UAV Photogrammetry for Architectural Heritage Survey

CBL4UAV Photogrammetry

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Big Idea

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- Stakeholders' Responsibilities and Characteristics
- Stakeholders' Perspectives
- Essential Questions

Challenge Proposal

- Which problem do we want to address
- How the problem is unique?
- How does the problem connect to the five competencies?
- Which need justifies this challenge?

Big Idea

'UAV Photogrammetry for Architectural Heritage Survey’

Stakeholders’ Responsibilities

Stakeholders	Responsibilities in CH Context
Ministry of Cultural Heritage Tourism & Handicrafts (MCTH) (Central Government)	Establishing the policies and specifications & supervising the implementation
Administration of Cultural Heritage in Provinces (Local Government)	Implementing the policies of architectural heritage protection
Cultural Heritage Department of Cities	Identification, documentation, registration, preservation, restoration, conservation of artifacts, etc.
Local Community / Local Residents	Participating in the protection of architectural heritage and understanding the policy in the architectural heritage protection
Expert group	Providing intellectual support for the protection of architectural heritage
Media	Reporting and disseminating news, events, and information about the state of conservation of architectural heritages
Consulting Engineer Companys for the Restoration of Architectural Heritages	Proposing and executing architectural heritage restoration projects according to the condition of the artifact, budget, and requirements of quality and time
Visitors/ Tourists	Providing feedback and suggestion for the architectural heritage protection

Stakeholders’ Characteristics

Stakeholders	Internal	External
Direct Influence	o Local Residents o Consulting Engineer Companys for the Restoration of Architectural Heritages	
Indirect Influence	o Ministry of Cultural Heritage Tourism & Handicrafts (MCTH) (Central Government) o Administration of Cultural Heritage in Provinces (Local Government) o Expert Group o Cultural Heritage Department of Cities	o Visitors/ Tourists o Media

Stakeholders' Perspectives

From the local community point of view, UAV photogrammetry surveying gathers abundant precise data that can be used for introducing architectural heritage.

This may get the needed attention of Architectural Heritage enthusiasts and different communities that effecting the state of the conservation of the artifacts.

Cultural property experts addressed the technical matters of interior space data capturing by UAV and parametric 3D modeling challenges when they use point cloud data obtained from processing UAV-captured Pictures.

From the viewpoint of Consulting Engineer Companys data gathered by UAV photogrammetry survey provides the essential geometric information that they need for conservation purposes in an accurate, precise, and time-efficient manner.

The necessity and costs of applying this technique are exposed for discussion by the local government.

The central government cares about the protocols, considerations, and security issues of UAV photogrammetry when it will be used for civil and cultural projects.

Essential Questions

- How to use UAV photogrammetry for the conservation of Architectural Heritage?
- How to generate a complete 3D model of Architectural heritage using a UAV Photogrammetry survey?
- 3- How to accelerate the parametric modeling process of complex Architectural Heritage surveyed by UAV photogrammetry?

Challenge Proposal

Which problem do we want to address?

How the problem is unique?

How does the problem connect to the five competencies?

Which need justifies this challenge?

Which problem do we want to address?

- 3D Documentation of Architectural Heritage using UAV Photogrammetry for Conservation Purposes

How the problem is unique?

Identification and documentation are the first steps in the conservation of Cultural Heritage. Traditional survey and 3D documentation methods of Architectural Heritage are challenging, tedious, time-consuming, and error-prone due to the special geometry, ornament, and texture complexity in most of these structures.

Aiming to solve the problem of difficult data collection and modelling, many researchers proposed and evaluated using unmanned aerial vehicle photogrammetry for identifying, documentation, digital restoration, and monitoring immovable cultural heritage.

How the problem is unique?

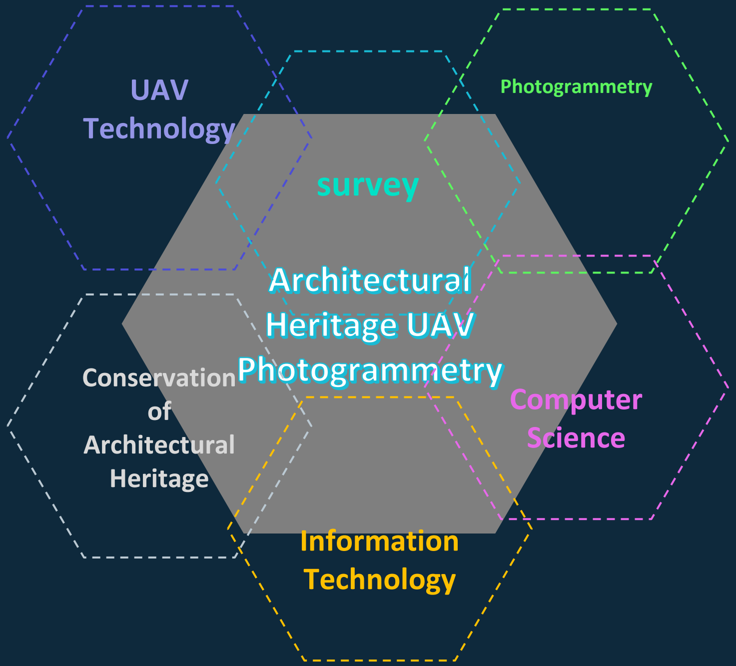
The results of mentioned research show the capability of UAV photogrammetry as a rapid, accurate, time-efficient, and flexible method for data acquisition, modelling, and monitoring of complex, extended, hard-to-access, and high-rise architectural heritage.

