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Documentation of Historical City Using Oblique UAV Imagery: Case Study of the Traditional Terrace of the Jewish Neighbourhood in Akre.

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A B S T R A C T:

UAV photogrammetry is a crucial technique for conserving cultural heritage sites, particularly oblique images. However, studies on this method are limited. The Jewish Neighbourhood in Akre, with its significant historical and architectural value, needs urgent documentation to prevent further deformation. This article aims to present the methods and techniques of data acquisition and processing to document the traditional terrace form of the Jewish Neighbourhood. UAV was used to capture 337 images at an altitude of 40 meters with a tilted camera angle of 45 degrees. Agisoft Metashape photogrammetry software was used to process the images and produce a 3D digital surface model of the buildings, quantitative and qualitative methods were carried out to assess the accuracy of the deliverables. In addition, Global Mapper and ArcGIS software were used to drive more documentation details that would serve to set the required operational guidelines to preserve the traditional terrace form of this site. Results show that the accuracy of the produced 3D model is high and further proves that UAV photogrammetry using oblique images is an effective technique for documenting such complex historical sites.

1.Introduction

Conservation of cultural heritage (historic buildings) contributes highly to sustainability as it represents the identity of the territory and people. It is also considered a fundamental element in attracting tourists and is ecologically beneficial due to the lower carbon footprint of the historic buildings.

Documentation of the physical characteristics of cultural sites is a crucial activity within the conservation plan of a site (LeBlanc and Eppich, 2005). Both qualitative data (e.g., shape, pattern, texture, colour) and quantitative data (e.g., size, ornamentation details, orientation, position "horizontal and vertical coordinates") are required for documentation procedures.

According to Alsadik (2020), most of the sites in Iraq lack proper documentation. A few examples of local research on the use of UAVs for documentation in the context of Iraq are achieved by Palanirajan et al., (2019), Alsadik (2020), Ismael (2021), and Qubaa et al. (2022). However, despite being arguable, it is considered to be the best alternative because of the high number of undocumented heritage sites and the relative inaccessibility of most heritage sites specifically in the Kurdistan Region, research on UAVs in the context of Iraqi cultural heritage documentation remains scarce (Ismael, 2021).

Akre is a historic city, including the Jewish Neighbourhood, and is recognized nationally as a cultural heritage site (Ministry of Culture and Information of Iraq, 1970). Its traditional terrace form and considered as one of the defining features that pose the value of the site. Today, this feature is continuously being threatened by the changes mainly man-made changes in the buildings and therefore requires an efficient technique for documentation before the site experiences further deformation. This is the first time that UAVs have been used for documentation of the traditional terrace form of the Jewish Neighbourhood of Akre historic city.

In 2022, Akre's historic city was partially documented under another study project, using hand measurements and theodolite. But it was a labour intensive and time-consuming process as the deployed teams were able to document only a few small scattered clusters of the existing historic buildings (Ismael & Hasan, in press).

The main goal of this work is to illustrate the feasibility of using tilting UAV photogrammetry for the documentation of the traditional terrace form of buildings in the Jewish Neighbourhood. The study includes: (1) Producing 3D surface models of the buildings, (2) Deriving path profiles of the buildings in the neighbourhood, (3) Digitizing the study area to illustrate the pattern, and identifying the type and condition of the buildings along with the height of each building.

This also served as an attempt to highlight the significance of tilting UAV photogrammetry for documenting cultural heritage sites in the research context. More importantly, the local government needs the results of the documentation of the traditional terrace form of the buildings in the Jewish Neighbourhood specifically in the historic city at large. This would help them develop the operational guidelines for issuing building permissions which could include form and height of buildings, the number of stories, and the complicated pattern connecting the buildings in the neighbourhood.

2. LITERATURE REVIEW:

Recently unmanned aerial vehicles (UAVs) are very commonly used in the documentation of cultural sites. They can capture overlapped images remotely in a relatively affordable and time-efficient manner, using available software for flight planning. This in turn allows rapid generation of 3D digital surface models of sites for documentation and model reconstruction in a variety of applications (Themistocleous, 2020). Consequently, UAVs are considered a sustainable method of documentation (Themistocleous, 2020; Girelli et al., 2005).

Photogrammetry is defined as the art and science of extracting 3D information from overlapped images of buildings or structures and converting them into 2D and 3D digital models. UAV images that are processed via photogrammetry are known as UAV photogrammetry, which was first defined by Eisenbeiss (2009) as "a photogrammetric measurement platform, which operates remotely controlled, semi-autonomously, or autonomously, without a pilot sitting in the vehicle". In his dissertation of 2009, Henri Eisenbeiss discusses the application of UAVs for capturing aerial images of cultural sites using rotary UAVs. This technology marked a turning point in cultural heritage documentation as UAV technology started becoming a preferable alternative to other terrestrial techniques for cultural heritage documentation. Studies show the rotary UAV type is preferable to the fixed-wing UAV type for historic building documentation due to its ability to capture images at low altitudes, which helps in obtaining more reliable information on small- and medium-size sites (which constitute the majority of cultural sites) (Federman et al., 2018; Themistocleous, 2020; Ismael, 2021).

In addition to the aforementioned merits, UAV photogrammetry is also considered an innovative technique for documentation due to its ability to capture oblique images, thus covering angles which would otherwise be difficult or impossible to cover from the ground (Aicardi et al., 2016; Gerke, 2009; Themistocleous, 2020). This in turn helps to better understand the significance of a site and the problems or defects in the site (Council of Europe, 2009). Consequently, this helps in applying an inter-disciplinary approach for addressing and solving site problems. Compared to traditional orthographic (vertical) UAV photogrammetry, oblique photogrammetry offers a view from a different perspective than vertical photogrammetry, and the ability to shoot photos from different angles.

Thus, providing additional valuable information on height, length, and area measures of features if data is correctly geo-referenced (Yi Lin et al., 2015; Gomarasca, 2012). The tilted angle can capture both sides as well as the top of the buildings compared to the vertical imagery that usually captures the buildings from the top and slightly sides of the buildings that are located at a distance from the centre. Oblique imagery can be effectively used in the documentation of historic buildings (Höhle, 2013), it helps create 3D surface models with facade details, and in generating virtual images of city areas (Tommaselli et al., 2013). However, oblique imagery also has notable drawbacks such as an extended range of the measuring area, and failures in image matching caused by high objects obscuring objects behind them (Sadeq, 2019).

