Cultural Heritage Visualization and Virtual Restoration - Photogrammetry and Lidar for Stone Slab Houses and Old Paiwan Indigeneous Settlements, Taiwan

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KEY WORDS: 3D scanning, indigenous settlements, cultural heritage, archaeology, anthropology, mapping, representation, 3D model, virtual reconstruction

ABSTRACT:

When large scale of UAV photogrammetry and Lidar for mapping a Taiwanese aboriginal settlement with stone slab houses has been carried out, terrestrial 3D photogrammetry and scanning are applied to middle and small-scale recording individual buildings to get architectural form with decorations in detail . When constructing the basic data of cultural assets, especially in the mountain area, it is necessary to apply new technology to carry out efficient and accurate settlement mapping works. In this paper, taking an old Paiwan aboriginal settlement an example, a detailed examination of a stone slab house with three different 3D techniques is put into practice. The 3D data can be further used for digital archive, virtual presentation, and data query through network resources. The results of this study show that, in a large-scale of settlement surveys, aerial surveying technology is efficient for constructing the topography of a settlement and provides competent and spatial information of authentic landscape form, while terrestrial photogrammetry and scanning for middle and small scales record individual buildings to provide more details of architectural forms. They both together construct authentic landscape and architectural form of a settlement and furthermore are able to reveal the hidden settlements of archaeological sites under dense forests. The application of 3D technology, greatly increasing the efficiency and accuracy of mapping and recording, is very much helpful for visualization, virtual restoration, and conservation of indigenous settlements cultural heritage, especially in such high and steep forest.

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1. CONTEXT

Old Paiwan settlements
(https://youtu.be/NR2X5JI04Sw)

The place of old Paiwan settlements(Fig. 1) (including several old settlements such as Kapadainan, Kalicekuan, Padain, Caljisi, Kapaiwanan, Kapaiwan, Supaiwan) is the birthplace of the aboriginal Paiwan tribes. The history of this area can be traced back at least more than 4,000 years ago. The earliest settlement was closer to the Creek Itapul and aborigines gradually moved up to the upper part of the east and west sides of the creek, migrated widely and spread throughout the Kavulungan (Dawu Mountains) of southern Taiwan. This place is the birthplace of the Paiwan, Rukai, and Beinan aborigines. The investigation of this birthplace of Paiwan started on 1999/01/01. The investigation has been carried out for more than 20 years, and the research was firstly published in 2003. During 2004~2005, the restoration of the Supaiwan elementary school was designed (Fig. 2) and the reconstruction of Taruljayaz's stone slab house of Padain (Fig. 3, Fig. 4) was reconstructed as well.
(https://youtu.be/xRCvb_8JNxs;
https://youtu.be/sPD7MI2IkGo).
The virtual restoration of the stone slab house is carried out through digital technologies in 2023 (Fig. 5)
The old Paiwan settlements were hit hard by the typhoon in 2009. After 2017, villagers earnestly go back to the old settlements to develop tourism. Supaiwan and Caljisi/Padain are two sites designated as cultural heritage as "settlement architecture cluster" respectively in 2019 and 2020 by the Ministry of Culture of Taiwan. Besides, the area of old Paiwan settlements including the two cultural heritage sites will be designated as " a natural and cultural ecological landscape area" by the Ministry of Communications of Taiwan.

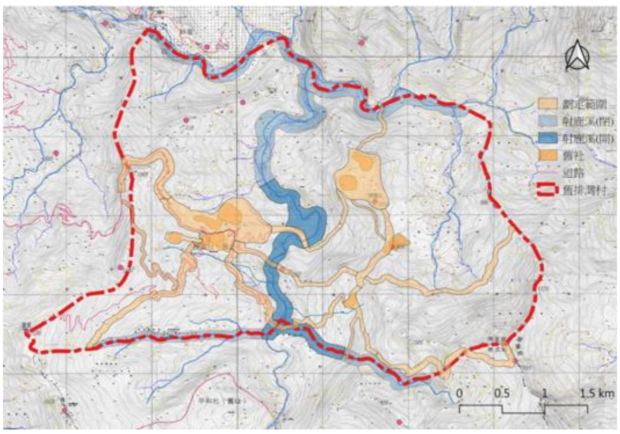

Fig. 1 GIS mapping of old paiwan settlements, an area will be designated as "a natural and cultural ecological landscape area" including two cultural heritage sites, Taiwan.

