CBL4UAV Photogrammetry

Phase 2

Investigate

2022

Assignment 2 part 1- Guiding Questions

Outcome a) Information and reflection

Photogrammetry applications have a long history of achievements in 3D recording and architectural documentation. Photogrammetry techniques based on UAVs equipped with digital cameras have become some of the most promising and practiced techniques in the last few years. The implementation of UAVs opens various new interdisciplinary utilization and research directions and has become progressively common because of the considerable potential in terms of accuracy, cost, and abilities.

The conservation of architectural heritage, especially of those that face threats and are already heavily damaged starts from capturing and recording their existing state. This may safeguard them from further deterioration in the sense that visual records can foster and streamline future interventions that aim to reverse recent damage. Therefore, UAV photogrammetry as a non-destructive, precise, and cost-effective method can be used in different stages and for various purposes in the conservation of architectural heritage.

Outcome b)

Table 1 The list of the questions that need to be answered to identify the best solution to the challenge

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?	

Outcome c) Guiding Questions

1- What are the differences between UAV Photogrammetry procedures for identifying, mapping, documenting, and monitoring architectural heritage?
2- Which parameters affect the UAV photogrammetry framework?
3- What are the restrictions and challenges of applying UAV Photogrammetry for Architectural Heritage?
4- How can the data captured by UAVs be used in multidisciplinary contexts to represent, protect, and manage architectural heritage?

5- How can evaluate the role of UAV surveys in the conservation of architectural heritage sites?

Outcome d) Resources (people, books, etc.)

1. Dominici, D., Alicandro, M., Rosciano, E., & Massimi, V. (2017). MULTISCALE DOCUMENTATION AND MONITORING OF L'AQUILA HISTORICAL CENTRE USING UAV PHOTOGRAMMETRY. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, *42*.
2. Germanese, D., Leone, G.R., Moroni, D., Pascali, M.A., Tampucci, M. (2019). Towards Structural Monitoring and 3D Documentation of Architectural Heritage Using UAV. In: Choroś, K., Kopel, M., Kukla, E., Siemiński, A. (eds) Multimedia and Network Information Systems. MISSI 2018. Advances in Intelligent Systems and Computing, vol 833. Springer, Cham.
3. Guo, Q., Liu, H., Hassan, F. M., Bhatt, M. W., & Buttar, A. M. (2022). Application of UAV tilt photogrammetry in 3D modeling of ancient buildings. *International Journal of System Assurance Engineering and Management*, 13, 424-436.
4. 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.
5. O'Keefe, K. (2022). Detecting and Monitoring Change to an Arctic Heritage Site Using UAV Photogrammetry: A Case Study from Qikiqtaruk / Herschel Island, YT. In (Master Thesis)
6. Ulvi, A. (2022). Using UAV Photogrammetric Technique for Monitoring, Change Detection, and Analysis of Archeological Excavation Sites. *Journal on Computing and Cultural Heritage (JOCCH)*, *15*(3), 1-19.

Outcome e) Changes reflection.

The use of UAV photogrammetry for the conservation of architectural heritage was initially investigated with the necessity of replacing methods with high precision and accuracy and lower cost compared to manual and traditional methods. Based on the research done and its ability to document the geometrical information of the artifacts in a precise and correct manner, a step was taken further and the investigation of its application to obtain other information of these works at different stages of the life cycle of architectural heritage was also taken into consideration. Also, the challenges of UAV photogrammetry in the production of 3D models in a way that meets the diverse needs of this field were sought.

Assignment 2 part 2- Guiding Questions

Outcome f) Information and reflection

According to the interviews conducted with the stakeholders and the study of the literature on the subject, it seems that there are still no specific guidelines and methods for identification, mapping, documentation, monitoring, and managing the architectural heritage. But it would be important to provide standardized methods to perform measuring operations to collect certified metric data. The final result could be a database to support the entire stage of conservation of cultural heritage and also a checklist of "what to do" and "when to do it".

Outcome g) Revised guiding questions.

1. Which parameters and considerations have to be taken into account for 3D modelling Architectural heritage using UAV photogrammetry?
2. How it's possible to describe a complete and reliable way to 3D model Architectural Heritage through UAV Photogrammetry?
3. How do the various applications of architectural heritage 3D models (Identification, mapping, documentation, diagnosis, and restoration) affect the UAV photogrammetry workflow?

Outcome h) Possible activities and possible recourses for guiding questions.