The resultant 3D model might not be a definitive source of geometric information needed for the development of operational guidelines for protecting the significance of cultural sites, specifically if the sites have undergone changes partially affecting their character-defining elements. Therefore, historical photographs in this case are considered to be an important source of information for the reconstruction of cultural sites by employing photogrammetric methods that evolved overtime from an entirely manual process to semi-automatic, and then fully automatic (Maiwald et al., 2017). Research shows that the main factors affecting the accuracy of the model generated from processing the images acquired using UAV are the type of cameras or sensors, the angle used to capture images, the number and geometric distribution of ground control points (GCPs), obstacles and wind condition, images overlap, camera calibration, appropriateness level of flight height, direction, mode to the site characteristics and the details required for documentation (Gerke, 2009; Themistocleous, 2020; Ahmed et al. 2022; Gerke & Przybilla, 2016; Elkhrachy, 2021; Palanirajana et al., 2019).

The ability of UAVs to remotely capture high-quality oblique images and the development of computer software especially free versions for data processing have led to a breakthrough in the documentation of cultural sites and the heritage engineering field in general.

3. MATERIALS AND METHODS:

3.1 Study Area:

Akre as a district is located in Duhok Province in the Kurdistan Region of Iraq. Akre city is the centre of Akre district with a latitude (36° 45′ 12.85″ N) and a longitude (43° 54′ 6.04″ E) (Figure: 01 & Figure: 02). The historical part of the Akre city is registered in the National List of Heritage Sites of Iraq (1970). It has a long history dating back to about 700 years B.C. on the basis of the history and archaeological sites found in and around the old city (Duhok General Directorate of Antiquities, 2022). The city consists of three historic neighbourhoods: Gorava, Qapaki, and Jewish which is locally known as Justay Neighbourhood (Figure: 03). The historic city includes about 650 buildings that were established on steep hillsides down the ancient castle. These buildings are organically distributed and connected in a complex way by narrow alleys and stairs, the main construction materials of those buildings are stones, and lime along with wood.

One of the most significant features of the city is the terrace form generated by historic buildings which represents the cultural landscape that has evolved over time due to the interaction of people with nature (Figure: 04). Today, this traditional terrace form has been affected by the changes resulted from the replacement of the historic buildings with new ones (Figure: 05). Additionally, the ability of people to use the roofs of the houses located below their houses for daily activities (enabled by the terrace form) is decreasing over time (Ismael, 2015). The Jewish Neighbourhood of the Akre historic city is the most significant part of the city in terms of the historical and architectural value of its buildings (Ismael & Hasan, in press). This neighbourhood has experienced less changes compared to other parts of the city. However, it urgently needs operational guidelines to control changes to the buildings before they lose their own individual and collective values represented in the traditional terrace form. Previously, there was partial documentation of the buildings in Akre historic city as part of a project funded by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) organisation; however, it only involved hand measurement and total station methods.

Only about 80 buildings out of a total of 650 in the Akre historic area were documented (interior and exterior layout). Priority was placed on the buildings that were most historically significant and that have maintained the traditional terrace form. Four groups, each consisting of two architects, one surveyor and one archaeologist, were tasked with documenting the historic buildings located within the historic area in four clusters of buildings, which have preserved the terrace form of the historic area.

This project lasted for 40 working days within which each of the four groups was able to document only one cluster that consisted of 6-7 houses (Ismael & Hasan, in press). The slow pace of the documentation during the project (which involved using hand measurement and theodolite) highlighted the need for a more efficient technique for documentation of the traditional terrace form (such as UAV photogrammetry).

Figure 1: Akre district in Kurdistan Region of Iraq
Source: Sedeeq (2017).

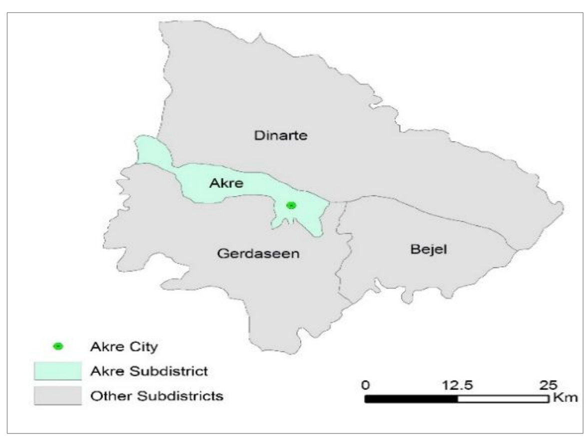

Figure 2: Akre city in Akre district
Source: Ismael (2015).

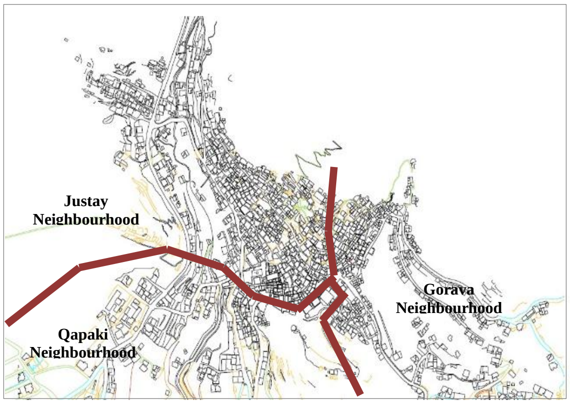

Figure 3: Three neighborhoods in Akre historic city

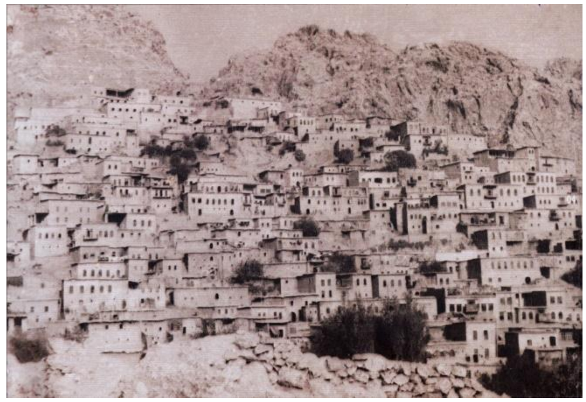

Figure 4: Traditional terrace form of Akre historic city.

