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Using UAV for the digital, documentation, monitoring of culture architectural heritage: a case study of Sisheng ancestral hall, Shenzhen, China

Architectural heritage preservation and dissemination are an important and interesting field in Cultural Heritage. However, for the surveying, mapping and monitoring of architectural heritage, traditional survey methods cost a lot, take much time, and easily cause secondary damage to ancient architectural heritage. Due to the high efficient of the Unmanned Aerial Vehicle (UAV) which may be a smart solution for safe and fast data collection, Taking the Sisheng ancestral hall as a case study, this paper obtains a high-precision point cloud data model and creates an HBIM model through UAV data, which provides a workable solution for the digital protection and the monitoring of architectural heritage. The collected data is processed not only to provide reference data support for cultural relics protection, but also as a reference for long-term heritage monitoring.

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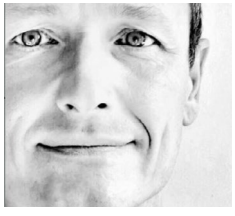

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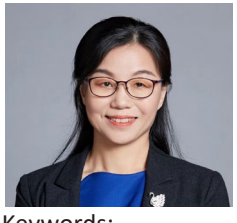

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Keywords:
UAV; Digital documentation; Monitoring; Digital protection; HBIM

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1. INTRODUCTION

Architectural heritage preservation and dissemination are an important topic in Cultural Heritage in all the world. As ancient buildings have dangerous or difficult to access areas, Unmanned Aerial Vehicle (UAV) may be a smart solution for safe and fast data collection [1]-[2]. For the surveying, mapping and monitoring of architectural heritage, traditional survey methods consume a lot of money, take a long time, and easily cause secondary damage to ancient architectural heritage. In recent years, drone technology has continued to rise, especially the rapid development of small intelligent drone technology [3]. Drones equipped with different sensors can comprehensively and quickly obtain large-scale building information, three-dimensional image remote sensing images, and are important for archaeological research and architectural heritage protection [4].
This paper introduces the technologies and methods of the application of UAV images in the protection of architectural heritage with examples, and shows that UAV images provide new technical support for the protection of cultural relics. The collected data is processed not only to provide reference data to support for cultural relics protection projects, but also as a reference for long-term heritage monitoring.

2. CASA STUDY

Fenghuang Ancient Village is located at the foot of Fenghuang Mountain in Shenzhen, China. It is an ancient village with a history of more than 700 years. There are currently more than 60 well-preserved residential buildings from 1600 to 1800, which have important historical and cultural value. They have been recognized by Shenzhen cultural relics experts as the only undamaged and well-preserved ancient architectural complex in Shenzhen.
Using the Sisheng Ancestral halls as a case study, this research focus on the process of obtaining the data through drones, and then carrying out digital protection and restoration (Fig. 1). It is located on the south side of Fenghuang village and built in Late Qing Dynasty (about 1840-1860), Sitting northeast to southwest. The hall has three bays, one main entrance and one courtyard. Its width is 9.7 meters, its depth is 14.5 meters and covers an area of 140.65 square meters. The building is brick-wood-stone structure, plain brick wall, stone wall foundation and stone wall corner. A stone plaque inscribed with "Sisheng's Ancestral Hall" is hung on the concave door. There are paintings under the eaves, woodcarving figures, flower and eaves boards. There is Lang Fang (houses) on both sides of the courtyard. Stone pillars are erected in the back hall, with a beam construction mixed column and tie with post and lintel. Gable roof, bake hall is an ear-shaped fire seal, gray plastic antique purlin, two-sides slope, red titles, green glazed tiles.

Fig. 1 The photos of Sisheng ancestral hall

3. METHODOLOGY ACQUISTION

According to the research results of this topic and the current data collection standards that can be achieved by UAV oblique photography, combined with the current software and hardware status of the team, the operation is divided into four stages: Previous preparation, Outdoor operation, Data processing and Data application. Its specific work flow is shown in Fig. 2:

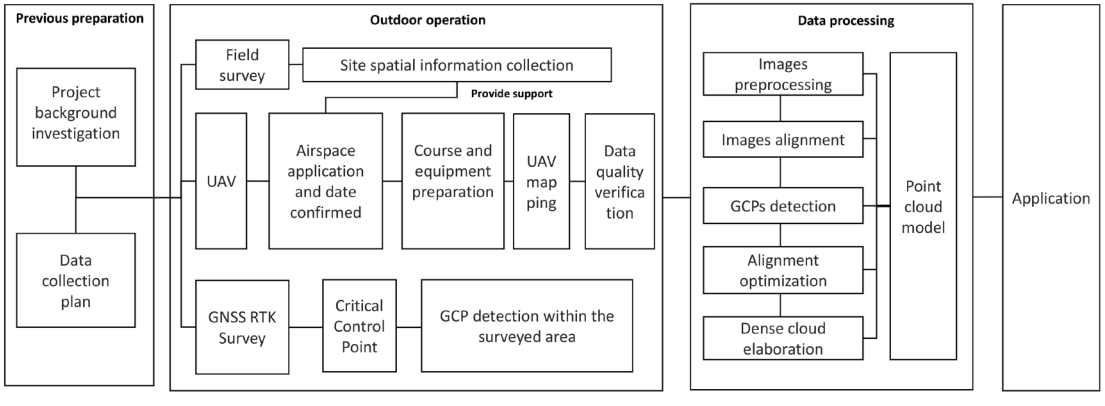

Fig. 2 UAV operation process for architectural heritage

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(1) Previous preparation. It is the stage of formulating the overall observation and surveying and mapping plan. The drone is launched at a height of about 50 meters for preliminary flight operations to obtain relevant image data such as surveying and mapping the overall space of the building and surrounding environment information. The image information fed back by the drone, combined with the relevant historical documents, can be used for the preliminary assessment of the building value. The aerial photography range, path and accuracy can be designed according to the measurement requirements.
(2) Outdoor operation. It is the stage of close-up measurement of a single building. The working height of the drone does not exceed the building body. The multi-angle, close-up and high-precision shooting operations must meet the professional needs of the protection of the single building, so as to ensure that the building details are truly reflected [2]. As shown in Fig. 3.

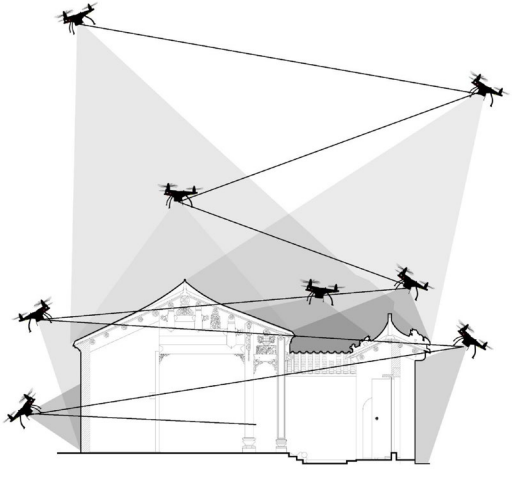

Fig.3. Flight-paths for drone

(3) Data processing. It is the stage of using relevant photogrammetry software, such as Pix4D, Agisoft Metashape, etc., to processing the collected data and import RTK data. Finally, a building point cloud information model with absolute elevation information is generated, as shown in Fig. 4

Fig.4. 3D model of oblique photography

4. RESULT AND DISCUSSION

4.1 Digital documentation (HBIM)

As a new type of modern surveying and mapping technology, UAV remote sensing is widely used in ancient building surveying and mapping due to its high efficiency and high precision. The 3D reconstruction of ancient buildings using the acquired point cloud data is an important part of the protection of ancient buildings, and the digitization of ancient buildings can realize 3D digital information management, and can easily query and analyze the space and attribute information of ancient buildings [4].
Its main workflow is shown in Fig. 5.
HBIM model can manage, monitor in real time and save ancient building information, and provide support for the management, protection, repair, overall translation and off-site restoration of ancient buildings. It provides detailed and accurate engineering data for the restoration of damaged ancient architectural cultural heritage, and has practical application value for the research, utilization, dissemination and sharing of the value of these precious architectural cultural relics.
Taking the Sisheng ancestral hall as an example, the point cloud model obtained by the drone can also be used as a reference for HBIM modeling. The cross-sectional profile of the building can be