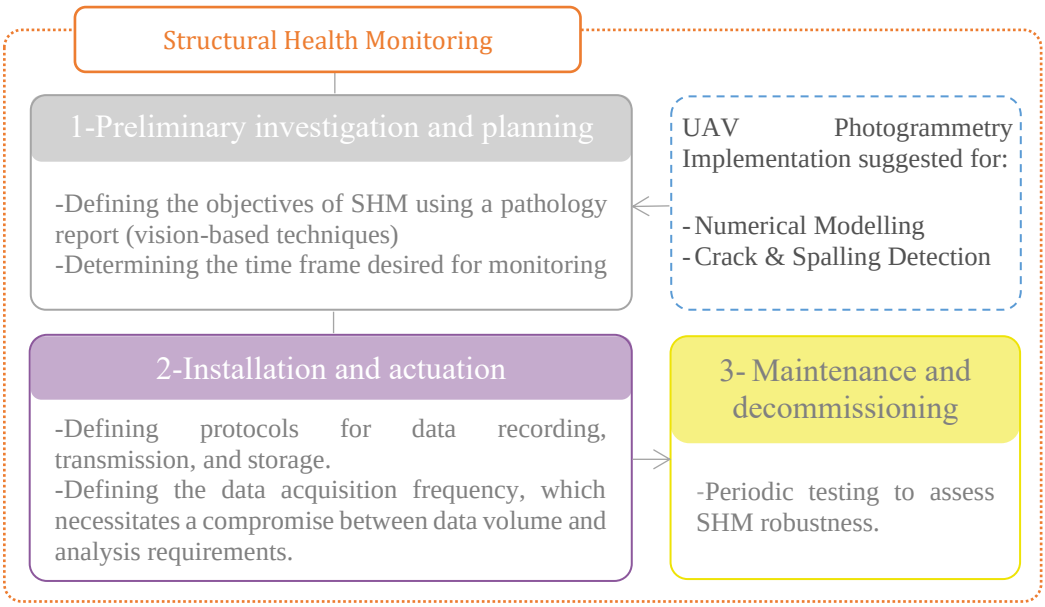

Figure 1 Structural health monitoring systems for smart heritage and infrastructures in Spain

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.

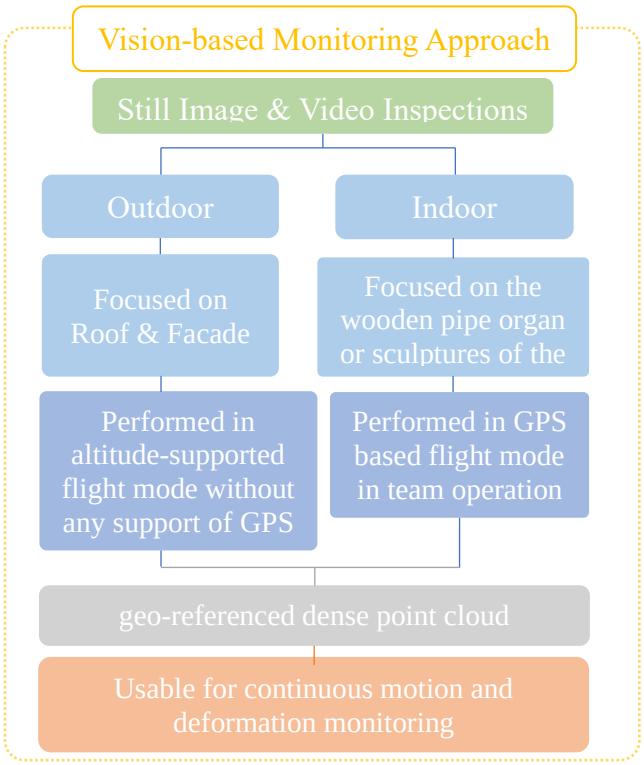

Figure 2 Vision-based monitoring of heritage monuments

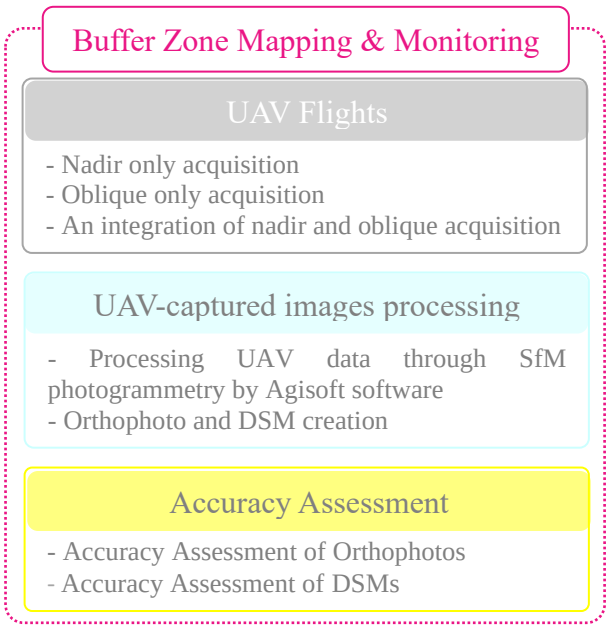

Figure 3 Developing a Guideline for Unmanned Aerial Vehicle's Acquisition Geometry

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.

