# APPLICATION OF CONSUMER–LEVEL UAV PHOTOGRAMMETRY IN DIGITAL SURVEY OF CLIFF-BURIAL CULTURE RELICS: A CASE STUDY OF MOUNT WUYI

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**KEY WORDS:** Unmanned Aerial Vehicle (UAV), Nap-of-the-Object Photogrammetry, Accuracy, Digital Survey, 3D Reconstruction, Cliff-Burial.

**ABSTRACT:**

The cliff-burial was an ancient funerary ritual once popular in the Far East Asia (Figure 1), in which the dead were buried high on the cliffs with log coffins (the "hanging coffins") left in the natural caves, excavated grottoes or on some wood piles.
In view of the fact that the cliff-burial sites are usually located on the escarpments overlooking the rivers and with great slope, where the conventional 3D survey means, such as ground laser scanning and traditional aerial photogrammetry, is out of option. This study explores the possibility of using UAV (consumer–level drone) with substantial improvement in survey accuracy, range and flight control (Figure 2), which aims to lay the foundation for the global cliff-burial culture heritage research. A survey method extendible on other excavated funeral sites would be tested and codified, as a possible follow up of the research on some study cases in Far East Asia and Europe.

## 1. INTRODUCTION

As an old burial custom, the cliff-burial were kept log coffins (hanging coffins) on the escarpment or the cliff cave facing the water, rather than burying corpse (Chen, 1992). Nowadays, in some remote areas of Southeast Asia and Pacific Islands, such ritual is still in practice by e.g., the Sagada in the Philippines, the Torajas of Sulawesi and the Dagos of Orchid Island, Taiwan. It is very important to conserve the historical information of the sites as soon as possible, not only because it is required by heritage protection but also it is significant in the fields of ethnic migration and cultural assimilation (Chen, 1992). Furthermore, in Matera, Italy, there are several hypogeum sacred sites used as tomb which can be compared with the ones studied in China and East Asia.



**Figure 1.** Spatial-Temporal Graph of Global Cliff-Burial Sites

A recent matrilineal genetic study of the hanging coffin people in Southern China and Northern Thailand has found that the matrilineal genetic diversity of the Hanging Coffin people from southern China is much higher than those from northern Thailand (Zhang et al., 2020). As the harsh process of long-distance migration normally causes the reduction in population size, which reduces genetic diversity, this finding is consistent with the hypothesized single origin of the Hanging Coffin custom in southern China about 3,600 years ago. The earliest log coffins dated 3620±130 BP by the tree-ring oxygen isotope chronology and $^{14}$C radiocarbon are those found in Mt. Wuyi (Chen, 1980; Zeng et al., 1980; Pumijumnong and Wannasri, 2015), the UNESCO world mixed heritage site.

Although some of the oldest hanging coffin without disturbance have lasted for over 3 thousand years, they are very fragile and easy to lose during the process of urbanization, especially the infrastructure construction, such as riverside road-building, and tourism development. In fact, we have most of the coffins lost within the recent 7 decades in southern China, especially in Sichuan and Fujian. Historical literature between the Three Kingdoms Period (220CE - 280CE) and the Qing Dynasty (1636CE - 1912CE) indicate that there used to be a large number of hanging coffins in the Mt. Wuyi region (Chen, 1992). The most recent comprehensive survey of hanging coffins in Mt. Wuyi was carried out in August 1979, and limited by the technology available in South China in the 1970s, information on the specific cliff height, location, coffin form and remains of each relic site is mostly recorded in vague descriptions with no quantitative documentation, such as images, 3D model or geographic coordinates. The then found 18 sites with 19 coffins
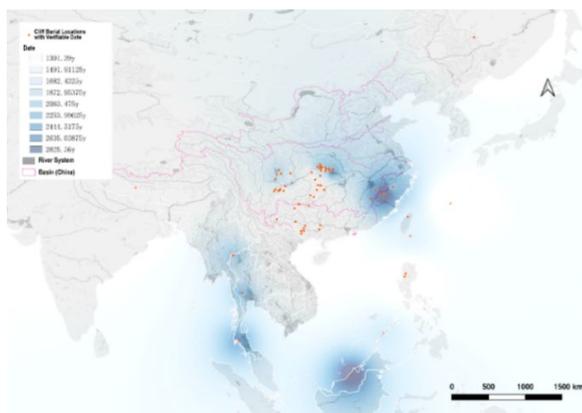
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had now been severely damaged over time, leaving no coffin intact (Cultural Heritage Group of Chong'an County Culture Museum, 1982). It thus seems to us an urgent task to find out what has been left, which is fundamental for further conservation research to meet the UNESCO requirements of World Heritage site management.