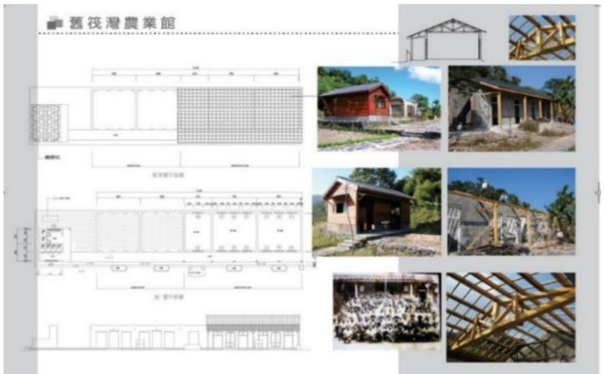

Fig. 2 Restoration of the Supaiwan elementary school (2004)

Fig. 3 Reconstruction of Taruljayaz house (1), 2004~2005

Fig. 4 Reconstruction of Taruljayaz house (2), 2004~2005
(https://youtu.be/xRCvb_8JNxs)

Fig. 5 Terrestrial Lidar of Taruljayaz house scanned in 2023

2. DIGITAL DOCUMENTATION FOR A STONE SLAB HOUSE

Investigating the current situation of the ruins of the aboriginal settlement to expand the understanding the interaction between a settlement and aborigines requires more detailed investigations. Considering that the traditional method requires a lot of manpower, time, and money, the 3D digital analyzed image of LiDAR data is used to assist the current situation of the survey. Using 3D scanning equipment or LiDAR measurement equipment and 3D model technology of multi-view image measurement, and digital 3D point clouds can be used to digitally compare the styles and sizes of stone slab houses of different tribes. In addition to the research on the construction technology of stone slab houses, it also provides three-dimensional digital preservation functions. LiDAR for short is the abbreviation of "light detection and ranging." LiDAR can measure the distance of objects with laser light, because the speed of light is fixed, as long as you know the time from the emission to the reception of the light pulse can be converted into the distance from the transmitter to the object, and the horizontal angle and vertical angle can be calculated to quickly establish a 3D numerical image model of the real scene, so as to improve the efficiency and accuracy of the investigation.

Fig. 6. UAV photo of Supaiwan, 2021

On 2021/07/16, supaiwan setttlem was taken UAV photos (Fig. 6), and qapullu house was scanned with three scanning methods. They are Kaarta Contour mid-range 3D scanner (Fig.7), Mantis F6 medium short 3D scanner (Fig. 8), and 3DF 4Zephyr multi-view image measurement (Fig. 9 Gexcel 3D Reconstructor, 3D point cloud monuments digital city processing software) .

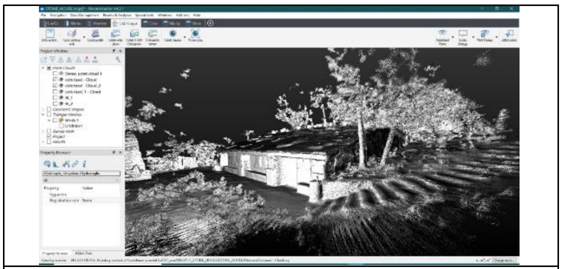

Fig. 7 Kaarta Contour mid-range 3D scanner

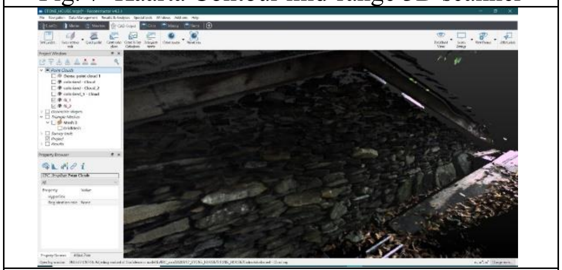

Fig. 8. Mantis F6 medium and short 3D scanner

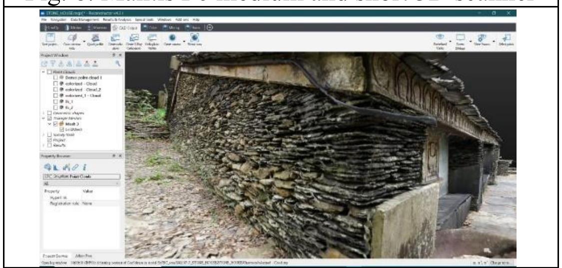

Fig. 9. 3DF 4Zephyr multi-view image measurement (3D modeling technology)

The threes techniques are expoited to collect 3D images, together reconstruct the appearance of the house, and accurately digitize the surrounding topography with trees. The instruments, processes, and results are discussed as follows.