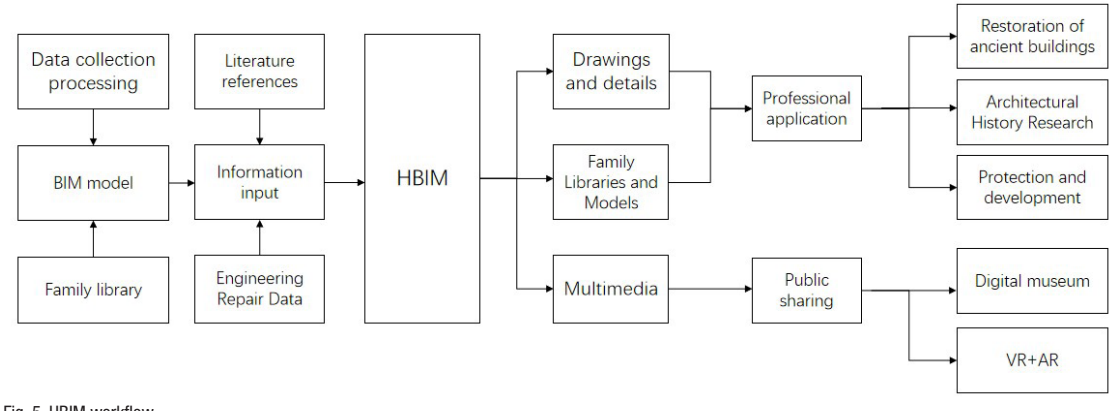

Fig. 5. HBIM workflow

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obtained from the point cloud model. Except for geometric data, data of material types, physical properties, and structural forms can be also gradually added to the BIM model, as shown in Fig. 6.

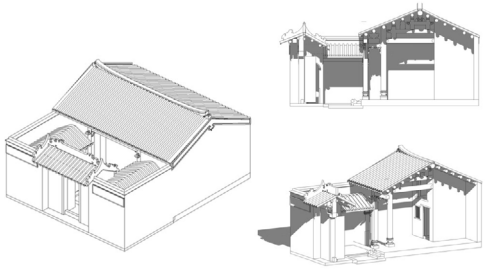

Fig. 6 - HBIM model of Sisheng ancestral hall

An HBIM model with extremely high geometric accuracy and a large amount of construction engineering information can become a database for integrated management of architectural heritage, and can be continuously enriched and improved with the update of measurement data (see Fig. 6). Due to the irregular shapes and low accessibility, there is not easily measured by hand. From image acquisition by drone to point cloud generation to HBIM modeling, the entire process is more convenient and accurate.
The characteristics of the composition of ancient Chinese buildings consist of different building components which are connected by tenon and mortise. This composition system is consistent with the combination of various families of BIM. Therefore, one of the main achievements of the HBIM process for the Sisheng ancient buildings in Fenghuang Village is the creation of a component family library. See Fig. 7-8. The introduction of HBIM technology and the proposal of digital protection technology for ancient buildings in Fenghuang Village mark that the protection work has moved from two-dimensional manual repair to the era of information-based protection.