Unlike other types of cultural heritage and burials, the location of the cliff-burial sites is difficult to reach without applicants. For example, the Jinji Cave site in Mt. Wuyi has a height up to 30-50 metres above the stream. On the Luoping River sites (Badong County, China) and the Tabon Cave site (Palawan Island, Philippines), some coffins are as high as 100-200 metres above the water (Chen, 1992). Fortunately, the rise of the consumer drone market and the rapid iteration of photogrammetry technologies had opened new opportunities for digital surveys of cultural heritage with economical devices. Given the lower requirements of preliminary research for 3D measurement accuracy and the greater emphasis on consistency, small UAVs equipped with low-resolution amateur cameras can also be used to acquire photogrammetric data from cultural heritage sites (Adamopoulos et al., 2019; Calantropio et al., 2018; Kršák et al., 2016). Besides, the image information, as real situation of detected sites, can help in post-analysis with additional metric archives (Rinaudo et al., 2012). Remote sensing technology, such as 3D laser scanning technology and photogrammetry, in fact, is safer and more efficient than manual contact measurement in the process of high slope investigation (Ye et al., 2020). Particularly, close-range photogrammetry based on smart unmanned aerial system has huge potential for unreachable cliff investigation (Zhou et al., 2021).
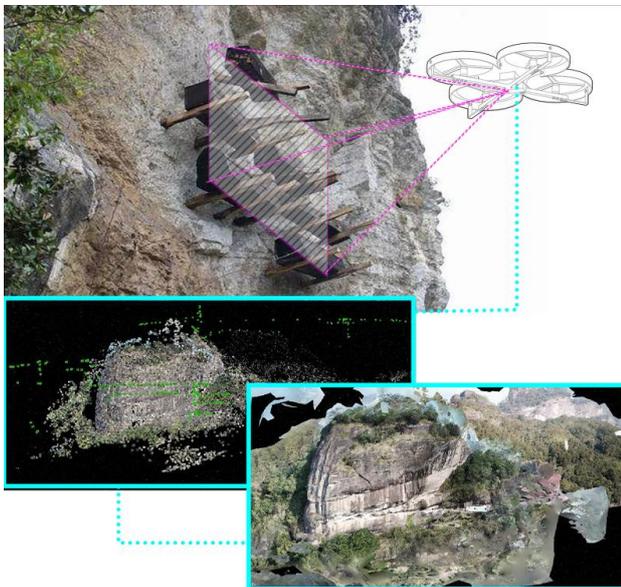


**Figure 2**. UAV Photogrammetry Application on Baiyun Temple Cliff-Burial Site, Mt. Wuyi

The UAV photogrammetry is used in the reconnaissance and documentation on slopes, cliffs, high dams, and other similar terrains, as the complex environment makes other remote sensing survey methods difficult. Compared to total station and 3D laser scanning, the UAV survey requires the least amount of landing plot, operation time and higher accuracy, in comparative experiments of the 3D real scene model for building elevation, with various measurement techniques (Li, 2019). Compared with traditional aerial photography which requires large, long-range fixed-wing UAV, the small-sized rotary-wing UAV with single lens is a safer and lower-cost surveying method that can acquire and process the maximum amount of detailed information in a flight. The small-sized rotary-wing UAVs with single lens is thus more suitable for photogrammetry on slopes or cliffs (Ye, 2019). The current research aims to explore the efficiency and practicality of the digital survey methods, in terms of geographical information recording, 3D data acquisition and etc.

## 2. APPLICATION OF UAV PHOTOGRAMMETRY IN CULTURAL HERITAGE ON CLIFFS

Currently, two major types of photogrammetry are in use on small-sized consumer drones: the conventional oblique photogrammetry and the nap-of-the-object photogrammetry. Both techniques have advantages and disadvantages and should be utilized in conjunction with the specific terrain research. Compared to oblique photogrammetry, nap-of-the-object photogrammetry enables efficient acquisition of sub-centimetre or even millimetre ultra-high resolution images of the ground (e.g. landslides, dams, high slopes, etc.) or the surface of artificial objects (e.g. tall ancient buildings, landmarks, etc.) and thus implement the fine-grained 3D reconstruction, which is an excellent means of digital survey of cultural heritage (Tao et al., 2019). However, it is not suitable for large scale DOM and DSM geographic information acquisition for surrounding environment. Therefore, oblique photogrammetry is normally incorporated with nap-of-the-object photogrammetry in 3D modelling of high dam in hydropower projects especially in steep slopes and shaded areas (Zhang et al., 2021).

In an Ottoman monument located in Xanthi, Greece, the low budget cultural heritage digitisation and the high precision 3D model reconstruction are achieved with the Structure-From-Motion (SFM) and Dense Multi-View 3D Reconstruction (DMVR) algorithms (Koutsoudis et al., 2014). The combination of the SFM-DMVR algorithm and low-cost UAV technology makes it possible to acquire and process 3D data at low cost for operators with non-surveying-and-mapping backgrounds, such as architecture (Sun and Cao, 2015).

In the case of the Huashan Petroglyph in Guangxi, China, the use of nap-of-the-object photogrammetry allows large outdoor artefacts on cliffs and high slopes to be digitised in three dimensions with high accuracy for conservation (Luo, 2021). The operational procedures for photogrammetric studies on cliff heritage is also explored with added manual waypoint detection to ensure proper signal reception at key waypoints over the recessed cliffs and tree cover (Luo, 2021). Being three-dimensional solid, the hanging-coffin, however, is different from the flat petroglyph, in terms of the UAV route planning and the lighting condition in the caves.

In summary, using UAV photogrammetry in the digital survey of the cliff environment is not only technically feasible but also with higher accuracy sufficient for cultural heritage conservation purposes. With the help of the SFM-DMVR algorithm, three groups of key documentation measurements are expected as follows. First, the measurements describe the current conditions of the hanging coffins on the cliff in terms of size, shape, coffin cover and coffin body preservation status, etc. Second, the geographical coordinates describing the accurate location of the coffins referring to their geographical environments, such as the location of the cliff or cave, the structure of the supporting structure, etc. Third, the measurements describing the conditions of the coffins in caves, such as the stacking mode of coffins and the layout of cliff caves, etc.

Nevertheless, the unique characteristics and challenges of this technology as it has never been used in previous surveys of cliff-burial sites requires more experiments on the factors influencing the accuracy before an on-site survey.