In recent years, the extensive usage of UAVs in academic and commercial applications has encouraged their expansion, putting forward the challenge of identifying common procedures and feasibilities of UAVs, along with benchmarks for researchers.

While in the high-ranked universities the manual and traditional methods still are used by the experts and students of conservation for identification and documentation of cultural properties. So, there is an essential need for learning UAV photogrammetry as a multidisciplinary method for acquiring and processing required data for Architectural Heritage conservation purposes.

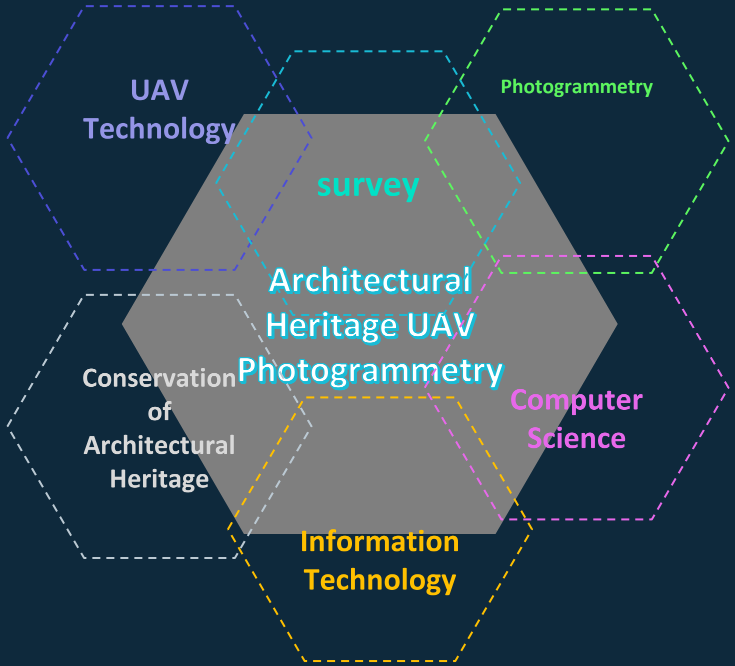
How does the problem connect to the five competencies?

Architectural Heritage surveys carry out to respond to different data requirements and purposes such as identification, documentation, 3D modeling, pathology, 3D virtual reconstruction, restoration, monitoring, and management of these cultural properties. UAV photogrammetry of Architectural heritage as one of the surveying methods requires acquisition planning and parameter determining using interdisciplinary knowledge of Cultural Heritage, mapping, photogrammetry, and UAV technology.



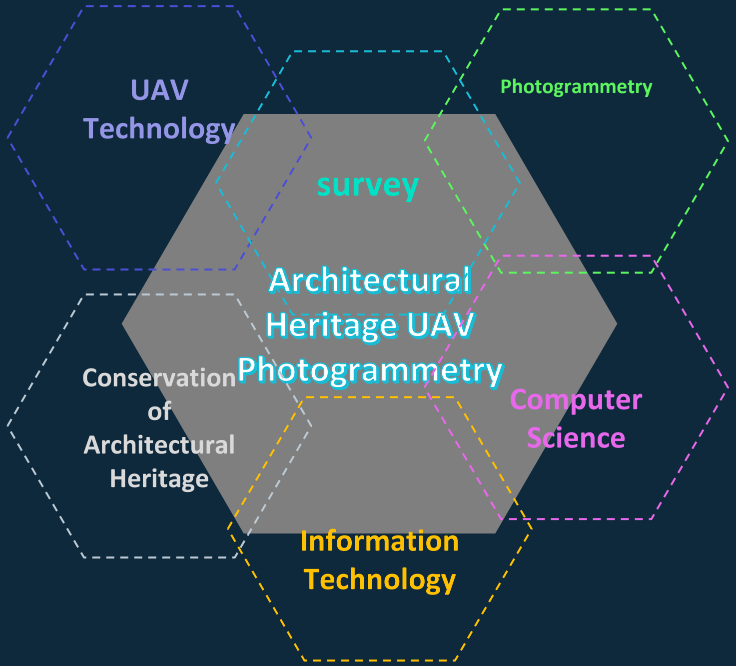
How does the problem connect to the five competencies?