2.1 With Portable Handheld Scanning (LiDAR)

2.1.1 Kaarta Contour: Kaarta Contour is a versatile mobile mapping platform with a range of 30 meters and a data rate of 35,000 points per second. Portable handheld scanning, instant 3D point cloud modeling from input to output (Fig. 10), the Contour offers significant speed advantages while providing the flexibility to capture small, complex spaces and can be used in a variety of indoor and large outdoor applications. In particular, the handheld device can quickly walk on the mountain road and the trails around the slate house to ensure a complete digitization of the appearance of the slate house and the surrounding terrain environment, and the rapid result presentation (Fig. 11).

Fig. 10. Immediate scan and immediate overlay, on-site viewing of 3D point cloud

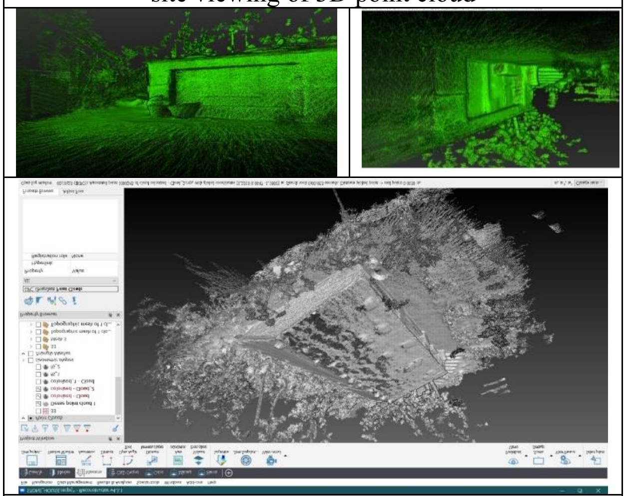

Fig.11. Virtual reconstruction of the stone slab house and the surrounding topography after scanning with Kaarta Contour

2.1.2 Mantis Vision F6: The Mantis Vision F6 is a high-convenience and high-precision handheld device, lightweight, portable, and high-precision. It records the details of the slate stacking method, and digitizes the slates of different sizes, places, and the gaps of the slates. Use various scanning angles at close range to reduce the scanning dead angle, and record the complete point cloud with immediate true color and immediate overlap (Fig. 12). The wood carving decoration on the slate house is clearly presented, the operation process and the scanning point cloud results (Fig. 13).

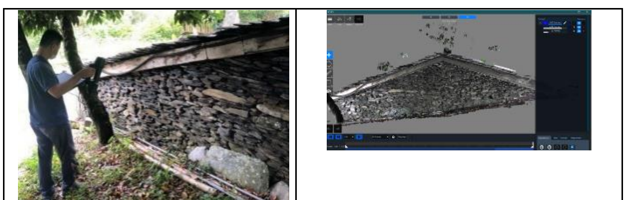

Fig. 12. Mantis F6 records the details of the slate stacking of a slate house

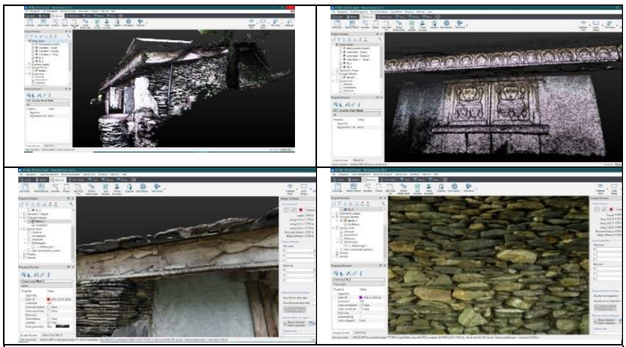

Fig.13. Mantis F6 point cloud scan clearly showing details of slate stacking and wood carving