## 3. PRELIMINARY EXPERIMENTS

### 3.1 Hardware and Software

In this research, the former cliff of Baiyun Temple located in the west of Mt. Wuyi was chosen as the experiment site of a digital survey by UAV photogrammetry with a DJI Mavic Pro (Shenzhen DJI Sciences and Technologies Ltd., Shenzhen, China) as a mid-priced consumer drone, whose size and weight are also manageable to carry to the hilly site (Table 1). The site was later reconstructed by DJI TERRA software based on SFM-DMVR algorithm.

| Type | Size & Weight | Fov | Price |
|---|---|---|---|
| | 83 x 83 x 198mm (H x W x L) | | 6499CNY |
| | | 78.8° | (in China) |
| DJI MAVIC PRO | 743g (Total) | | |
| | Pixel | Pan & Tilt Angle | |
| | 12.35 megapixel (Effective) | -90°- 30° (Pitch Angle) | |
| | 12.71 megapixel (Total) | 0° / 90° (Roll Angle) | |

**Table 1.** Basic Information of Consumer-Level UAV Equipment (DJI NEWS, 2016; "Mavic Pro Technical Parameter," 2022)

### 3.2 Test of the Baiyun Temple Cliff-Burial Site

The trial flights include two steps. Firstly, the nap-of-the-object photogrammetry was used as the main tool to scan the coarse model of the Baiyun Temple site to obtain the basic conditions of its caves (Figure 3). As a new photogrammetry method invented in 2018, the nap-of-the-object photogrammetry offers a method for grasping high precision images of vertical surfaces by segmenting intricate terrain into units (Tao et al., 2021, 2019).

Secondly, a refined photogrammetric route was planned to fulfil a higher precision model by software of Waypoint Master (WPM) and Rocky Capture. Derived from the coarse model, the possibility of further refining the route was evaluated according to the experiment control group and the environmental characteristics of the Baiyun Temple site.
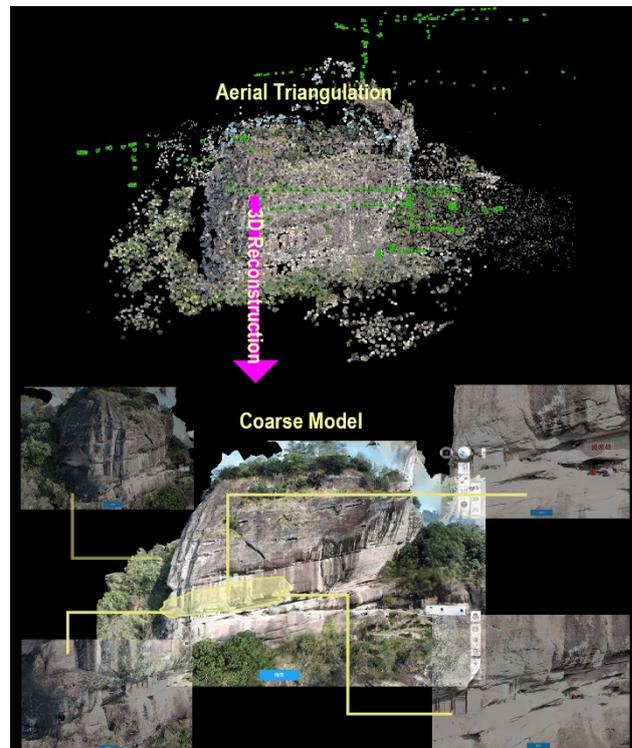


**Figure 3**. Coarse Model Results of the Baiyun Temple Site Based on the Nap-of-the-Object Photogrammetry Data
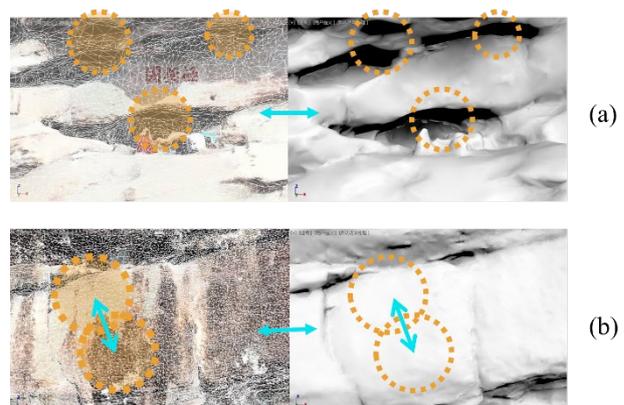


**Figure 4**. Quality Comparison of Different Areas Derived from the Coarse Model Results

We select partial areas of the coarse model for inspection and propose a few hypotheses: The deep part of cliff cave has a poor quality of 3D reconstruction with a large triangular surface indicating detail missing, possibly due to the dark conditions in the cave. Similarly, the cliff face, which has a lighter colour and more even texture, has fewer details in the 3D reconstruction, and the model tends to be smoother (which might cause the modelling error).

In summary, two key factors influencing the survey results in relation to the lighting condition of the coffin include the space of the cliff cave (the depth, the scale of the opening and etc.) (Figure 4a) and material (related to colour, texture, and etc. (Figure 4b) of the coffin.

### 3.3 Ground Survey and Simulating Pre-Test of the Jinji Cave Cliff-Burial Site

As most of the better-preserved sites, such as Jinji Cave, are located in a drove forbidden zone, where UAVs are not allowed to take off without a special flight permit. While waiting for the permission, a test simulating the Jinji Cave site was carried out to test the influence that different factors have on the photogrammetric and modelling results by the trial flight on the Baiyun Temple site, and proposes a general procedure for UAV photogrammetry on cliff-burial sites.