Determining Ground Sampling Distance (GSD), mapping scale, Ground Control Points, Check Points, and optimal trajectory configurations are the conjunction points that photogrammetry and architectural heritage knowledge meet each other. On the other hand, designing the flight plan requires consultation and cooperation between photogrammetry specialists and the UAV operational team.



How does the problem connect to the five competencies?

Processing the gathered data at the first step is a photogrammetric process when it produces a point cloud or even a textured 3d surface model. Whenever the obtained architectural heritage`s point cloud needs further processing to create a 3D parametric model or Building Information Model, there will appear a need for a group of other knowledge fields. IT, Computer Science, and Software Programming are the main knowledge fields needed to employ for the 3D modeling of architectural heritage according to the complex and unique geometry of these artifacts.



Which need justifies this challenge?

Today the world is losing its architectural and archaeological cultural heritage even faster than it can be documented.

Human-caused disasters, such as war and uncontrolled development, are major culprits. Natural disasters, neglect, and inappropriate conservation are also among the reasons our heritage is vanishing.

Considering the existence of numerous architectural heritages across the world and countries, there has to be knowledge of implementing UAV photogrammetry as a quick and cost-effective same time accurate, and flexible method to acquire this artifacts data.

Investigate

Guiding Questions

The List of Guiding Questions

Guiding Activities/Resources

Mapping Possible Activities and Possible Recourses for Answering Guiding Questions

Analysis

- Analysing, digesting, and synthesizing the findings
- A foundation for the solution
- A time plan for the act phase

Guiding Questions

Question List

Factual Questions	Interpretative Questions
1. UAV photogrammetry can be used in which stages of architectural heritage conservation?	1. How would the state of conservation of destroyed architectural heritage be if their structural health had been monitored at the first steps of destruction?
2. What knowledge, equipment, and tools are needed for UAV monitoring of Architectural Heritage?	2. How will be the monitoring of AH in the future according to the advances of deep learning and machine learning?
3. How long often should the monitoring process be repeated?	
4. What are the challenges of using UAV photogrammetry for CH monitoring?	3. What are the differences between identifying, mapping, and monitoring architectural heritage using UAV surveys?
5. Who plans & executes the monitoring frameworks?	

Guiding Activities/Resources

Structural Health Monitoring

1-Preliminary investigation and planning

-Defining the objectives of SHM using a pathology report (vision-based techniques)
-Determining the time frame desired for monitoring

UAV Photogrammetry Implementation suggested for:

- Numerical Modelling
- Crack & Spalling Detection

2-Installation and actuation

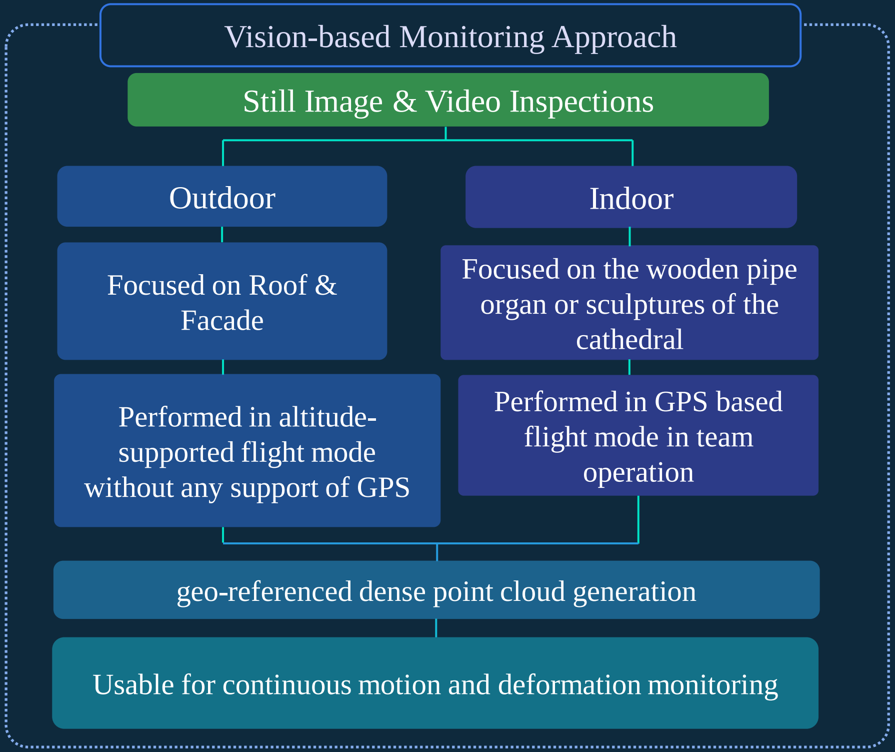
-Defining protocols for data recording, transmission, and storage.
-Defining the data acquisition frequency, which necessitates a compromise between data volume and analysis requirements.