4.2 Data monitoring

The daily monitoring of architectural heritage is no

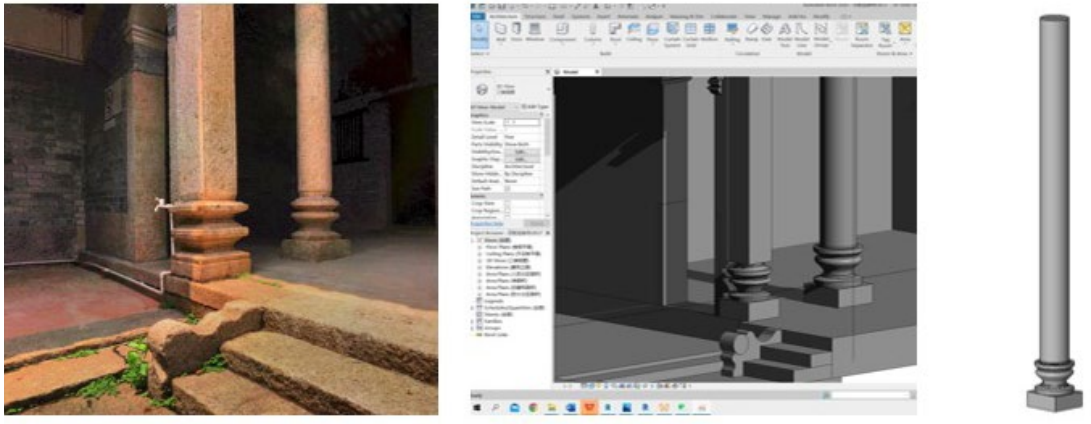

Fig. 7. BIM family of HIBM

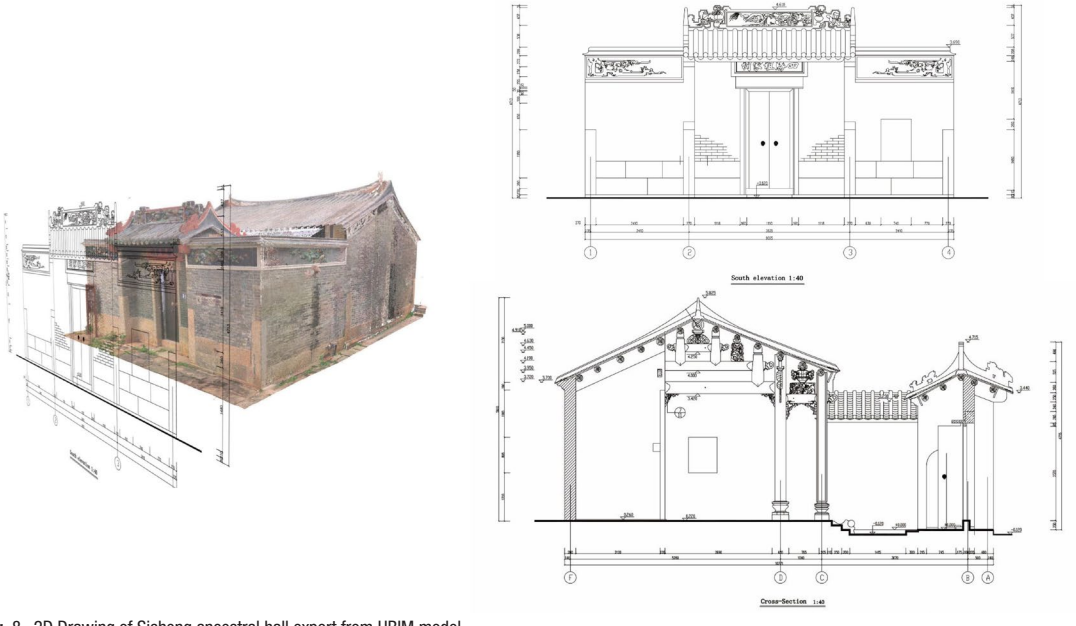

Fig. 8. 2D Drawing of Sisheng ancestral hall export from HBIM model

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longer cumbersome manual monitoring. Through regular monitoring work, some "symptoms" such as building deformation, settlement, weathering, damage, etc. in the architectural heritage can be found in time.Then using digital means conducts disease analysis to find out the problem, adjust the protection management method in a targeted manner, and formulate protection and repair measures.

The content of architectural heritage monitoring is mainly divided into the health monitoring of architectural heritage itself, the surrounding environment and social environment of architectural heritage, etc. The monitoring objects of different building types have different diseases.

In the architectural heritage protection project of Sisheng ancestral hall, its main diseases include insect pests, cracks, uneven settlement, structural inclination, since it is a traditional Chinese wood frame building. For decorative components, such as inscriptions and sculptures, the main diseases are cracking, weathering, surface peeling, surface dust adhesion, etc. The surrounding environment of the building is the vegetation, water system, climate, protection range and the carrying capacity of tourists around the heritage.

According to the accuracy requirements of different monitoring objects in the protection of historical buildings in Fenghuang Village, the high-precision 3D point cloud model obtained by the drone is obtained by the triangular model or high-definition digital photo texture mapping. And it can be reach the millimeter level, so relevant data results can be used for damage monitoring of architectural heritage surfaces. For instance, the orthophoto map can fully record the small and medium changes of historical buildings (see Fig. 9)

In processing of floor settlement detection, The traditional building deformation detection method usually selects several sampling points from the detection object, and draws a conclusion through the analysis of the three-dimensional coordinates of the sampling points. The reliability of this method depends on whether the sampling points are representative, and whether a small number of