2.2 Photogrammetry

3D modeling technology of multi-view image measurement adopts 3DF Zephyr, which is a commercial photogrammetry and multi-view image 3D modeling software. It is a simple operation interface and powerful editing function developed by 3Dflow, an Italian software company. 3D models can be calculated through this 3DF Zephyr photogrammetry software whether from photos or videos. It is built on 3Dflow's proprietary and cutting-edge reconstruction technology, which has by far the most accurate, automatic, and the best designed multi-view stereo algorithm on the market. It uses a single-eye fixed focal length 35 mm full-frame camera SONY A7. The overall workflow first performs multi-angle surround-view shooting of the existing scene, then calculates the common position points of multiple images to generate feature conjugate points, calculates high-density feature point clouds, establishes a polyhedron (mesh) model, and then calculates the texture material. A 3D virtual reality model is generated from multiple images, and the process is a 3D virtual reality technology generated by processing and size correction after modeling with 3DF Zephyr images. The digital 3D reality model can be zoomed in, zoomed out, moved, viewed from multiple angles and other operations during browsing, and the length, width, height, area, and volume of the objects in the 3D reality model can be checked to be consistent with the data information of the reality. The 3D real scene image modeling can be used for site planning, area measurement, and earthwork calculation. In addition, it can be connected with Gexcel Reconstructor 3D analysis software for orthophoto, terrain analysis, section analysis, contour line, variation difference analysis, and planning virtual scanning space map of digital reality model, etc. (Fig. 14)

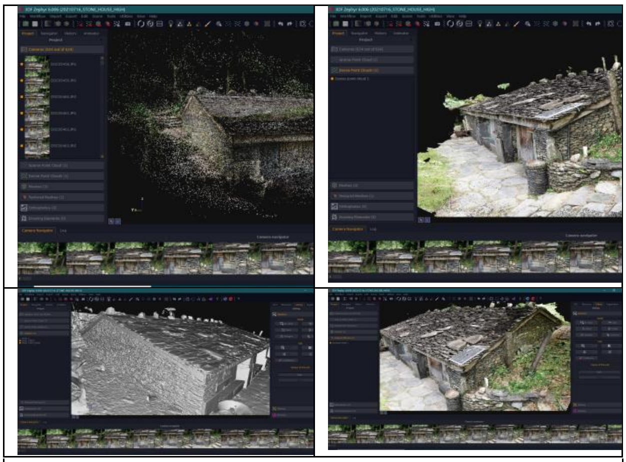

Fig. 14. 3DF Zephyr automatically calculates conjugate features, high-density point cloud, mesh model, texture model process

2.3 Integration of scanning and photogrammetry

Integrating and present point cloud software, Gexcel Reconstructor 3D digital city production team adopts a professional software. Gexcel Reconstructor 3D analysis software. It is in a leading position in 3D processing software. Gexcel can not only process a variety of 3D laser scanner data formats, but also can process 3D point clouds to project 2D images and terrain data from any camera (Fig. 15to Fig. 17).

It can be easily observed and marked to show the stacking method of the slate, including the size of the slate, the gaps in the slate, and the placement of the slate on the facade. Make a correct size orthophoto map to record the irregular stacking method, and it is easier to interpret and understand when viewing the orthophoto map (Fig. 18), which can provide effective help for future reconstruction or imitation of inheritance technology. Aiming at the terrain around the roof, high-density point clouds are used to create a 0.5-meter-high and delicate 3D terrain simulation to push back the topographic conditions of the site selection at the time. The grass is flat, with distinctive features, and the three-dimensional terrain can simulate and restore the topography (Fig. 19).

2.4 Drawing in CAD

The point cloud transfer from the scanning acquisition stage can automatically generate a plane inspection image map. The slate house plane image is scanned in the mountainous area and the point cloud is imported into the automatically generated plane, and the slate house plane image map can be inspected in real time on the spot. The software function also includes point cloud output and export of complete image CAD format processing flow. The orthophotos are retrieved in CAD format as references to draw the plan, elevations, and sections of the house (Fig. 20).