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.

Outcome i) Categorization and prioritization of the questions.

1. How it's possible to describe a complete and reliable workflow to 3D model Architectural Heritage through UAV Photogrammetry? (Interpretative question)
2. Which parameters and considerations have to be taken into account for 3D modelling Architectural heritage using UAV photogrammetry? (Factual question)
3. How do the various applications of architectural heritage 3D models (identification, change detection, diagnostics, management) affect the UAV photogrammetry workflow? (Interpretative question)

Assignment 2 part 3- Guiding Questions

Outcome j) Information and reflection

At the initial stages of the conservation of architectural heritage, UAV photogrammetry can be used for identification and mapping that obtains accurate textured 3D models. 3D modeling of Architectural Heritage using UAV photogrammetry has three main steps; The first is acquisition planning; the Secondary is data acquisition, and the third step is data processing. Considering the flexibility and adaptiveness of this method can be used for change and health monitoring of these artifacts. If the designed acquisition trajectory is repeated in specific time intervals, the collected data can be used for change detection and management. In some cases, when an urgent detection is needed, like post-disaster damage assessment, UAV photogrammetry can be the safest and fast method for inspection. Also, when there is a need for pathology data acquisition, using different sensors mounted on UAVs and data fusion can create reliable and precise pathological data for determining conservation operations.

Outcome k)

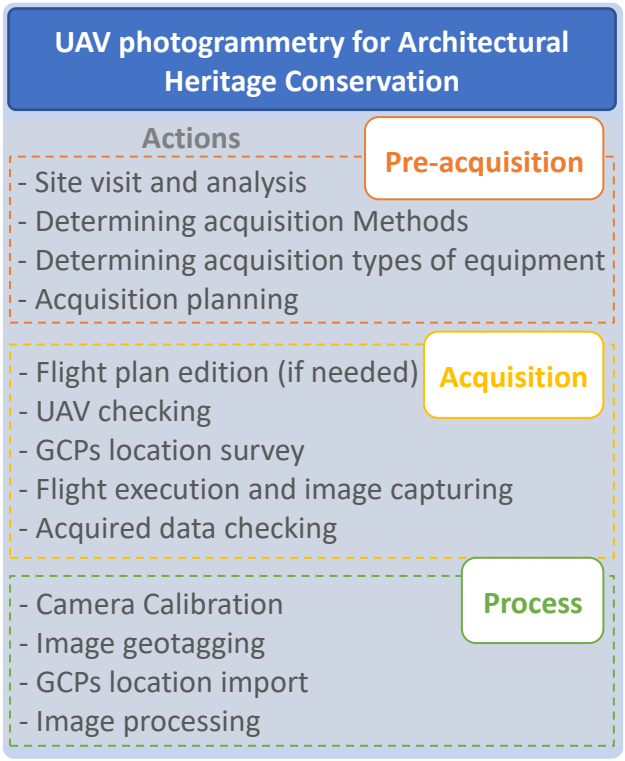

Figure 4 UAV Photogrammetry for Architectural Heritage Survey Research Activity

Outcome l)

Table 2 The aligned questions with considered perspectives and objectives

Questions	Considered perspectives & objectives
How it's possible to describe a complete and reliable workflow for 3D modeling Architectural Heritage through UAV Photogrammetry?	To define an accurate and reliable workflow for 3D modeling Architectural Heritage through UAV Photogrammetry.
Which parameters and considerations have to be taken into account for 3D modeling Architectural heritage using UAV photogrammetry?	To determine effective parameters and essential configurations that are necessary to take into account in UAV photogrammetry acquisition, processing, and post-processing workflows for 3D modeling architectural heritage.
What are the differences between identifying, mapping, and monitoring architectural heritage using UAV surveys?	Defining a clear and extensible workflow for UAV-based surveys to acquire various data required for the conservation of architectural heritage.
What are the restrictions and challenges of applying UAV Photogrammetry for Architectural Heritage 3D modeling?	To extract the pros and cons of UAV photogrammetry when applied to the conservation of architectural heritage to consider a solution or use complementary methods.
How can the data captured by UAVs be used in multidisciplinary contexts to represent, protect, and manage architectural heritage?	Discovering the further abilities of created UAV-based 3d models to be used in multidisciplinary contexts to protect and prompt architectural heritage.
How can evaluate the role of UAV surveys in the conservation of architectural heritage sites?	To evaluate the reliability and efficiency of UAV photogrammetry in the identification, mapping, documentation, digital reconstruction, diagnostics, monitoring, and management of architectural heritage.