### 3.3.1 The Simulation

The cliff-burials from southern China to SE Asia have generally 13 varieties in section (Figure 5). Jinji Cave and other cliff-burial caves in Mt. Wuyi region are predominantly shallow, inwardly concave, and the coffins are placed roughly parallel to the cave openings (Type 1 in Figure 5).
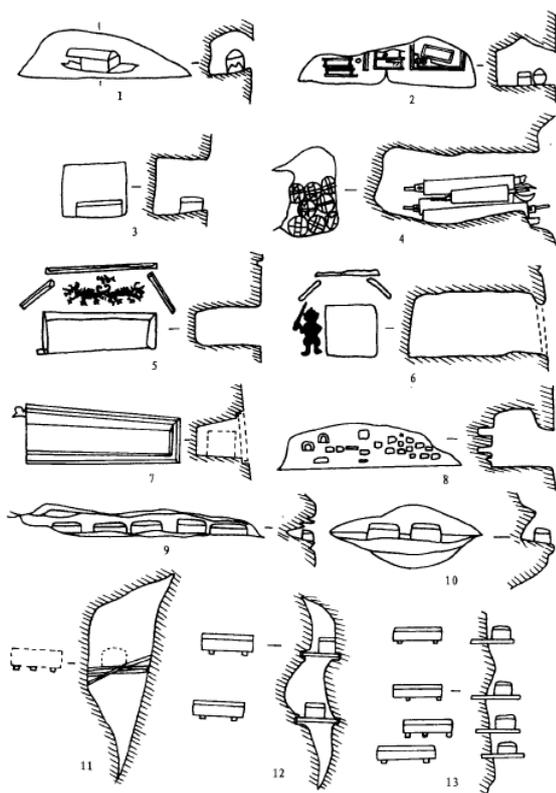
**Figure 5**. Diagram showing the different forms of cliff burial places (Wu, 1999) p. 316, fig.1

To simplify the cave condition, a building balcony with a similar orientation and opening size is chosen as the simulated environment for the Jinji Cave (Figure 6). A model of log coffin made of similarly coloured cardboard was placed in the window openings of the balcony, facing the pound underneath.
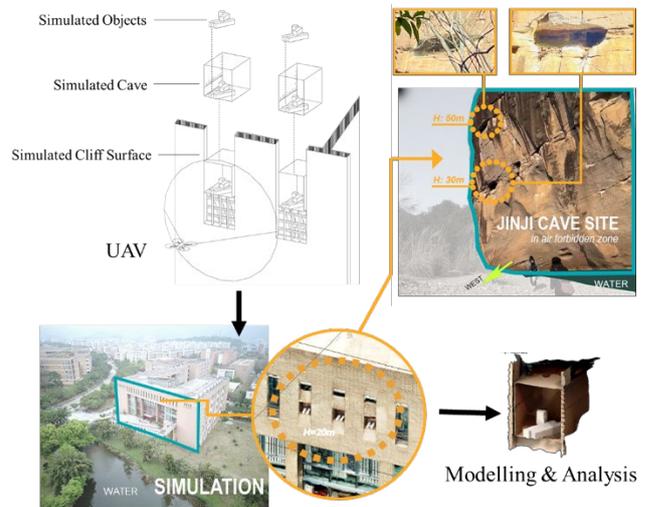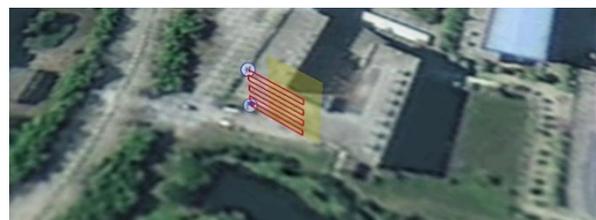
**Figure 6**. Simulating Tests for Jinji Cave Cliff-Burial Site

| Parameters | R1 | R2 | R3 |
|---|---|---|---|
| Distance to Surface | 8m | 5m | 7m |
| Flight Speed | 0.4m/s | 0.2m/s | 0.4m/s |
| Course Overlap | 90% | 90% | 90% |
| Side Overlap | 75% | 75% | 75% |
| Flying Altitude Range | 10m-20m | 10m-20m | 16-24m |
| Pitch Angle | 0° | 0° | -26° |
| GSD | 0.3cm | 0.2cm | 0.3cm |
| Aperture | 2.2 | 2.2 | 2.2 |
| Number of Photos | 87 | 64 | 37 |

\* The flight of each group consists of R1, R2 and R3

**Table 2**. Aerial Photogrammetry Technical Data of Simulation

Factors were controlled one by one in the simulation experiments:

Firstly, the lighting conditions factors. Poor lighting conditions lead to graver error in the determination of calibrating inherent orientation and distortion (Burdziakowski and Bobkowska, 2021). The clarity of the model information at different depth scales and the accuracy of the model at different width-height ratios of the cave opening (Figure 7) are compared to determine to what extent spatial factors influence the lighting conditions.