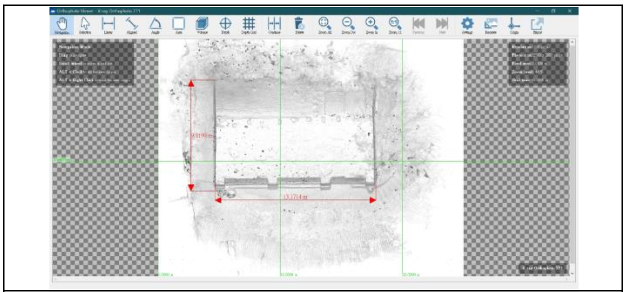

Fig. 15. Automatic generation of slate house plane image by importing point cloud on-site of mountain area

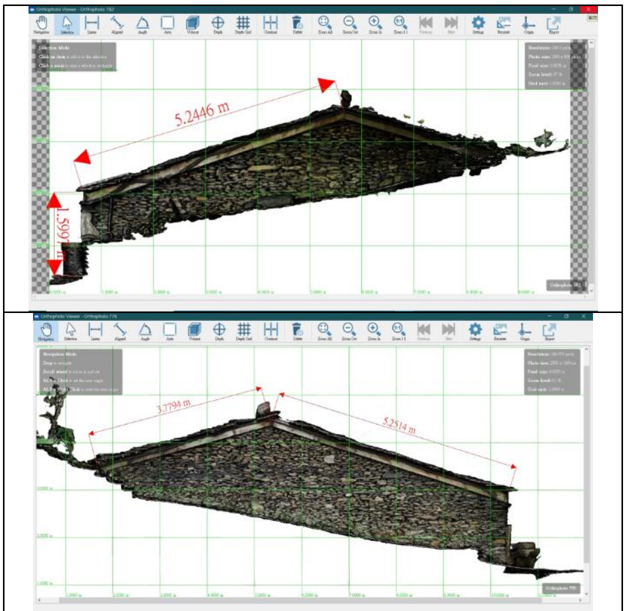

Fig. 16. Orthophotos on the left and right sides

Fig. 17. Roof orthophoto

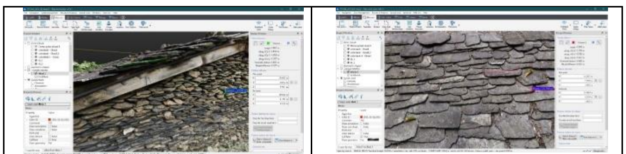

Fig. 18. Observation notes showing how the slabs are stacked

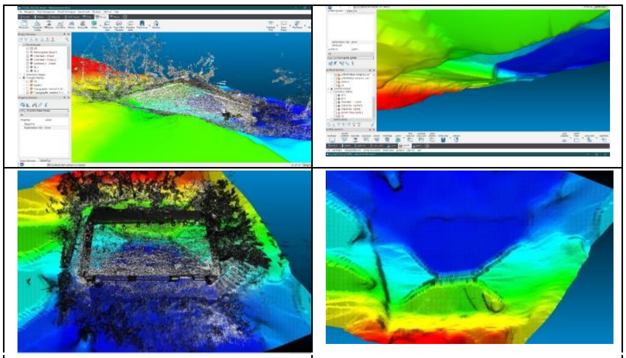

Fig. 19. Highly refined digital 3D terrain

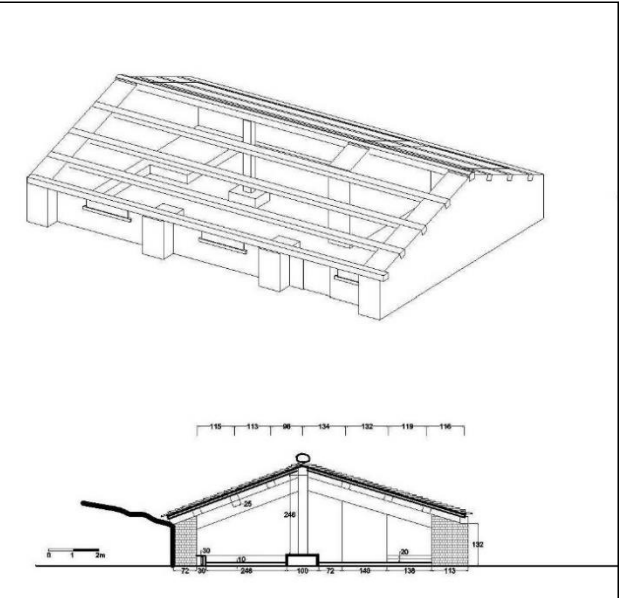

Fig. 20. Horizontal, vertical, and cross-sectional digital drawings (CAD) of orthophotos obtained by 3D scanning technology