Figure 05: Jewish Neighborhood, red boundaries illustrate new buildings affecting traditional terrace form Source: Author (2023)

3.2 Data Acquisition and Processing:

UAV photogrammetry workflow consists of three main phases: flight planning, data acquisition and data processing.

3.3 Flight Planning:

The flight plan should contain the following data: a flight schedule; pattern; altitude; the number of flight paths; the number of photos to be captured; the right camera settings; the overlap between the images; as well as, any weather-related requirements (e.g., temperature, wind, light, or irradiance limitations) (AgEagle, 2020). Obtaining a permit is a requirement for any UAV-based procedure. The University of Duhok, College of Engineering, Department of Surveying has a UAV permit ID that is annually updated. However, when the flight is at a low-altitude (as in our procedure with UAVs being 40m above the buildings), the local government and residents have to be informed of the flight time. The eleventh of January 2023 was chosen as the ideal day for conducting a UAV procedure based on information provided by UAV FORECAST mobile application. An iPhone 13 Pro Max was used to download the application and obtain information about days suitable for UAV usage. Another free application “All-In-One Offline Maps” (Psyberia, 2023) was used on an Android mobile device. It allowed for the use of maps even without an Internet connection to identify the area of interest, which had an area of 7460 m^2. Another important step is the selection of a take-off and landing location for the UAV. This was challenging because of the historic building's density and terrace form, and the existence of a few relatively open spaces in the historic city being steep and/or having trees.

Thus, the roof of a house was chosen as the take-off and landing spot. To ensure the UAV can navigate to a landing spot and avoid damage to the UAV, calibration of the UAV's compass is required (Themistocleous, 2020). The calibration has been done by holding the UAV horizontally and rotating it 360 degrees. The UAV Status Indicator turned solid green by Holding the UAV vertically, with its nose pointing downward, and rotating it 360 degrees around a vertical axis.

3.4 Ground Control Points Measuring:

Eleven GCPS were established in the targeted area and, their coordinates (Easting, Northing, Elevation, and Altitude) were taken (Table: 01, Figure: 06) using e-Survey E200 GNSS Receiver and through RTK Relative positioning method. However, "Duhok" station was used as a base. WGS84/UTM zone 38N with E45° 00' 00" central meridian used as the projection coordinate system of the mission.

The eleven temporary GCPs were marked with a large cross and numbered using a red spray, to make them more visible; GCPs were placed homogeneously at the corners and in the middle of the survey area, and at high and low altitudes. Using the surface of buildings' roofs, balconies, wall corners of the demolished buildings, and alleys. GCP1, GCP4, GCP5, GCP7.GCP9, GCP10 and GCP11 were used as control points. While GCP 2, GCP3, GCP6, and GCP8, were used as checkpoints (Table: 01, Figure: 07). The time taken for establishing each GCP was approximately 12 minutes. In order to select a suitable flight pattern, it is important to understand the characteristics, significance and problems of the site along with the main aim of the site documentation.

Table 01: The Real Value of Coordinate Easting, Northing, and Elevation of GCPs and Check Points

Point	Easting (m)	Northing (m)	Elevation (m)	True Altitude (m)
GCP1	401304.082	4068843.264	761.740	778.284
GCP2 (Check point 1)	401284.699	4068856.684	759.192	775.737
GCP3 (Check Point 2)	401261.913	4068886.140	759.982	776.530
GCP4	401258.191	4068873.867	755.686	772.233
GCP5	401215.358	4068873.294	742.172	758.719
GCP6 (Check Point 3)	401242.163	4068842.970	740.703	757.247
GCP7	401270.906	4068803.328	739.635	756.176
GCP8 (Check Point 4)	401302.728	4068892.484	775.736	792.284
GCP9	401290.199	4068887.100	772.929	789.477
GCP10	401264.056	4068925.912	777.063	793.614
GCP11	401310.262	4068903.884	781.627	798.176