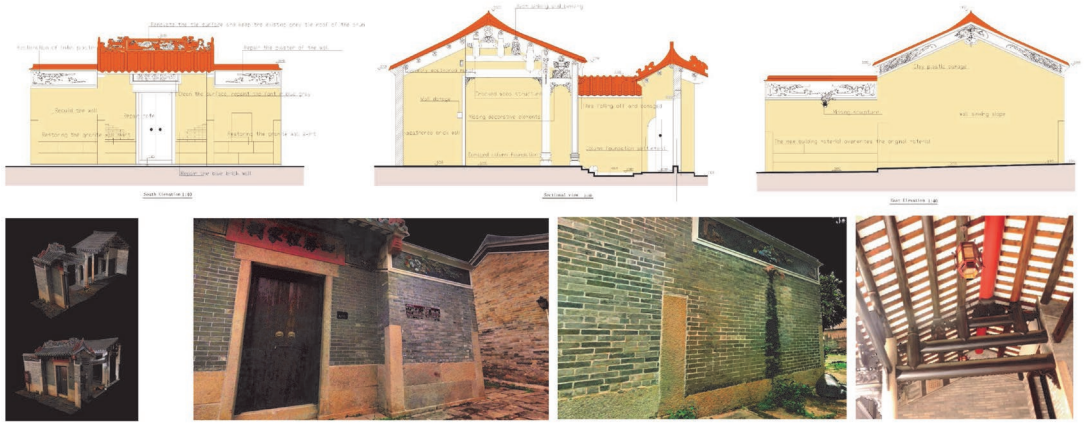

Fig.9 - Damage analysis diagram

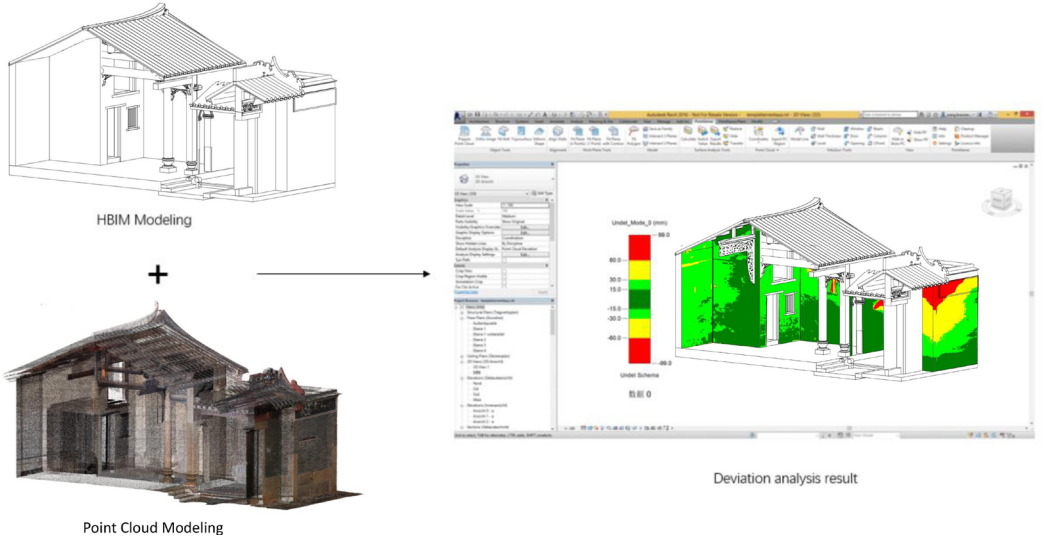

Fig.10 - The output of Deviation Analysis

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sampling points can accurately reflect the overall situation. The point cloud model offers the possibility of deformation detection at the global level. By comparing with the horizontal plane, the settlement of the floor slab can be obtained accurately and intuitively. The analysis results show that there is subsidence on the ground floor of the Sisheng ancestral hall. During the surveying and mapping process, we found that the excavated foundation of neighbor house is not backfilled after collapsing, and accumulates by water all the year round, which leads to the subsidence of the foundation. That is what cause the obvious subsidence of the floor slab. The data of the analysis results provide the basis for decision-making of technical intervention.

The flatness analysis of the walls of historical buildings using point cloud scanning data can intuitively display millimeter-level changes, and use technical means to amplify small changes and highlight change trends, which is helpful for research and judgment.