Secondly, the characteristics such as texture (Figure 8) and colour (Figure 9) of the objects in the cave. Figuring out how the texture and colour influence the accuracy of photogrammetry can help us to evaluate the detectability potential of the objects in the cliff-burial site.
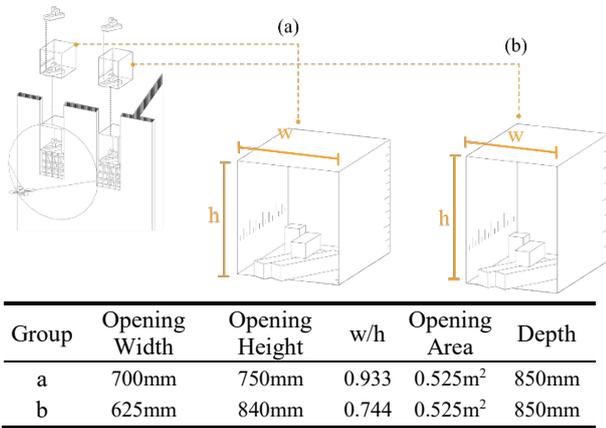
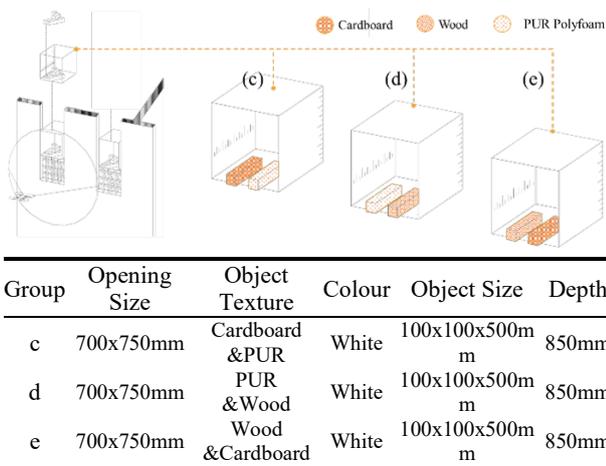| Group | Opening Width | Opening Height | w/h | Opening Area | Depth |
|---|---|---|---|---|---|
| a | 700mm | 750mm | 0.933 | 0.525m² | 850mm |
| b | 625mm | 840mm | 0.744 | 0.525m² | 850mm |

**Figure 7**. Technical Data of Group a and Group b



| Group | Opening Size | Object Texture | Colour | Object Size | Depth |
|---|---|---|---|---|---|
| c | 700x750mm | Cardboard &PUR | White | 100x100x500mm | 850mm |
| d | 700x750mm | PUR &Wood | White | 100x100x500mm | 850mm |
| e | 700x750mm | Wood &Cardboard | White | 100x100x500mm | 850mm |

**Figure 8**. Technical Data of Group c, Group d, Group e



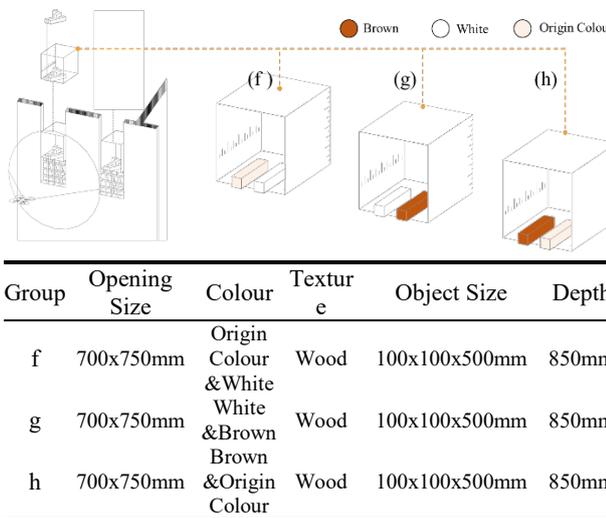| Group | Opening Size | Colour | Texture | Object Size | Depth |
|---|---|---|---|---|---|
| f | 700x750mm | Origin Colour &White | Wood | 100x100x500mm | 850mm |
| g | 700x750mm | White &Brown | Wood | 100x100x500mm | 850mm |
| h | 700x750mm | Brown &Origin Colour | Wood | 100x100x500mm | 850mm |

**Figure 9**. Technical Data of Group f, Group g, Group h

### 3.3.2 Accuracy Defining

Once the model has been reconstructed, the image control points can be used to pair up the real object to the scanned model and then take a 60mm range to sample the model to obtain a valid modelling range (Figure 10a). After the model has been processed, the accuracy of the photogrammetric modelling results is shown.

The morphological accuracy depends on point deviation analysis by Rhinoceros software, calculating the distance between point cloud (extracted with 1mm grid, from the photogrammetric model) and real object (Figure 10b), and counting further their mean distance and standard deviation (Robert McNeel & Associates, 2021) (Figure 10c). Parameter of standard calculates deviation the dispersion degree between modelled point clouds and standard real surface, which illustrates the quality of the modelled surface. Meanwhile, the mean distance stands for the scale accuracy.
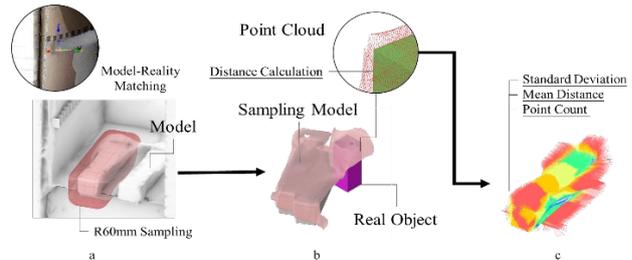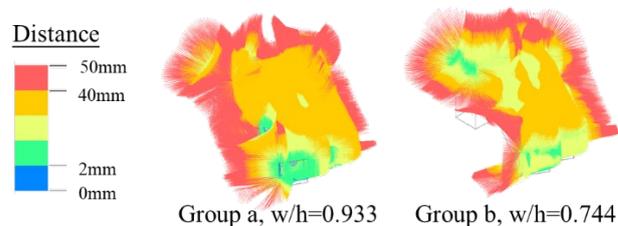