Figure 06: GCPs Marking and surveying using instrument eSurvey E200 GNSS

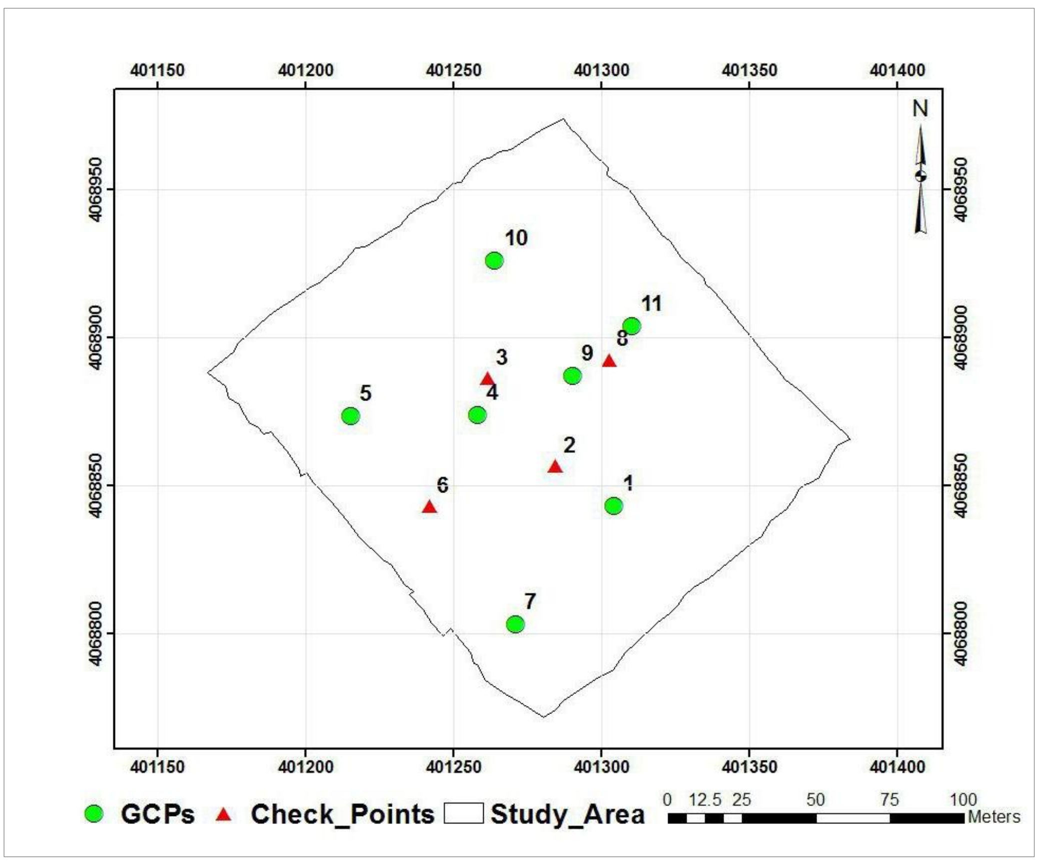

Figure 07: Spatial distribution of 7 GCPs, and 4 Checkpoints over study area

Since the study area is complex due to the organic pattern and high density of the buildings distributed on the hillside, having highly varied surface dimensions, double grid mission and oblique image with a 45° down titled camera was elected for capturing 90% overlapped images from an absolute altitude of 40m above the buildings in the study area (the upper part) and Pix4D capture software was used to set a flight plan. In the Double Grid mission, the UAV turns by 180° between two consecutive lines, which implies the heading of the UAV is not constant. Therefore, the oblique images are not orientated in the same direction.

The UAV facing forward throughout the flight means the dataset will contain images with four different orientations. This ensures capturing the buildings from the sides and the top to produce a high-quality 3D surface model of the terrace form. For capturing the aerial image of the study area, a DJI Phantom 4 Pro UAV equipped with a camera type (DJI 1" CMOS Effective pixels: 20M) was used. The calibrated camera, having a focal length of 8.8 mm, forward and overlaps of 90% flew at a height of 40m above the buildings in the upper part of the study area, the height has increased to reach 95 m above the lower part of the study area (Figure: 08, Table: 02).

Figure 08: UAV flight by Pix4D Capture

Table 02: UAV Flight details

Tilt Angle	Overlap	Absolute Altitude	No. of Flight Path	GSD	Area	No. of image	Time
45°	90%	40-95 meters	17	2.47 cm/pix	93m x 115m	337	15 minutes

3.5 Data Processing:

The following steps were applied in order for data processing using a Lenovo L13 Yoga laptop equipped with an Intel i7-10510U CPU clocked at 1.8 GHz:

The 337 captured images were loaded to the Agisoft Metashape software to start the data processing phase using the Structure from Motion (SfM) photogrammetric method. SfM is a photogrammetric

- method to create a three-dimensional model of an object, feature or topography, using sufficient overlapping of two-dimensional photographs taken from different locations and orientations to generate a rapid and automated dense point cloud and 3D mesh model of the site (Themistocleous. 2020). SfM is applied in many 3D modelling software such as Agisoft Metashape software, which is used in this study.
- Setting the coordinate system using (WGS 84/ UTM ZONE 38N), UAV camera reference

(WGS 84 (ESPG::4326) and for marker reference select (WGS 84/ UTM Zone 38N).

- Aligning photos by selecting the accuracy of 'Highest'. This step includes aerial triangulation and bundle block adjustment (BBA). At this stage, Metashape searches for feature points on the images and matches them across images into the points. It also finds the position of the camera for each image and refines camera calibration parameters (estimates internal and external camera orientation parameters) (Figure: 09).
- These parameters are used to calculate the relationship between the three-dimensional world and the two-dimensional image captured by the camera.

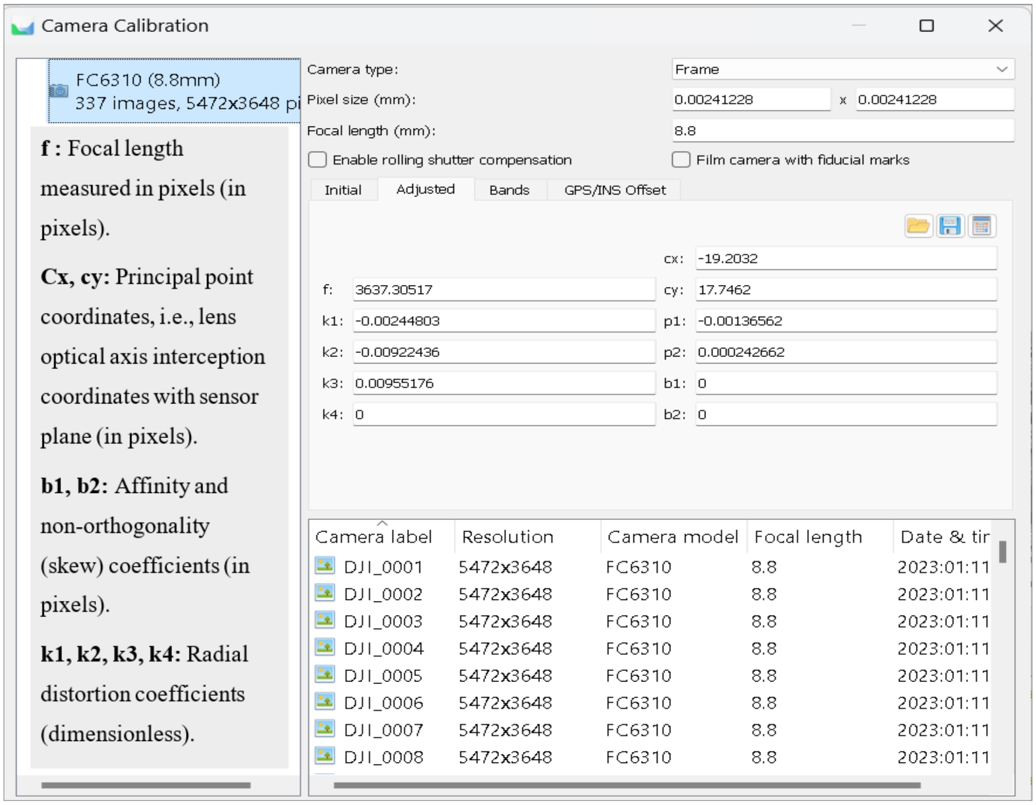

Figure 09: Parameters used in the interior orientation

Radial lens distortion (k1, k2, k3, k4) coefficient is the symmetric distortion caused by the lens due to imperfections in curvature when the lens was ground. In most cases, the errors introduced by radial lens distortion (around 1 to 2 µm) are much smaller than the scanning resolution of the image (around 25 µm) (Pascual, 2021).