3- Maintenance and decommissioning

- Periodic testing to assess SHM robustness.

Source: Baeza, F. J., Ivorra, S., Bru, D., & Varona, F. B. (2018). Structural health monitoring systems for smart heritage and infrastructures in Spain. In Mechatronics for cultural heritage and civil engineering (pp. 271-294). Springer, Cham.

Guiding Activities/Resources



Source: Hallermann, N., Morgenthal, G., & Rodehorst, V. (2015). Vision-based monitoring of heritage monuments: Unmanned Aerial Systems (UAS) for detailed inspection and high-accuracy survey of structures. WIT Transactions on The Built Environment, 153, 621-632.

Guiding Activities/Resources

Buffer Zone Mapping & Monitoring

UAV Flights

- Nadir only acquisition
- Oblique only acquisition
- An integration of nadir and oblique acquisition

UAV-captured images processing

- Processing UAV data through SfM photogrammetry by Agisoft software
- Orthophoto and DSM creation

Accuracy Assessment

- Accuracy Assessment of Orthophotos
- Accuracy Assessment of DSMs

Nikolakopoulos, K. G., Kyriou, A., & Koukouvelas, I. K. (2022). Developing a Guideline for Unmanned Aerial Vehicle's Acquisition Geometry for Landslide Mapping and Monitoring. Applied Sciences, 12(9), 4598.

Analysis

Analysing, digesting, and synthesizing the findings

The advancement of technologies related to UAVs and types of image-based, range-based, and magnetic sensors mounted on them have improved, evolved, and expanded their use in the cultural heritage field. So today, in addition to taking aerial images and producing textured 3D models, other information related to architectural heritage pathology and structure systems can also be obtained and processed. by installing lightweight thermal sensors or GPRs (Ground Penetrating Radars) on the UAVs.

Even nowadays, the demand for the necessity of using non-destructive methods to collect pathological data and monitor architectural heritage structures is a matter of course. Therefore, the use of UAVs in architectural heritage conservation has expanded from the initial stages to its entire life cycle.

Analysis

Analysing, digesting, and synthesizing the findings

In the early stages of architectural heritage conservation, the visible imaging of the UAV is used to identify and obtain primitive data with less detail in general. Architectural heritage`s 3D model can be generated from the photogrammetric processing of this data individually or in combination with other geometric data (such as laser scanner gathered point clouds). These precise and correct metric digital documents provide the basis for the parametric modelling of architectural heritage in BIM environments.

Analysis

Analysing, digesting, and synthesizing the findings

In the next stage of architectural heritage conservation, recognition of outstanding values and obtaining pathological data of artifacts should be done. The collected data should be presented in more detail and with more diverse aspects. For example, the data acquired with thermal sensors combined with the data from visible sensors provide accurate information about the location of moisture and crack pathologies.

This way, by creating a three-dimensional geometric model and creating the parametric model accordingly in the Building Information Modelling environments, geometric and non-geometric information needed for architectural heritage conservation can be integrated into a single model.

Analysis

Analysing, digesting, and synthesizing the findings

The biggest challenges of processing the collected and existing data are related to this stage. BIM environments have been provided for new building design and modelling that have known geometry and structure. While the architectural heritage has an uncertain geometry and structure, then reverse engineering is needed for their parametric modelling. This process is time-consuming and costly due to uniqueness, geometry complexity, and the uncertainty of the unexposed structures of the assets.

To respond to these challenges many researchers have suggested innovative technologies to acquire data and examined using deep learning, programming, and designing plugins for BIM-related software to post-process gathered data. But still, there is no certainly and clearly defined method for Historic Building Information Modelling in a cost-effective manner.

Analysis

Analysing, digesting, and synthesizing the findings

At the management stage of the conservation process, UAV photogrammetry plays a critical role in gathering accurate, fast, and cost-effective data necessary for change detection and monitoring of architectural heritage. In the cases that have digital twins, this data could be used for lifetime prediction and lifecycle management of the artifacts.