2.5 Virtual Reconstruction and Sharing

Set up on a website (http://oarc.npust.edu.tw/padain/3D.html) and through the POTREE network resource platform to present 3D models and provide query functions (Fig. 21). Potree is an API (application programming interface) developed by the Vienna University of Technology. It uses the octree tree data structure and the Potree (tree sticking technology) software algorithm. Based on the point cloud renderer of WebGL, it is a user-friendly interface platform for image processing on large-scale point cloud data. The results of 3D scanning are applied to the Potree browsing technology platform to present the 3D model as follows:

Fig. 21. 3D data display and query using network resource Potree (http://oarc.npust.edu.tw/padain/3D.html)

3. AERIAL /TERRESTRIAL PHOTOGRAMMETRY AND LIDAR FOR SETTLEMENTS

3.1 The first stage of documentation: mapping the layout of Supaiwan -UAV photogrammetry

It was carried out an area of 11 hectares of Supaiwn on 2022/06/04. With full-frame camera RXIRII, 1.5 cm resolution orthophoto of aerial photography can be obtained at a shooting height of 120 meters, and can be combined with PPK (Post Processed Kinematic) system and ground control points (GCP) to be improved to 10 cm shooting accuracy.
Aerial photogrammetry and its application on mappinhg including flight plan, UAV photogrammetry and orthophoto data construction, aerial survey results, and process of mapping have been discussed in the previous papers (Lu et all, 2023).

Fig. 22. Supayuan orthophoto image, 2022

The orthophoto of Supaiwan settlement (Fig. 22) is imported into CAD to draw the layout of the stone slab houses under the coordinate system of WT97. Since at the year of 2022, the southeastern corner of the settlement is still under the dense woods, the layout of stone slab houses in this area are from in-site investigation. The two kinds of data, one from aerial photogrammetry and the other from in-site investigations for those stone slab houses under dense woods are not able to be documented by UAV photogrammetry. The result of mapping combined the two kinds of data in the WT97 is shown on the Fig. 23.

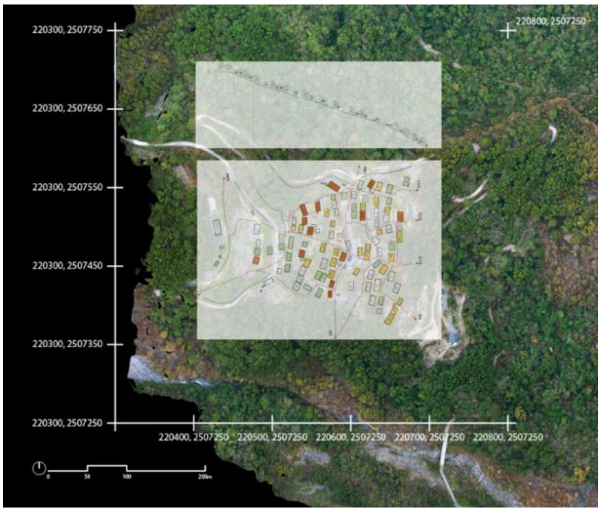

Fig. 23. Mapping the layout of the settlement of Supaiwan about 6 hectars (WT97) after the orthophoto of Supaiwan and in-ste investigations

3.2 The second stage – Aerail/Terrestrial Photogrammetry and Lidar

3.2.1 Scope and techniques:

In 2023, the further survey of Kapayuwanan was carried out - an arial photogrammetry of 180 hectares and Lidar of 16 hectares (660m~860m), and the terrestrial Lidar of 1 hectares (660m~680m). The instruments and accuracy survey data list are as followings:

- Aerial photogrammetry: full-frame 24-megapixel camera, 1.5 cm resolution accuracy (sony RX1R II).
- Aerial Lidar: aerial multi-echo LIDAR (GreenValley LiAir V70) with an optimal scanning distance of 80 meters
- Terrestrial Lidar: 3D scanner (Terrain Scanner, Z+F IMAGER 5016)
- set 4 common ground control points and 5 aerial photography ground control points, and use high-precision GPS equipment to achieve measurement accuracy within 2 cm in the E-GNSS method. Overlap of lidar and ground points cloud data,
  Average ICP error: 0.0869 m, Maximum ICP error allowed:0.0874m

The orthophoto from aerial Lidar and integrated with terrestrial Lidar is shown in Fig. 24

Fig. 24. Aerial LIDAR of Kapayuwanan in 2023

3.3 Representation

3.3.1 3D real scene/Terrestrial Lidar:

The southeastern corner of the settlement is sorted out after the year of 2023, owing to the inappropriate management of the cultural heritage site by setting fire and with insecticide, the stone slab houses under the dense woods have more clear profiles (Fig. 27~28).