Tangential distortion (P1, P2) is sometimes called de-centering distortion because the primary cause is the lens assembly not being centered over and parallel to the image plane. The geometric effect from tangential distortion is not purely along the radial axis.

The skew coefficient (b1, b2) is the number of pixels per unit length in each direction on the CCD sensor. The curved nature of a lens results in radial and tangential distortion. Several distortion coefficients can quantify these, mostly neglected as it is zero. However, the images focused on the study area are also captured some parts out of the study area in the background of the photographs. The result of aligning photos was 135,065 Tie points. This high number can be attributed to oblique imaging capturing a bigger area than the targeted area, so after removing the unwanted area, the Tie points became 64,109 (Figure: 10).

Figure 10: The extracted tie point from the stereo images which is counted as 64,109

- Geo-referencing procedure started by importing the Easting Northing and Elevation of GCPs (GCP1, GCP4, GCP5, GCP7, GCP9, GCP10, GCP11) measured in the field using E200 eSurvey GNSS Receiver and ensuring that the project reference is still the same after adding the GCPs. This could be done by checking in the reference settings. Seven GCPs have been used as control points; those GCPs were (GCP1, GCP4, GCP5, GCP7, GCP9, GCP10, and GCP11) (See Figure: 11).

The process of Geo-referencing continued with marking three GCPs on their place on photos by using the command "Placing Marker". After that, the rest of the GCPs appeared on the map automatically and started marking each GCP in its location on the images. Each GCP should be placed on at least three photos, then it needs to optimize the camera to see the estimated error of each GCP and along with the total error, the estimated error of control points was (0.0131m).

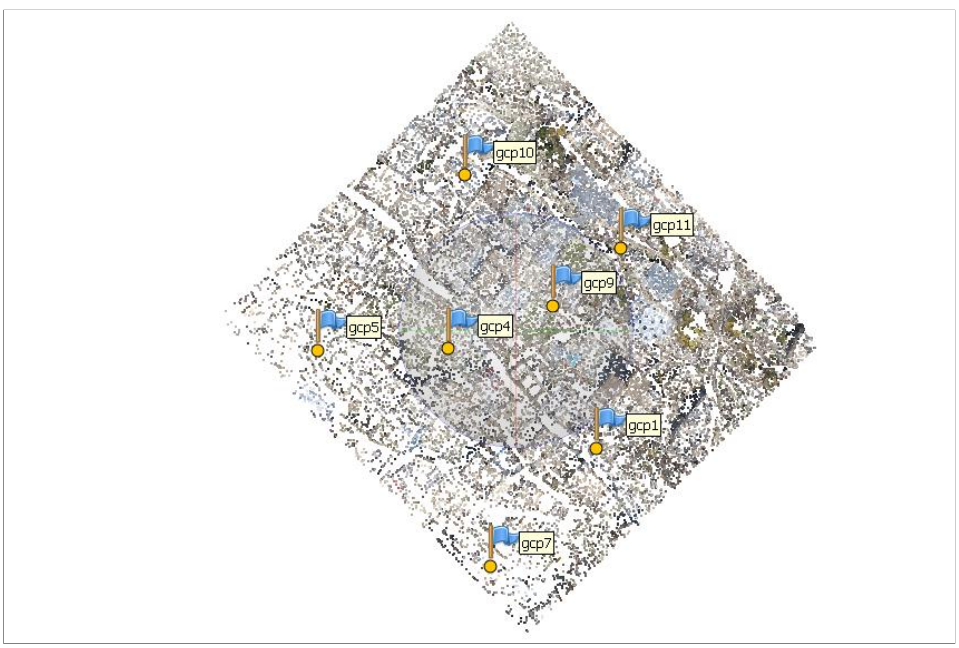

Figure 11: Control Point used for Geo-referencing

4. RESULTS:

4.1 .Creating 3D Surface Model:

Rapid and automated generation of a dense point cloud (8,726, 999 points) of the study area, and then the deliverables; Mesh (3D polygonal model), texture, Tiled Model, Digital Elevation Model (DEM), with a resolution 7.39 cm/pix, and orthomosaic with a resolution 1.97cm/pix were produced in order (Figures: 12, 13, 14, and 15 show the deliverables).