Analysis

A foundation for the solution

Foundations for UAV photogrammetry for Health Monitoring of Architectural Heritage

Phases	knowledge	Tool	Equipment
Pre-acquisition	- Photogrammetry - UAV Technology - Architecture - Cultural Heritage	UAV flight planning software	Personal computer or Laptop
Acquisition	- Photogrammetry - UAV Technology - Cultural Heritage - Land Surveying	UAV flight execution software	- Terrestrial station - Laptop - UAV - Sensors - Smartphone - Power suppliers - Land Surveying Equipment
Process	- Photogrammetry - Cultural Heritage - Land Surveying	- Photogrammetry software - Land Surveying Software	Personal computer or Laptop

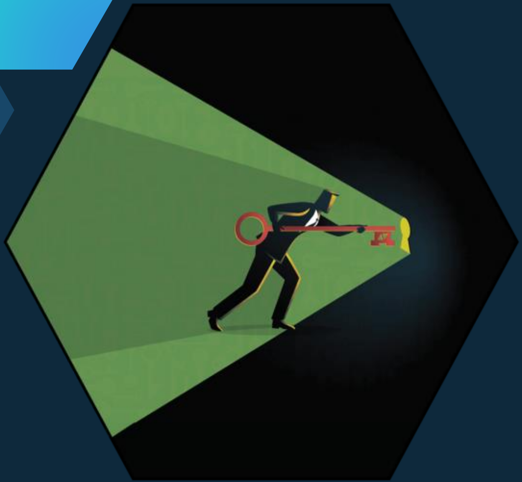
Analysis

A time plan for the act phase

Pre-Acquisition Phase
1-2 Days
28-29 Dec 22

Acquisition Phase
1-2 Day
30-31 Dec 22

Process Phase
4-6 Days
1-7 Jan 23



Action

Solution Development

- 3D Modelling of Architectural Heritage Using UAV Photogrammetry for Conservation Purposes

Implementation

- Pre-acquisition
  - ◇ Case study introduction
  - ◇ Site visit and analysis
  - ◇ Determining acquisition methods
  - ◇ Determining acquisition types of equipment
  - ◇ Acquisition planning
- Acquisition
  - ◇ Flight plan edition (if needed)
  - ◇ UAV checking
  - ◇ GCPs location survey
  - ◇ Flight execution and image capturing
  - ◇ Acquired data checking
- Process

Evaluation

- ◇ Results
- ◇ Discussion

Solution Development

3D Modelling of Architectural Heritage Using UAV Photogrammetry for Conservation Purposes

Actions

Pre-acquisition

- Site visit and analysis
- Determining acquisition Methods
- Determining acquisition types of equipment
- Acquisition planning

Acquisition

- Flight plan edition (if needed)
- UAV checking
- GCPs location survey
- Flight execution and image capturing
- Acquired data checking

Process

- Camera Calibration
- Image geotagging
- GCPs location import
- Image processing

Implementation- Case Study Introduction

The Caravanserais are one of the most important forms of Persian Architecture that emerged and created cause of routes development and needs related to the travel’s demands and requirements.

Caravanserais are usually a place that provides safety for Caravans and travelers against natural risks like rain, snow, storms and floods, or from danger of robbers in the roads. That’s why the structure of Caravanserais is like a castle and good fortified.

In Persian Caravanserai World Heritage nomination file, there are 25 Caravanserais, from all over Iran which are selected from hundreds of Caravanserais.