In the case of this paper, through the comparison of the point cloud model and HBIM model, and then generate a rainbow map, as fig. 10, and identify the discriminative area and deviation value. This comparison method is not only accurate and intuitive, but also efficient and easy to use. At the same time, it is also used to compare with the idealized model to find the components of the buildings in Fenghuang Village that are easily damaged due to deformation, crooked flashes, etc.

5. CONCLUSION

The surveying and mapping method of UAV solves the timeliness of collecting a large amount of data on architectural heritage, improves the accuracy of data, and provides important information reference and data support for the comprehensive protection strategy of architectural heritage. At the same time, the improvement of measurement accuracy also brings new opportunities for architectural history research and architectural heritage protection.

When using the UAV to construct the 3D point cloud model and the orthophoto image of the Sisheng ancestral hall, it can most directly show the appearance and status of the building. The data monitored and early warned of the ancient building provides the most direct and basic data for the protection project. At the same time, the constructed HBIM model is also an important way of digital protection of architectural heritage. However, UAV image acquisition also has its scope of application and limitations. For building interiors and building facades with narrow spacing, the use of UAVs will be limited. Therefore, for the surveying, mapping and digital protection of architectural heritage with large scale, complex details and high precision requirements, more technologies need to be used comprehensively. In the application to Sisheng ancestral hall, the following technologies or methods need to be adopted:

(1)High-precision photogrammetry: it is used for the surveying and mapping of historical murals and colored paintings, and can generate high-definition orthographic projection maps as the base map for disease analysis.

(2)Non-destructive monitoring: using ray, ultrasound, infrared imaging and other technologies for information collection to capture information that is invisible to the naked eye (wall defects, finish strength, foundation conditions, etc.)

(3)Display of AR and VR: display the acquired point cloud and model data through multiple channels.

UAV images combined with 3D reconstruction technology not only improve the efficiency of cultural relics protection work, but also provide more accurate data. With the development of drone technology and the continuous progress of related software, this method will be more widely used in the protection of cultural relics and buildings, and become an important way of scientific and technological protection of cultural relics and buildings.

REFERENCES

Germanese, D., Pascali, M. A., Berton, A., Leone, G. R., Moroni, D., Jalil, B., ... & Benassi, A. (2019). Architectural Heritage: 3D Documentation and Structural Monitoring Using UAV. In VIPERC@ IRCDL (pp. 1-12).

Aicardi, I., Chiabrando, F., Grasso, N., Lingua, A. M., Noardo, F., & Spanò, A. (2016). UAV PHOTOGRAMMETRY WITH OBLIQUE IMAGES: FIRST ANALYSIS ON DATA ACQUISITION AND PROCESSING. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 41.

Themistocleous, K., Agapiou, A., & Hadjimitsis, D. (2016). 3D documentation and BIM modeling of cultural heritage structures using UAVS: the case of the Foinikaria church. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 42, 45.

Ulvi, A. (2021). Documentation, Three-Dimensional (3D) Modelling and visualization of cultural heritage by using Unmanned Aerial Vehicle (UAV) photogrammetry and terrestrial laser scanners. International Journal of Remote Sensing, 42(6), 1994-2021

Barba, S., Barbarella, M., Di Benedetto, A., Fiani, M., Gujski, L., & Limongiello, M. (2019). Accuracy assessment of 3D photogrammetric models from an unmanned aerial vehicle. Drones, 3(4), 79.

Edelsbrunner, H., Kirkpatrick, D., & Seidel, R. (1983). On the shape of a set of points in the plane. IEEE Transactions on information theory, 29(4), 551-559.

Li, M., Cheng, D., Yang, X., Luo, G., Liu, N., Meng, C., & Peng, Q. (2021). High precision slope deformation monitoring by uav with industrial photogrammetry. In IOP Conference Series: Earth and Environmental Science (Vol. 636, No. 1, p. 012015). IOP Publishing.

Mancini, F., & Pirotti, F. (2021). Innovations in photogrammetry and remote sensing: Modern sensors, new processing strategies and frontiers in applications. Sensors, 21(7), 2420.

Pádua, L., Adão, T., Hruška, J., Marques, P., Sousa, A., Morais, R., ... & Peres, E. (2018, April). UAS-based photogrammetry of cultural heritage sites: A case study addressing Chapel of Espírito Santo and photogrammetric software comparison. In Proceedings of the International Conference on Geoinformatics and Data Analysis (pp. 72-76).

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