Figure 12: Dense Point Cloud

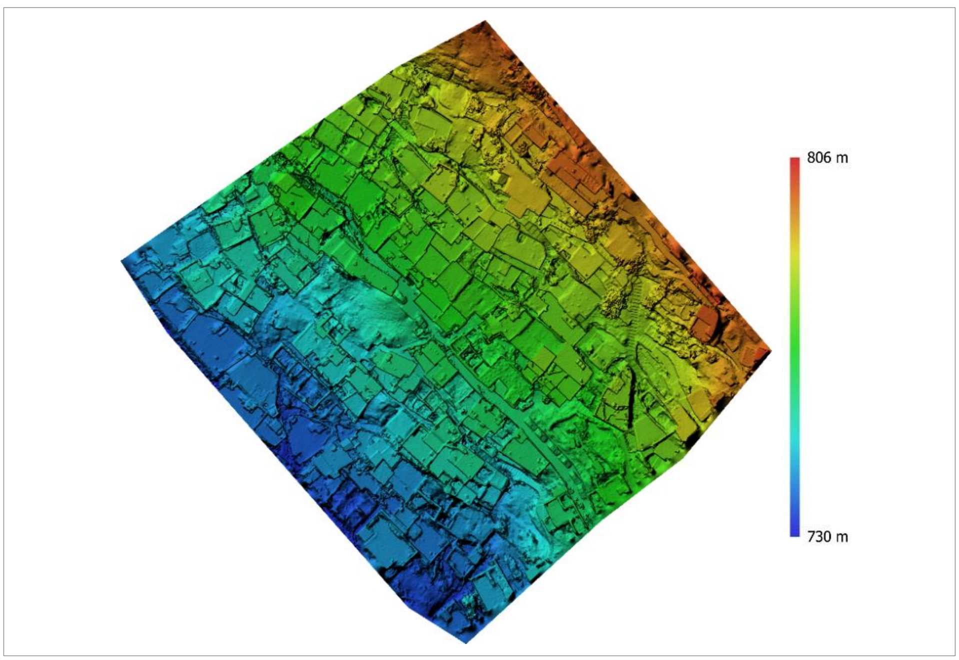

Figure 13: DEM

Figure 14: Orthomosaic

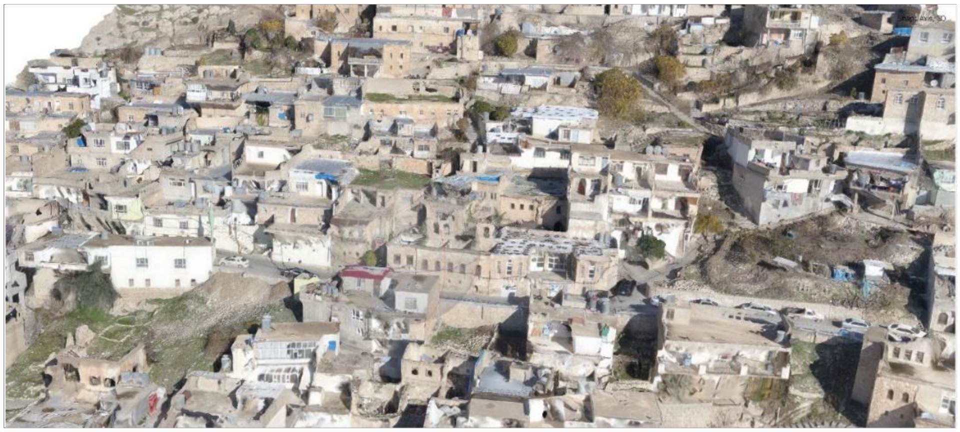

Figure 15: 3D Textured Model from South East view

4.2 Path Profile:

The dense point cloud data of the study area was exported in ASCII pts format. Which is used to export points cloud from Agisoft Metashape to Global Mapper software in order to display a vertical profile along user-specified paths using loaded elevation data. one path profile was selected as an example to display the vertical profile of the buildings (Figure: 16). This helped in identifying the height of the buildings in the study area.

This will in turn guide the local government to develop the operational guidelines to protect the traditional terrace form of historic buildings, specifically for those buildings that have preserved the traditional style and architecture. The historic buildings that were replaced by newer buildings were marked with a red line. As shown in (Figure: 17) the new buildings are distributed along all parts of the study area, although the lower part of the study area has a relatively higher number.

Figure 16: Path Profile of the buildings, number are showing the new buildings

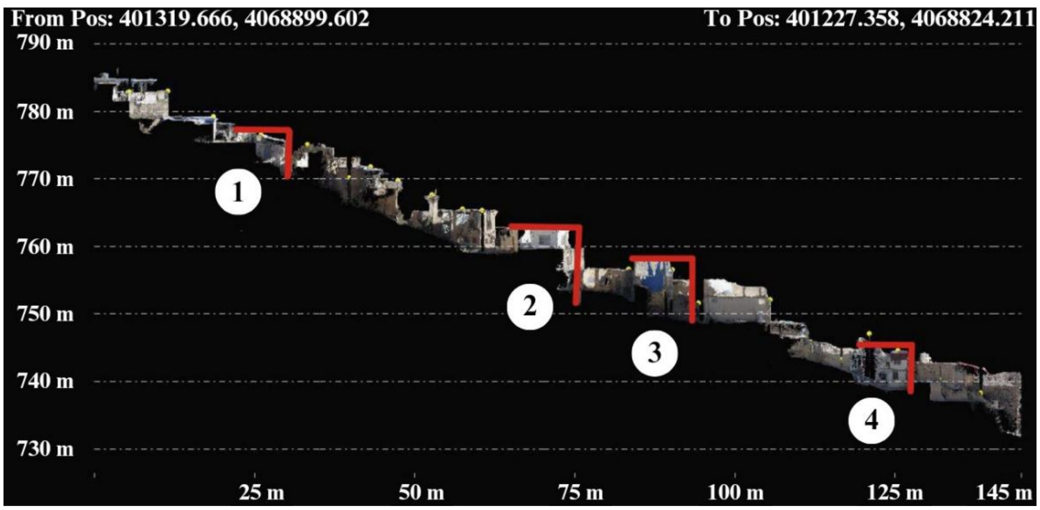

Figure 17: Path Profile, red line showing the new buildings

4.3 Digitizing the Urban Pattern of the Study Area:

Orthomosic data was exported to "Tiff" format and loaded in ArcGIS software, which was used to digitize the building boundaries in the study area. However, 3D model data were used to display the conditions and number of floors of each building (Figure 18). Digitizing also encompasses the alleys and stairs networks, and open and green spaces. This data is very important to understand the significance of the site and its originality in terms of its pattern.

These data along the building condition and number of floors data are also important, and serve as complementary data that can aid in setting guidelines for protecting the traditional terrace form of the study area (Figure: 18 and 19).