Implementation- Case Study Introduction

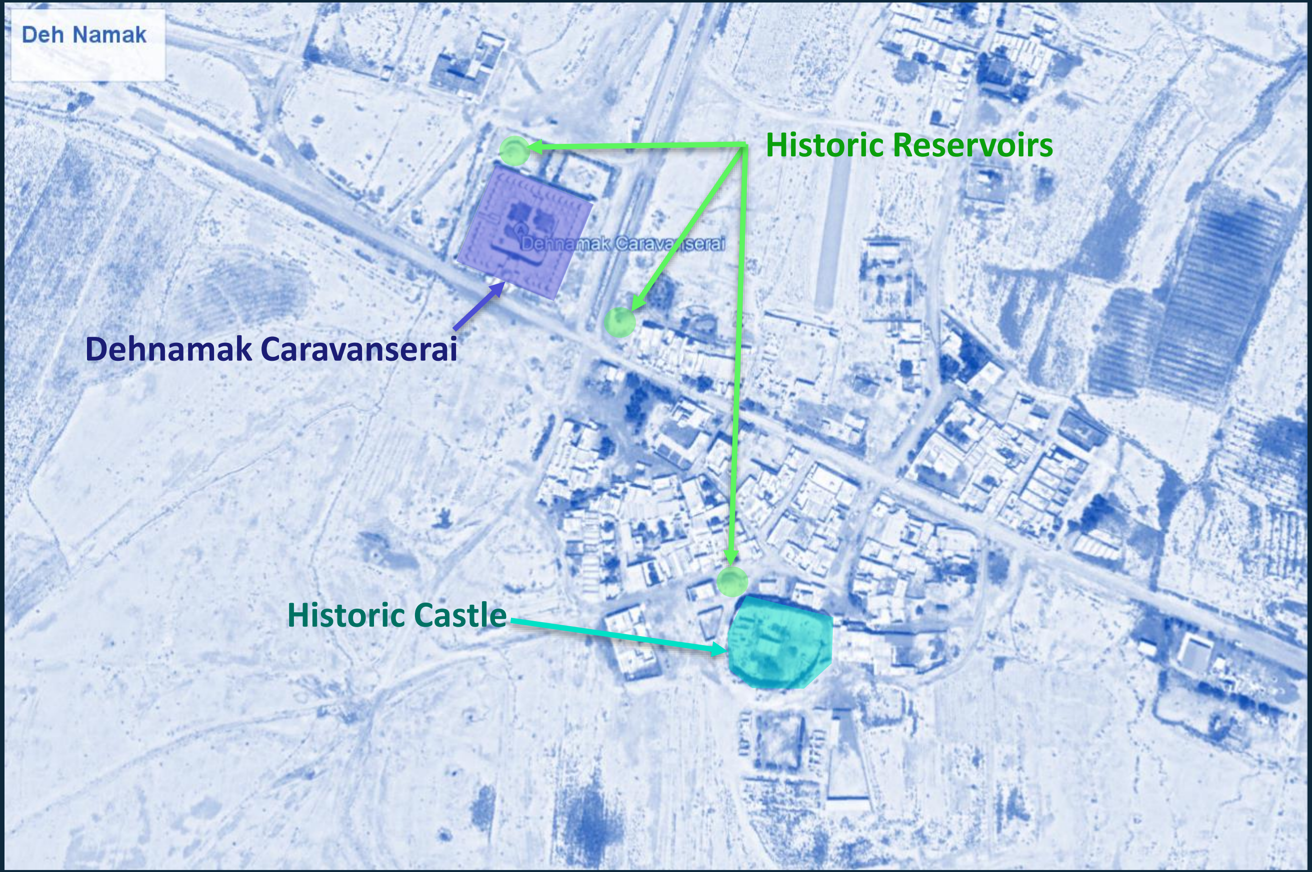
The act phase`s case study is the Caravanserai of Shah Abbasi (Dahnamak). This artifact is one of the caravanserais in the Persian caravanserai UNESCO Tentative nomination file.

It belongs to the Safavid era and is located in Dahnmak village in Aradan city.

This artifact was registered as one of the national heritage of Iran on 26 August 1974 with registration number 978.

This caravanserai has a Four-Iwān pattern plan. It has the central courtyard as the most characteristic element of Persian Caravanserai.

Implementation- Site visit and analysis



Implementation- Determining Acquisition Methods

Considering the artifact features and site analysis to define the proper pipeline that could be used for complete 3D modeling, the following three acquisition strategies were determined:

a) **Nadir imaging**

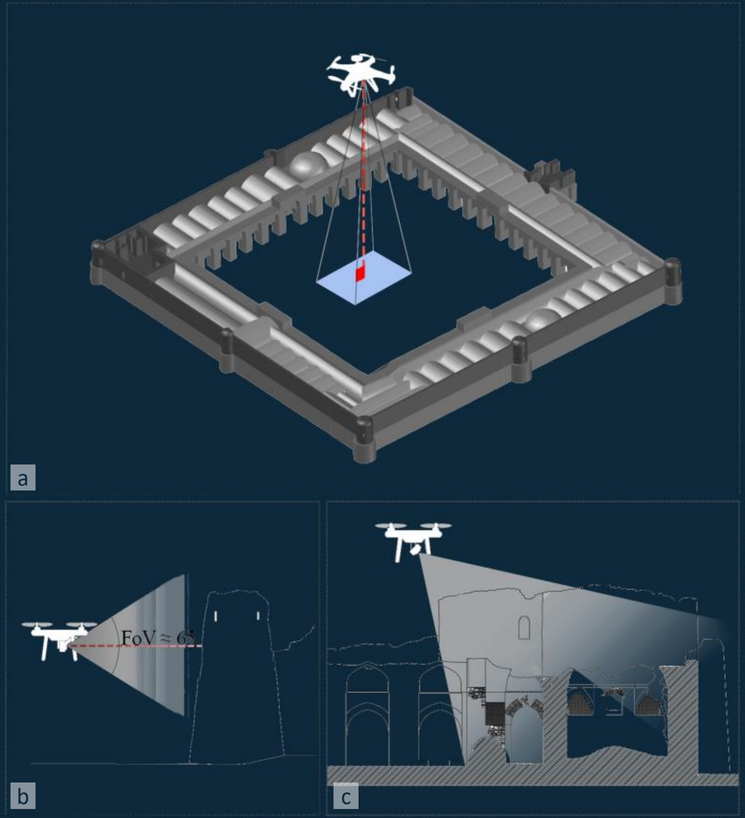
to capture the top view of the artifact and the enclosure.

b) **Horizontal imaging**

To capture the exterior and central yard façades of the caravanserai,

c) **Oblique Imaging**

To guarantee the photographic capture of the joining edges of the roof, exterior facades, and the façades of the central yard.