**Figure 10**. Calculation Rules of Accuracy

## 4. RESULTS

### 4.1 Accuracy Comparison

#### 4.1.1 Spatial Factors



| | Standard Deviation | | Mean Distance | |
|---|---|---|---|---|
| | a | b | a | b |
| Vertical Objects | 15.14607 | 13.46551 | 35.08083 | 34.03204 |
| Horizontal objects | 13.16131 | 12.53293 | 28.86914 | 27.42822 |
| Overall | 18.82674 | 18.43805 | 33.86289 | 32.67564 |

**Table 3.** Data of Groups a, Group b

With the same opening area and light intake, the taller cave opening is, the more accurate it is for vertical and lanky objects (poles, pillars, etc.), and vice versa for horizontal objects (coffins, beams, etc.) (Table 3). It seems that the more accurate results can be obtained when the width-height ratio of the objects is closer to the ratio of the cave opening. In general, it seems that the lower width-height ratio of the opening, the higher the overall accuracy (Table 3).

Moreover, in case the depth of the cave is less than 600 mm, the accuracy of the cave interior remains the same for different width-height ratios, while in case the depth is greater than 600 mm, the cave with a thin and tall opening shows a higher accuracy than the short and wide opening (Table 4).
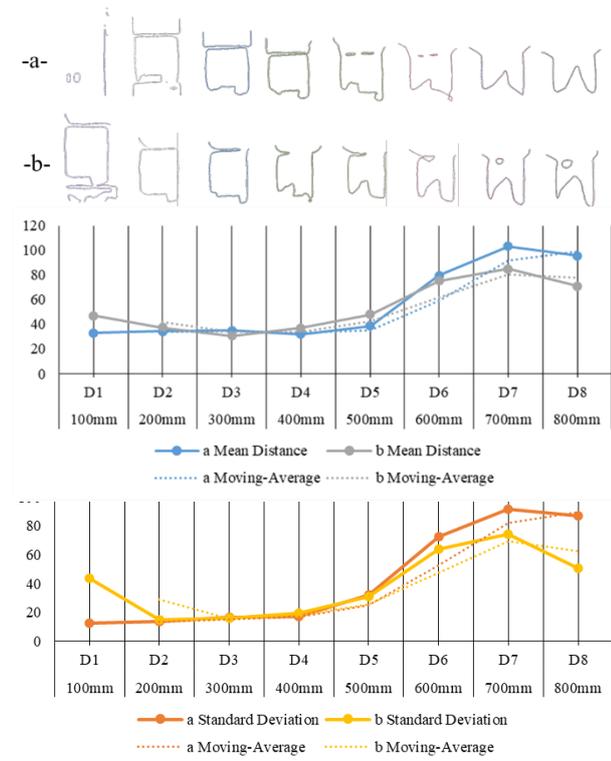
| Colour | Mean Distance | | | |
|---|---|---|---|---|
| | f | g | h | Overall |
| White | 22.68514 | 28.41289 | / | 25.61052 |
| Origin Colour | 23.46316 | / | 31.93432 | 27.56486 |
| Brown | / | 29.58018 | 31.02310 | 30.23346 |

| Colour | Standard Deviation | | | |
|---|---|---|---|---|
| | f | g | h | Overall |
| White | 16.07650 | 14.10188 | / | 15.08919 |
| Origin Colour | 16.95475 | / | 13.64147 | 15.29811 |
| Brown | / | 14.57504 | 16.22636 | 15.40070 |

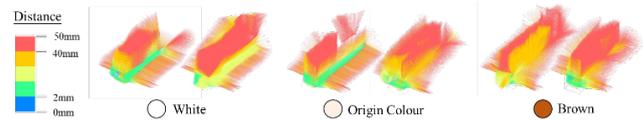**Table 6.** Data of the Colour Groups (Groups c, d, e)

In the material comparison experiments (Table 5 & 6), the variable factors in the texture groups (Groups c, d, e) and the colour groups (Groups f, g, h) did show variation in the model: objects with lighter surface colours and smoother texture showed lower standard deviation. This indicates that colour and texture can influence the detail in 3D reconstruction.

However, some of the hypotheses were rejected. Lighter colours showed lower mean distances, suggesting that lighter objects were measured and reconstructed with higher accuracy, while the roughness of texture showed no significant correlation with accuracy.

### 4.2 Guidance to the Procedure of UAV Photogrammetry for Cliff-Burial Sites

In the process of nap-of-the-object photogrammetry, previous flight and coarse products (Figure 3) are important for the planning of an accurate survey flight. From the coarse model of the Baiyun Temple site we can obtain not only the basic dimensions of the Baiyun cliff cave and the approximate shape of the objects in the cave, but the colours and probable textures of them.
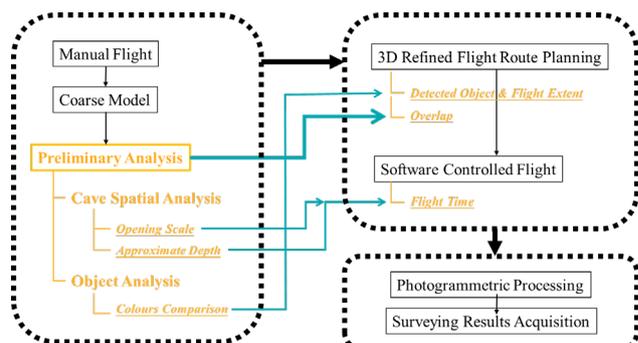