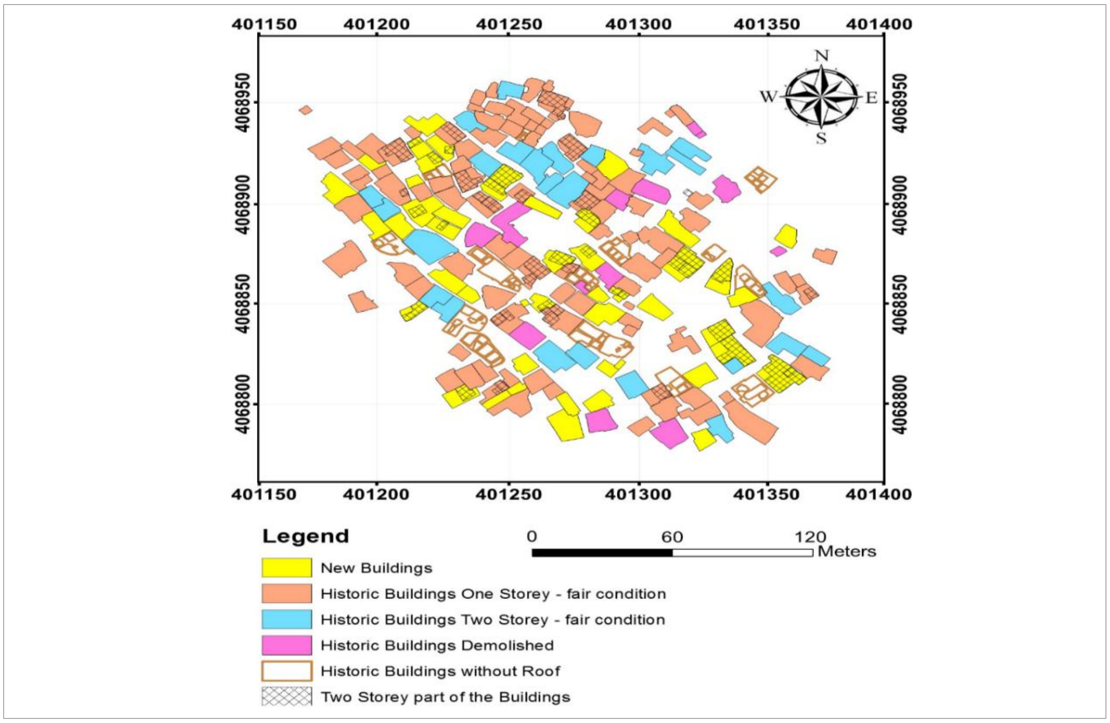

Figure 18: Building types and condition in study area

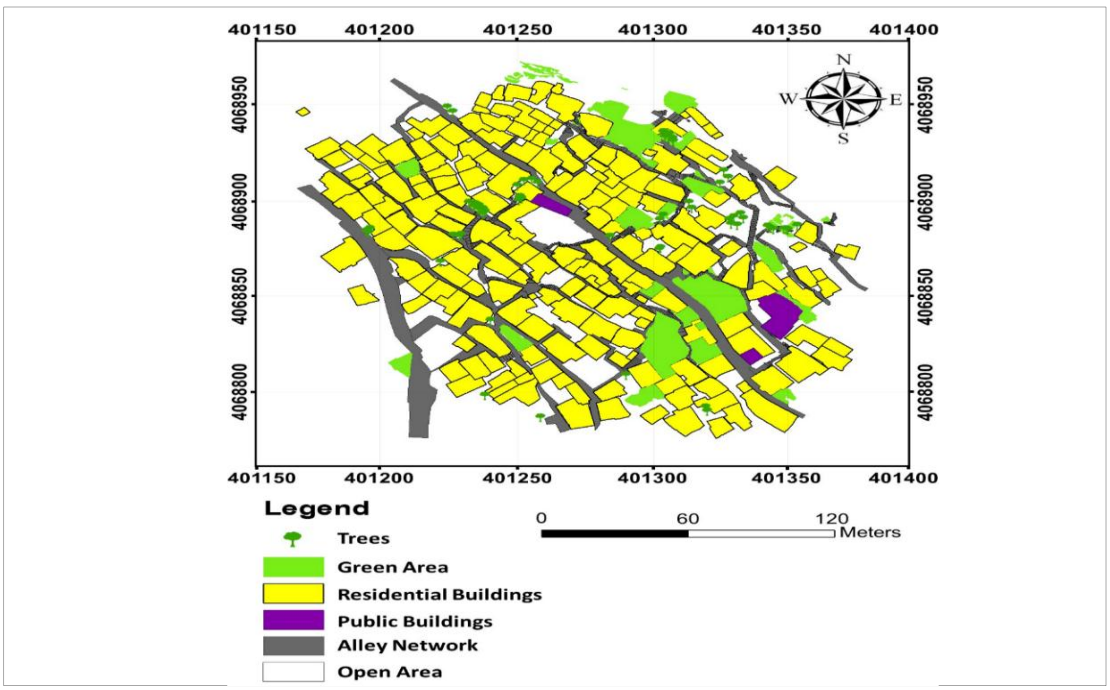

Figure 19: Land use in study area

5. DISCUSSION:

Data acquisition and processing took 12 hours and 44 minutes. This result shows that UAV photogrammetry and oblique images were time-efficient in producing the 3D surface model of the traditional terrace form of the Jewish Neighbourhood in Akre historic city. Quantitative evaluation of the accuracy of the deliverables is very important activity, Root Mean Square Error (RMSE) represent the most effective indicator to measure the accuracy of the horizontal/orthomosic, vertical, and the 3D model (Sanz-Ablanedo et al., 2018; Chen et al, 2022; Kršák et al., 2016; Gerke, 2009).

RMSE could be calculated using below equation:

$$RMSE = \sqrt{\frac{\sum (\Delta)^2}{n}}$$

RMSE represents the root mean square error; □□is the difference between the observed value of the checkpoints and the value on the orthophoto or digital surface Modle; n represents the number of check points.

Table (03) shows the RMSE of Check Points. the GCPs (GCP2, GCP3, GCP6, GCP8) are used as Checkpoints, these GCPs were marked on the created Orthomosaic of the study area by creating a "New Marker", the Agisoft software checkpoints and shows the coordinates in the Reference pane. Finally, it is important to compare the estimated coordinates of the 4 Checkpoints to their real coordinated observed in the field, the result of the comparison is shown in Table (03). However, discussing the accuracy of the deliverables based on the RMSE of the checkpoints is more reliable (Table: 03) (Sanz-Ablanedo et al., 2018; Elkhrachy, 2021; Okegbola, 2022; Azmi et al., 2014).