Implementation- Determining acquisition types of equipment

The Hubsan ZINO 2 plus (Figure below) was considered for the acquisition of the predefined geometrical area of interest with- the use of its own mobile application (the main parameters are presented in the table below).

Characteristics	Platform
UAV model	Quad-copter
Endurance	30 min
Weight	929 g
Dimension	12.83 x 10.24 x 3.74
Characteristics	**Sensor**
Resolution	12 MP
Dimension	1/2.3" CMOS
Focal Length	24 mm

Acquisition planning- Nadir Imagery

The nadir imagery aims to capture the upper parts of the artifact and the enclosure. The nadir acquisition flight planning was carried out taking into account the SfM approach and, consequently, choosing values of (longitudinal) over-lap (80 %) and (transversal) side-lap (65%).

The flight plan was designed with 14 Flight Lines (FLs) along the longitudinal direction of the caravanserai and cross direction to insure complete coverage of the interested area.

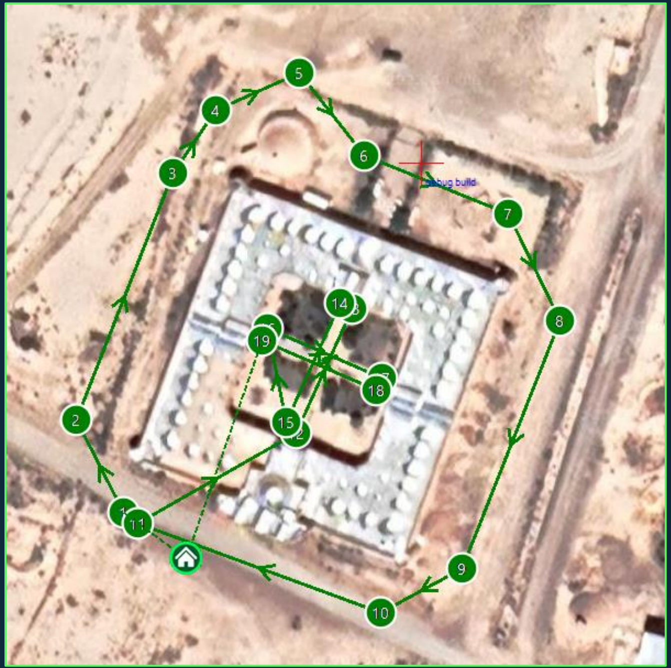
Acquisition planning- Horizontal Imagery

The second flight is considered to capture the exterior and central yard façades of the caravanserai.

This horizontal imaging flight planning is designed according to the highest part of the artifact.

In this step, the flight path was tried to conform to the external form of the caravanserai in order to avoid hidden sections as much as possible.

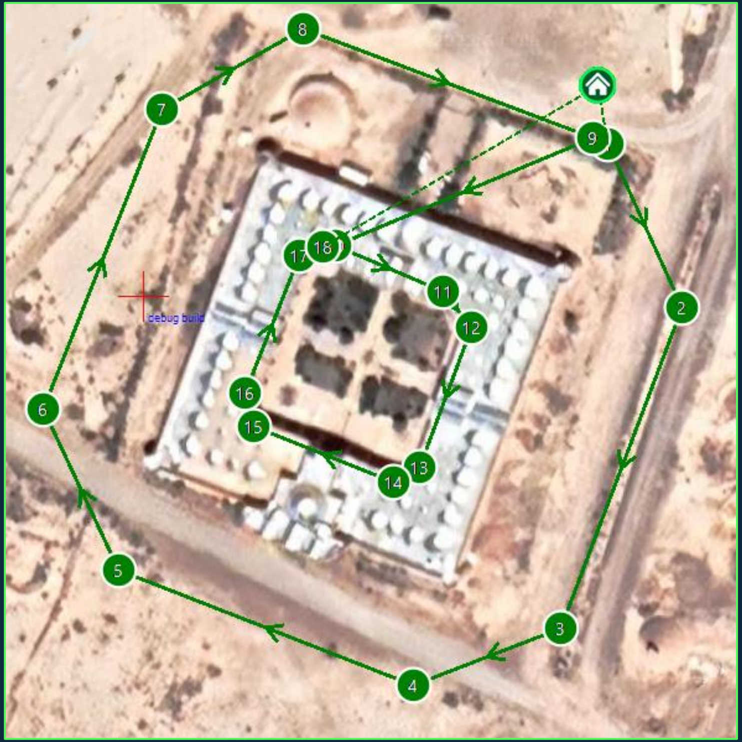
In the central courtyard, due to the presence of vegetation, perpendicular axes were considered for imaging.