**Figure 11**. Digital Surveying Procedures of Cliff-Burial Sites for Refined Results

Based on the simulation results, we are able to add specific details for the digital surveying procedures of cliff-burial sites to refine results (Figure 11). In the preliminary analysis based on the

| Depth | a | | b | |
|---|---|---|---|---|
| | Mean Distance | Standard Deviation | Mean Distance | Standard Deviation |
| D1 | 33.04707 | 12.65236 | 47.00714 | 43.51428 |
| D2 | 34.41166 | 14.02545 | 37.24385 | 15.18268 |
| D3 | 34.90660 | 16.89786 | 30.84044 | 16.32151 |
| D4 | 32.07785 | 17.41820 | 37.04155 | 19.72867 |
| D5 | 38.64378 | 32.53854 | 48.05937 | 31.08199 |
| D6 | 79.83992 | 72.46631 | 75.46413 | 64.24018 |
| D7 | 103.3154 | 91.58727 | 85.04044 | 74.52386 |
| D8 | 95.69036 | 87.28568 | 71.07579 | 50.52564 |

**Table 4.** Accuracy Analysis of Different Depths in Cave

### 4.1.2 Materials Factors



| Texture | Mean Distance | | | |
|---|---|---|---|---|
| | c | d | e | Overall |
| Cardboard | 9.982333 | / | 11.18573 | 14.17763 |
| Wood | / | 9.910299 | 12.91570 | 14.78677 |
| PUR | 12.679140 | 10.840990 | / | 13.20790 |

| Texture | Standard Deviation | | | |
|---|---|---|---|---|
| | c | d | e | Overall |
| Cardboard | 7.024136 | / | 6.142081 | 6.5831085 |
| Wood | / | 6.783286 | 6.712201 | 6.7477435 |
| PUR | 11.51175 | 7.737583 | / | 9.6246665 |

**Table 5.** Data of the Texture Groups (Groups c, d, e)

coarse model, the spatial characteristics of the cave should pay more attention to the scale of the openings and the approximate depth of the cave. For short and wide openings (e.g., the Jinji Cave site, or the type 1, 2, 9 in Figure 5), the photographic overlap should be increased, or the flight should be conducted in cloudy weather without direct sunlight to compensate for the lack of accuracy.

This is followed by prioritising the photogrammetry of objects which have similar width-height ratio with the cave opening. Apart from this, those objects that show lighter colours in the material analysis (which is more likely better for modelling quality) are more suitable for post-analysis, and thus the extent of the specific measurement area and hence the flight route parameters for accurate flight can be determined (Figure 11). This research takes the Baiyun Temple site as an example to plan a refined flight route (Figure 12).
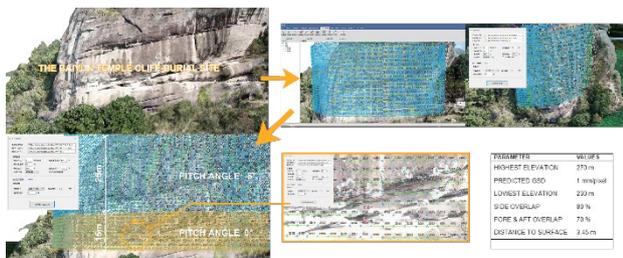


**Figure 12**. Accurate Survey Flight Route of Baiyun Temple Cliff-Burial Site

## 5.   DISCUSSION AND CONCLUSION

This study takes the Baiyun Temple and the Jinji Cave cliff-burial site in the Mt. Wuyi region as working cases and sets up control group experiments to investigate the effects of spatial factors and object factors have on the accuracy of photogrammetric measurements of cliff-burial sites.

Not only proves the applicability of the technology in the special environment of the cliff-burial sites, but the research also proposes corresponding optimization measures, which thus validates a new, efficient and safe method of digitally investigating the historical and cultural heritage of cliff-burials worldwide.

The results of the research and their guidance to the accurate route planning of the cliff burial site suggest operational details for the cliff-burial heritage site in terms of imaging methods, reflecting the differences between the application of photogrammetry in other cliff environments.

The shortcomings of this study are that the flight forbidden zone did not allow for detailed UAV photogrammetric measurements of relatively well-preserved cliff-burial sites, and even though the simulated environment had high similarity in spatial context, the existence of exceptions cannot be denied.  In addition to this, although the type of cliff-burial sites tested in the experiment is sufficiently representative (cliff cave occurs in cliff-burial cultures all over the world), there are other types of hanging coffins (Wu, 1999).  In further study, on site survey would be conducted to explore the application conditions of the survey methods.

## REFERENCES

Adamopoulos, E., Rinaudo, F., Bovero, A., 2019. First Assessments on Heritage Science Oriented Image-Based Modeling Using Low-Cost Modified and Mobile Cameras, in: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Presented at the The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, pp. 23–30. https://doi.org/10.5194/isprs-archives-XLII-2-W17-23-2019

Burdziakowski, P., Bobkowska, K., 2021. UAV Photogrammetry under Poor Lighting Conditions—Accuracy Considerations. Sensors 21, 3531. https://doi.org/10.3390/s21103531

Calantropio, A., Chiabrando, F., Rinaudo, F., Teppati Losè, L., 2018. Use and Evaluation of a Short Range Small Quadcopter and a Portable Imaging Laser for Built Heritage 3D Documentation, in: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Presented at the The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, pp. 71–78. https://doi.org/10.5194/isprs-archives-XLII-1-71-2018

Chen, C., 1980. A preliminary study on the structural characteristics of wood and its properties of boat coffins from Wuyishan, Fujian. Journal of Forest and Environment 29–36. https://doi.org/CNKI:SUN:FJLB.0.1980-02-004

Chen, M., 1992. Cliff-Burial in China. Chongqing Press.