3D Model, Horizontal, and Vertical RMSE could be obtained using below equations (1), (3) and (6), the total RMSE of the 4 checkpoints is (0.032m). Sanz-Ablanedo et al. (2018) illustrated alternative methods to discuss the accuracy of the generated models. High accuracy is achieved if RMSE-3D at checkpoints is <±2 × GSD or the Horizontal RMSE of checkpoints is 1.2 × GSD and the Vertical RMSE is 2 × GSD (Sanz-Ablanedo et al., 2018). The RMSE-3D for the checkpoints in the study area was 3.2cm as shown in (Table: 03). While the value of 2 x GSD(2.47cm/pix) was 4.94, which means that RMSE-3D value is less than 2 x GSD value. This implies that the accuracy was high.

$$\textbf{Total RMSE} = \sqrt{\frac{1}{n}\sum_{i=i}^{n} Error\ XYZ_i^2} \quad (1)$$

$$Error\ XYZ = \sqrt{ErrorX_i^2 + ErrorY_i^2 + ErrorZ_i^2} \quad (2)$$

n - Represents the total number of GCPs

$$\textbf{Horizontal RMSE} = \sqrt{(RMSE\ x)^2 + (RMSE\ y)^2} \quad (3)$$

$$RMSE\ x = \sqrt{\frac{1}{n}\sum_{i=i}^{n} Error\ X_i^2} \quad (4) \qquad RMSE\ y = \sqrt{\frac{1}{n}\sum_{i=i}^{n} Error\ Y_i^2} \quad (5)$$

Vertical RMS

$$RMSE\ z = \sqrt{\frac{1}{n}\sum_{i=i}^{n} Error\ Z_i^2} \quad (6)$$

Table 03: RMSE of Check Points

Label	X error (m)	Y error (m)	X Y error (m)	Z error (m)	Total (m)
Check Point 1 (GCP2)	0.001	0.002	0.002	0.008	0.008
Check Point 2 (GCP 3)	0.005	- 0.033	0.033	0.047	0.058
Check Point 3 (GCP 6)	0.022	- 0.001	0.022	0.003	0.022
Check Point 4 (GCP8)	0.014	0.008	0.016	0.006	0.017
Total	**0.013**	**0.017**	**0.021**	**0.024**	**0.032**

The horizontal RMSE of the checkpoints was 2.1cm which is less than 2.96 (1.2 × GSD) and, the vertical RMSE of checkpoints was 2.417cm which is less than 4.94 (2 x GSD). However, a qualitative assessment carried out during the data processing concluded that the density of the point cloud was insufficient in some parts of the model, specifically in the lower part of the study area, so it was giving less data on some of façades. This is the result of buildings being connected in a complex way on the hillside, and there are some buildings partially or totally hiding/obscuring the façade of the buildings behind them. This meant that the complexity of the urban pattern and form made it difficult for the 45-degree tilted camera to capture some scenes. Other angles besides the 45^{o} camera angle chosen for this study may have provided better results for capturing all the sides of the buildings. However, the resulting point clouds and 3D model were sufficient to display further important data such as path profile of the buildings and identify the type and condition of buildings. Another factor that possibly affects the generation of point cloud, is flight height disharmony. The UAV was 40 m above the buildings in the upper part of the study area. However, the height gradually increased to 95 m above the buildings in the lower part of the study area. Using flight plan software that optimizes the UAV position (such as Map Pilot 4 DJI Business) may have also provided better results by ensuring flight harmony with the terrain of the study area. This software is essential if the aim is to document the terrace form of the entire historic area. Among the important deliverables from data processing was the point cloud of the study area. The point cloud is useful when exported from Agisoft to other software (e.g., Global Mapper), which can show the path profile of buildings in any selected path in the study area in order to display more data about the study area. These data help further in setting guidelines for preserving the traditional terrace form, specifically for buildings that have preserved their traditional style. A separate set of guidelines must be made for newer buildings that have replaced the historical buildings by integrating data from UAV photogrammetry with the data of reconstruction using historical photographs of the study area, by employing photogrammetric method. Another important deliverable was the orthomosaic. Digitizing methods using ArcGIS software were applied to the orthomosaic to illustrate the complicated urban pattern of the study area. This gives another set of documentation data that can be useful for developing guidelines, especially in setting building footprints.

6. CONCLUSION:

This study demonstrated that UAVs are an effective and affordable option for oblique image acquisition. This work contributed to providing knowledge about using UAVs, specifically the DJI Phantom 4 Pro, for capturing oblique images and data processing and producing a highly accurate 3D surface model of the site. Although, oblique imagery is extending the range of the measuring area and sometimes causing failure in image matching, the tilting UAV photogrammetry proved to be efficient in documenting sites arranged in a complicated terrace form such as in our study area presented. However, due to changes in the traditional terrace form in the Jewish Neighbourhood over time, it is recommended further research toward integrate the data from UAV photogrammetry with data from other methods of photogrammetry, such as reconstruction using historic photographs. This would effectively help in setting an operational guideline for restoration of the traditional terrace form. Sufficient point cloud, that represents the whole area could not be obtained from one UAV flight using oblique images; it is recommended to conduct additional flights using different camera angles to ensure capturing the site very well. Alternatively, using flight plan software can optimize the UAV position to be in more harmony with the terrain, such as “Map Pilot 4 DJI business” software. The deliverables from UAV photogrammetry could be exported to other software to produce more documentation data of the site, as point cloud could be exported to Global Mapper to obtain path profiles of buildings. Moreover, the generated orthomosaic model could be exported to ArcGIS to illustrate the complicated urban pattern and building types and conditions in the study area. The collected data would help the government to set more comprehensive operational guidelines for the restoration of the traditional terrace form of the study area. Finally, this piece of work could encourage more studies on the use of UAVs for the documentation of cultural sites as they are in short supply in the context.

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