Acquisition planning- Oblique Imagery

Oblique imaging aims to guarantee the photographic capture of the joining edges of the roof, exterior facades, and the façades of the central yard.

In the central yard, the oblique acquisition was tried to obtain the side facing the flight axis so that the distance between the exterior oblique images was equal to the distance between the central yard oblique images, and the images have about 80% overlap.



Implementation- **Acquisition**

GCPs location survey

For aerial survey applications GCPs, are typically required as they can enhance the positioning and accuracy of the mapping outputs.

To evaluate the absolute location accuracy of the obtained 3D model, six ground control points (GCP) were considered. Four of them were placed in the corners of the artifact's roof. Two land areas were also placed in the center of the yard and in front of the subsidiary door. The precise geographical coordinates of these points were precisely acquired by the land surveyor.

Implementation- **Acquisition**

Flight execution and image capturing

The calibration procedure was performed before the actual flight. It is important to point out that equipment must be checked to ensure if they work well or not to avoid crashes and system failures due to malfunction.

The UAV was connected to the software via a radio transmitter and the automated flight could be accomplished. The take-off and landing were exercised manually via the remote controller for safety reasons.

The UAV pilot could visualize at any time the position of the aircraft on the software together with data such as acceleration, speed, and navigation.

The entire data acquisition procedure lasted around 5 hours and the flight duration was around 20 minutes per flight due to technical restrictions related to the drone model, and batteries were changed for each flight deployment. A total of 813 geotagged images were obtained,

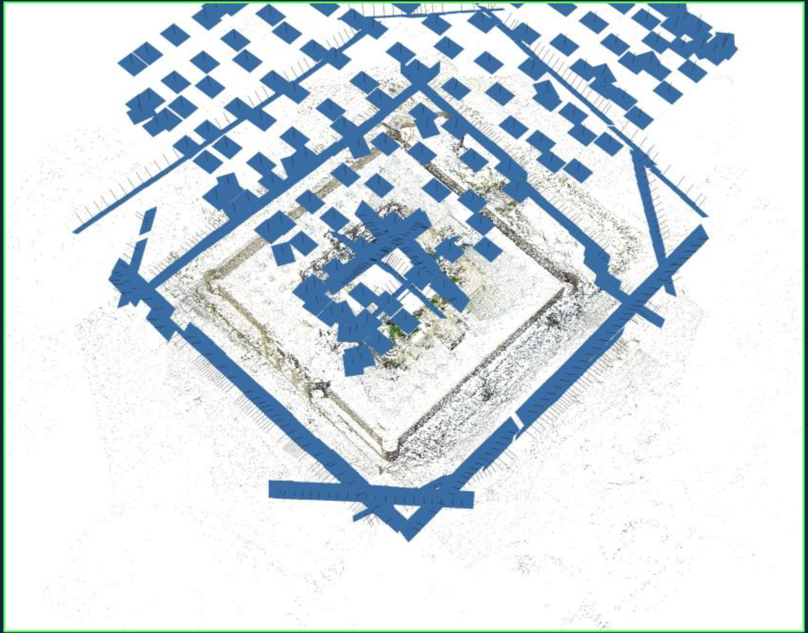
Implementation- **Process**

The procedure that allowed obtaining the 3D model from images can be summarized in the following main steps:

I. Alignment of the images,
II. Building the dense cloud,
III. Building the mesh.

Agisoft Metashape software, after loading the images, performs further operations in the alignment step:

• identifies and matches homologous image points in overlapping images,
• calculates and determines camera position for each image,
• refines camera calibration parameters.



Implementation- **Process**

As a result, first step generates a sparse point cloud and shows the positions of the cameras (Figure a).
In the second step, based on the estimated camera positions, the software builds a dense point cloud (Figure b).

Lastly, Agisoft Metashape reconstructs a 3D polygon mesh that represents the object, based on the dense point cloud obtained from the calculation of the measurements taken from the surface of the photographed object.

Evaluation- Results

Following the texture mapping with the multi-view aerial images and the subsequent reconstructed 3D mesh, the area of interest could be visualized with a low percentage of footprint deviation.

The mean reprojection error yielded by bundle adjustment was below 1 cm, which can be regarded as an adequate result for the measurement taken.

The accuracy of the alignment of the images were calculated on 6 targets: 4 were used as Ground Control Points (GCPs) and 2 as Check Points (CPs). The root-mean-square (RMSE) evaluated won GCPs was 2 mm while on CPs it was 3 mm.

Evaluation- Discussion

As a result of the high number of aerial multi-view images taken, fine coverage of the area was acquired. The 3D model was also well-structured due to a precise measurement of tie points and due to many aerial overlaps, which made it possible for the facades and roof of the artifact to be visible in the acquisition of the images. With multi-view aerial images, a photorealistic 3D model can be produced efficiently, with reduced time and cost to realize any project.