Cultural Heritage Group of Chong'an County Culture Museum, 1982. Distribution and status of boat coffins in Mount Wuyi. Ethnographic Studies, 4 246–249.

DJI NEWS, 2016. DJI Releases "YU" Mavic Pro Portable Drone. URL https://u.dji.com/cn/articles/36

Koutsoudis, A., Vidmar, B., Ioannakis, G., Arnaoutoglou, F., Pavlidis, G., Chamzas, C., 2014. Multi-image 3D reconstruction data evaluation. Journal of Cultural Heritage 15, 73–79. https://doi.org/10.1016/j.culher.2012.12.003

Kršák, B., Blišťan, P., Pauliková, A., Puškárová, P., Kovanič, Ľ., Palková, J., Zelizňaková, V., 2016. Use of low-cost UAV photogrammetry to analyze the accuracy of a digital elevation model in a case study. Measurement 91, 276–287. https://doi.org/10.1016/j.measurement.2016.05.028

Li, Q., 2019. Comparison and Analysis of Several Building Elevation Measurement Methods. Beijing Surveying and Mapping 33, 850–852. https://doi.org/10.19580/j.cnki.1007-3000.2019.07.025

Luo, F., 2021. the Use of Nap-of-the-Object Photogrammetry in the Conservation of Cultural Relics: the Case of the Huashan Rock Paintings in Ningming, Guangxi. Land and Resources of Southern China 39-41+46.

Mavic Pro Technical Parameter, 2022. . Mavic Pro Technical Parameter. URL https://www.dji.com/cn/mavic

Pumijumnong, N., Wannasri, S., 2015. Teak Log Coffins in Northwest Thailand: Dated by Dendrochronology and 14Cwiggle Matching. Applied Environmental Research. https://doi.org/10.14456/aer.2015.2

Rhinoceros, 2021. , PointDeviation | Rhino 3-D modeling. Robert McNeel & Associates. docs.mcneel.com/rhino/6/help/en-us/commands/pointdeviation.htm (7 November 2021)

Rinaudo, F., Chiabrando, F., Lingua, A., Spanò, A., 2012. ARCHAEOLOGICAL SITE MONITORING: UAV PHOTOGRAMMETRY CAN BE AN ANSWER, in: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Presented at the The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, pp. 583–588. https://doi.org/10.5194/isprsarchives-XXXIX-B5-583-2012

Sun, Z., Cao, Y.K., 2015. Data processing workflows from low-cost digital survey to various applications: three case studies of Chinese historic architecture, in: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Presented at the The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, pp. 409–416. https://doi.org/10.5194/isprsarchives-XL-5-W7-409-2015

Tao, P., He, J., Xi, K., Liu, K., Niu, Z., Duan, Y., Zhang, Z., 2019. Approaching photogrammetry method based on rotor unmanned aerial vehicle.

Tao, P., Zhang, Z., Duan, Y., Ke, T., Xi, K., He, J., 2021. Close photography three-dimensional flight path and attitude planning method and device for complex terrains.

Wu, C., 1999. A TYPOLOGICAL STUDY OF CLIFF BURIALS IN SOUTH CHINA. Acta Archaeologica Sinica 311–336. https://doi.org/CNKI:SUN:KGXB.0.1999-03-001

Ye, P., 2019. Application of UAV Photogrammetry in Geological Survey of High and Steep Slopes. World Nonferrous Metals 222–223.

Ye, Z., Xu, Q., Liu, Q., Dong, X., Wang, X., Ning, H., 2020. Application of Unmanned Aerial Vehicle Oblique Photogrammetry to Investigation of High Slope Rock Structure. Geomatics and Information Science of Wuhan University 45, 1739–1746. https://doi.org/10.13203/j.whugis20200077

Zeng, F., Yang, Q., Fu, S., 1980. A Survey and Preliminary Study on Boat Coffin Burials in Mount Wuyi. Cultural Relics 21–31. https://doi.org/CNKI:SUN:WENW.0.1980-06-002

Zhang, X., Li, C., Zhou, Y., Huang, J., Yu, T., Liu, X., Shi, H., Liu, H., Chia, S., Huang, S., Guo, Y., Shoocongdej, R., Ji, X., Su, B., 2020. A Matrilineal Genetic Perspective of Hanging Coffin Custom in Southern China and Northern Thailand. iScience 23, 101032. https://doi.org/10.1016/j.isci.2020.101032

Zhang, Z., Wu, F., Shang, H., Lyu, W., Wang, J., 2021. Application of Nap-of-the-Object Photogrammetry and Oblique Photogrammetry in Fine Modeling of High Dam in Hydropower Project. Northwest Hydropower 47-50+55. https://doi.org/CNKI:SUN:SBXX.0.2021-05-011

Zhou, H., Zhu, J., Li, J., Xu, Y., Li, Q., Yan, E., Zhao, S., Xiong, Y., Mo, D., 2021. Opening a new era of investigating unreachable cliff flora using smart UAVs. Remote Sens Ecol Conserv 7, 638–648. https://doi.org/10.1002/rse2.214