Fig. 27. High precision digitalization of ruins of stone slab houes' settlement of Supayuan trough terrestrial Lidar.

Fig. 28. Point cloud presentation, the colour mode of real scene of the stone slab houses ruin and landscape through terrestrial Lidar.

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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3.3.2 The 3D model and animation/UAV photogrammetry (Fig. 26)(https://youtu.be/8-LUbJsJk4g): Apply **"A**cute 3D Viewer" to visualize online 3D views of various places created by aerial photos through techniques of photogrammetry. One can check the elevation of any place as well.

Fig. 26. 3D model animation through aerial photogrammetry

3.4 Reavealing the hidden settlements of Kapayuwanan

The research finally is to combing the UAV photogrammetry and terrestrial LiDAR techniques to document the area northern to Supayuan, that is Kapayuan and Kapayuwanan u without accessibility, and the settlements nder dense forestry are revealed (Lu et all, 2023). (Fig. 25)

Fig. 25. Reveal the hidden settlements

3.4.1 Video: Revealing the past with humanities and digital technologies, Kapayuwanan, Indigenous settlements, Taiwan. (https://app.cipa2023florence.org/video-contest/?contest=video-detail&video_id=169961detail&video_id=169961)

Shaping the future is from revealing the Past. That is crucial to document, understand, and preserve the precious cultural heritage. Documenting with immediacy and high resolution become possible for rapid grow of digital technologies. It's astonishing, in the case of Taiwanese indigenous archaeological sites, UAV photogrammetry and Lidar successfully reveal the relics of stone slab houses in steep slope under dense forestry. The reveal of settlements with reclaimed landscape verifies oral transmission. Digital technologies support the contention of archaeology, anthropology, heritage preservation, and cultural landscape, indispensable for revealing the past and shaping the future.

4 CONCLUSION

For slate houses, medium and short distance 3D scanning and multi-view image measurement can be used, which can quickly, accurately, and meticulously collect the detail information of decorations. The point cloud data of two different scales and 3D digital data from photogrammetry can be integrated to present a house with decoration details and its site situation through 3D modeling and processing software. The orthophotos of roof plan and elevation can be obtain through 3D processing software as well.

The results of this study show that in large-scale settlement surveys, aerial survey technology can be used in the 3D reconstruction of the topography and landscape of settlements., while the 3D scanning can be applied to the small scale for the fine records of individual buildings. The application of aerial survey and 3D scanning technology greatly increases the efficiency and accuracy of surveying and mapping work, being very much helpful for preservation planning and virtual restoration and conservation, and can be widely used for the investigation of aboriginal settlements in the mountain area.

The integration of UAV and terrestrial 3D mapping technologies for the visualization and healthy diagnosis has been exploited. The performance of those technologies for the visual restoration can be presented in several aspects: documentation, mapping, representation, reconstruction, and sharing.

Documentation: Accurately record trees, the position of edifices, stone slab houses, landscape, and the surrounding terrain through post-processing analysis to verify the legends and historical materials passed down by the elders to restore aboriginal settlements.
Mapping: The layout of supayuan settlement was drawn according to orthophoto helping with in-site investigations for those house remains under the dense forest. (survey in 2022/06/24)
Representation: the real scene by color 3D point cloud mode in perspective view, showing road, stone slab houses, edifices, stone remains, trees, terrain , and landscape.
Construction and Sharing For the present conditions of sites have be carefully documented with digital technologies and represented with various ways and also shared in the web site. Athough we have virtually reconstructed the existing architecture and landscape with topography, there are so many decayed stone slab houses (ruin) can be virtual reconstructed to restore the original

settlement such as Pompeii and so may other world heritage sites. The follow up research will be the virtual reconstruction of those decayed ruin which needs more carful studies of each house and their styles and which period of architectural styles would be reconstructed. However, this papers has demonstrated the possibilities and quite a few performance of digital technology in the field of visualization and virtual restoration of cultural heritage of settlements, especially in such sever sites, and the partial performance has been shared with public.

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