. Duncan, C. I. Soils and foundations for architects and engineers. Springer Science & Business Media (1998).
5. Mohammad TR. Failure of a Ten-Storey Reinforced Concrete Building Tied to Retaining Wall: Evaluation, Causes, and Lessons Learned. InStructures Congress 2005: Metropolis and Beyond 2005 (pp. 1-9). **https://doi.org/10.1061/40753(171)239**
6. Chan TH, Hesse H, Ho SG. LiDAR-based 3D slam for indoor mapping. In2021 7th International Conference on Control, Automation and Robotics (ICCAR) 2021 Apr 23 (pp. 285-289). IEEE. **https://doi.org/10.1109/ICCAR52225.2021.9463503**
7. Mauriello ML, Froehlich JE. Towards automated thermal profiling of buildings at scale using unmanned aerial vehicles and 3D-reconstruction. InProceedings of the 2014 ACM international joint conference on pervasive and ubiquitous computing: adjunct publication 2014 Sep 13 (pp. 119-122). **https://doi.org/10.1145/2638728.2638731**
8. Shim CS, Dang NS, Lon S, Jeon CH. Development of a bridge maintenance system for pre-stressed concrete bridges using 3D digital twin model. Structure and Infrastructure Engineering. 2019 Oct 3;15(10):1319-32. **https://doi.org/10.1080/15732479.2019.1620789**
9. Spreitzer G, Tunnicliffe J, Friedrich H. Large wood (LW) 3D accumulation mapping and assessment using structure from Motion photogrammetry in the laboratory. Journal of Hydrology. 2020 Feb 1; 581:124430. **https://doi.org/10.1016/j.jhydrol.2019.124430**
10. Chae BG, Park HJ, Catani F, Simoni A, Berti M. Landslide prediction, monitoring and early warning: a concise review of state-of-the-art. Geosciences Journal. 2017 Dec; 21:1033-70.
11. Glaessgen E, Stargel D. The digital twin paradigm for future NASA and US Air Force vehicles. In53rd AIAA/ASME/ASCE/AHS/ASC structures, structural dynamics and materials conference 20th AIAA/ASME/AHS adaptive structures conference 14th AIAA 2012 Apr 23 (p. 1818). **https://doi.org/10.2514/6.2012-1818**
12. Grieves M. Digital twin: manufacturing excellence through virtual factory replication. White paper. 2014 Mar;1(2014):1-7.
13. Bemis SP, Micklethwaite S, Turner D, James MR, Akciz S, Thiele ST, Bangash HA. Ground-based and UAV-Based photogrammetry: A multi-scale, high-resolution mapping tool for structural geology and paleoseismology. Journal of structural geology. 2014 Dec 1; 69:163-78. **https://doi.org/10.1016/j.jsg.2014.10.007**
14. El-Omari S, Moselhi O. Integrating 3D laser scanning and photogrammetry for progress measurement of construction work. Automation in construction. 2008 Dec 1;18(1):1-9. **https://doi.org/10.1016/j.autcon.2008.05.006**
15. Wen F, Wolling J, McSweeney K, Gu H. Unmanned aerial vehicles for survey of marine and offshore structures: a classification organization's viewpoint and experience. InOffshore Technology Conference 2018 Apr 30. OnePetro. **https://doi.org/10.4043/28950-MS**
16. Mora P, Baldi P, Casula G, Fabris M, Ghirotti M, Mazzini E, Pesci A. Global Positioning Systems and digital photogrammetry for the monitoring of mass movements: application to the Ca'di Malta landslide (northern Apennines, Italy). Engineering geology. 2003 Feb 1;68(1-2):103-21. **https://doi.org/10.1016/S0013-7952(02)00200-4**
17. Gili JA, Corominas J, Rius J. Using Global Positioning System techniques in landslide monitoring. Engineering geology. 2000 Feb 1;55(3):167-92. **https://doi.org/10.1016/S0013-7952(99)00127-1**
18. Atkinson KB, editor. Close range photogrammetry and machine vision. Whittles; 1996.
19. Ekinci, A., Bazarbek, Y. "Evaluating Shrinkage Behaviour of Stabilised Cyprus/Kythrea Group Clays Using Close-Range Photogrammetry and Free Shrinkage". 26th European Young Geotechnical Engineering Conference. Tschuchnigg, F., & Schweiger, H. (Eds.) (2018).
20. Sturzenegger M, Stead D. Close-range terrestrial digital photogrammetry and terrestrial laser scanning for discontinuity characterization on rock cuts. Engineering Geology. 2009 Jun 12;106(3-4):163-82. **https://doi.org/10.1016/j.enggeo.2009.03.004**

21. Coggan JS, Wetherelt A, Gwynn XP, Flynn ZN. Comparison of hand-mapping with remote data capture systems for effective rock mass characterisation. In11th ISRM Congress 2007 Jul 9. OnePetro.
22. Martin CD, Tannant DD, Lan H. Comparison of terrestrial-based, high resolution, LiDAR and digital photogrammetry surveys of a rock slope. In1st Canada-US Rock Mechanics Symposium 2007 May 27. OnePetro.
23. Krosley L, Oerter E, Ortiz T, Ortiz TY. Digital ground-based photogrammetry for measuring discontinuity orientations in steep rock exposures. InGolden Rocks 2006, The 41st US Symposium on Rock Mechanics (USRMS) 2006 Jun 17. OnePetro.
24. Ekinci A, Muturi T, Ferreira PM. Aerial close-range photogrammetry to quantify deformations of the pile retaining walls. Journal of the Indian Society of Remote Sensing. 2021 May; 49:1051-66.
25. Harwin S, Lucieer A. Assessing the accuracy of georeferenced point clouds produced via multi-view stereopsis from unmanned aerial vehicle (UAV) imagery. Remote Sensing. 2012 May 30;4(6):1573-99. **https://doi.org/10.3390/rs4061573**
26. Snavely N, Simon I, Goesele M, Szeliski R, Seitz SM. Scene reconstruction and visualization from community photo collections. Proceedings of the IEEE. 2010 Jun 10;98(8):1370-90. **https://doi.org/10.1109/JPROC.2010.2049330**
27. Eltner A, Sofia G. Structure from motion photogrammetric technique. InDevelopments in Earth surface processes 2020 Jan 1 (Vol. 23, pp. 1-24). Elsevier. **https://doi.org/10.1016/B978-0-444-64177-9.00001-1**
28. Santagati C, Inzerillo L, Di Paola F. Image-based modeling techniques for architectural heritage 3D digitalization: limits and potentialities. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 2013 Sep;5(w2):555-60.
29. Vazaios I, Vlachopoulos N, Diederichs MS. Integration of lidar-based structural input and discrete fracture network generation for underground applications. Geotechnical and Geological Engineering. 2017 Oct; 35:2227-51.
30. Lato MJ, Vöge M. Automated mapping of rock discontinuities in 3D lidar and photogrammetry models. International journal of rock mechanics and mining sciences. 2012 Sep 1; 54:150-8. **https://doi.org/10.1016/j.ijrmms.2012.06.003**
31. Dewez TJ, Girardeau-Montaut D, Allanic C, Rohmer J. FACETS: A CLOUDCOMPARE PLUGIN TO EXTRACT GEOLOGICAL PLANES FROM UNSTRUCTURED 3D POINT CLOUDS. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences. 2016 Jul 16;41.
32. Orihuela A, Molina-Fajardo MA. UAV photogrammetry surveying for sustainable conservation: the case of mondújar castle (Granada, Spain). Sustainability. 2020 Dec 22;13(1):24. **https://doi.org/10.3390/su13010024**