Outcome m) Findings.

As mentioned before, there are different requirements for the application of UAV photogrammetry in the conservation stages of architectural heritage. According to the literature review, UAV photogrammetry is the most used for mapping and acquiring external 3D geometry of the architectural heritage.

UAV photogrammetry is the most suitable method for acquiring data from high, expansive, or limited-access architectural heritage. Also, in artifacts that are seriously damaged or have suffered natural disasters such as fire, earthquake, or flood, the use of UAV photogrammetry, in addition, to quickly collecting accurate and correct information to assess the situation and monitoring the artifact, prevents life and economic damage.

Since it is often not possible to use UAV photogrammetry to capture data from the interior spaces of architectural heritage, complementary methods such as laser scanners are usually used to obtain this data. By integrating the point clouds obtained from these two methods, a complete 3D model of the artifacts is be able to create. In the further steps, the generated 3D model can be used as

fundamental data for the parametric modeling of architectural heritage, which is necessary for information modeling of these artifacts.

Assignment 2 part 4: Guiding Questions

Outcome n) Information and reflection

Adopting UAV photogrammetry and laser scanning for generating textured 3D models of architectural heritage is an evaluated and approved method by many scientific research and projects. In the way of using UAV photogrammetry for the conservation of architectural heritage, serious challenges emerge when there is a need for sensor fusion, parametric modeling, and integrating different information in a single model. Here sciences like artificial intelligence, programming, and computer sciences meet to solve the problems.

Outcome o) Analyzing, 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.

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.

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.

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.

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.

Outcome p) The foundations for your solution

Table 3 Foundations for UAV photogrammetry for Health Monitoring of Architectural Heritage

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

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Outcome q)

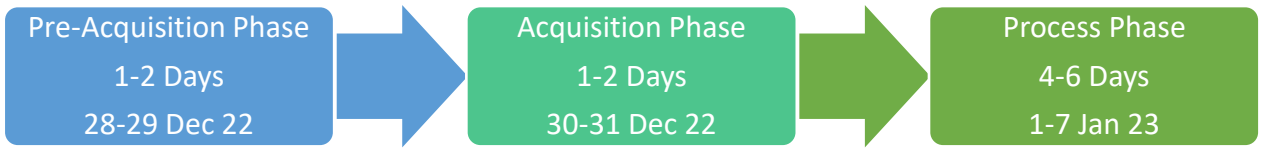

Figure 5 Time plan for Act Phase

Table 4 Guiding Questions

Phase 2: Guiding Questions			
No.	Essential Questions/ considered aspects	Guiding Question	Notes
1	How to use UAV photogrammetry for the conservation of Architectural heritage?	Which parameters and considerations have to be taken into account for 3D modelling Architectural heritage using UAV photogrammetry?	In this question, the difference in workflows and data collection parameters are aimed.
		How UAV platforms be more usable for diagnostic purposes?	In terms of the feasibility of mounting innovative lightweight sensors used for in situ pathology of cultural heritage on the UAV to investigate the damages of Architectural heritage.
		What are the complementary acquisition methods for UAV photogrammetry in its application for architectural Heritage?	In some cases, it may not be possible to acquire all the required data of the artifact using UAV photogrammetry.
2	How to generate a complete 3D model of Architectural heritage using a UAV Photogrammetry survey?	Which parameters guarantee the UAV Photogrammetry for optimum data acquisition?	To obtain influential factors in the design of data collection from architectural heritage
3	How to accelerate the parametric modeling process of complex Architectural Heritage surveyed by UAV photogrammetry?	What are the challenges of parametric modeling of Architectural Heritage using UAV photogrammetry data?	

Table 5 Guiding Activities

Phase 2: Guiding Recourses / Activities					
No.	Priority	Category	Guiding Question	Guiding Resources	Guiding Activities
1	First	Data acquisition	What are the differences between identifying, mapping, and monitoring architectural heritage using UAV surveys?	- Research and projects carried out to Identify, map, or monitor architectural heritage through UAV photogrammetry	- Studying the existing literature and conducted projects and comparing them to find the differences between workflows applied for the identification, mapping, and monitoring of architectural heritage. - Interview with the UAV photogrammetry and architectural heritage specialists for determining the required data features for each application and needed acquisition parameters and considerations.
			Which parameters guarantee the UAV Photogrammetry for optimum data acquisition?	- Well-experienced experts	Interview with the architecture photogrammetry specialist
			How UAV platforms be more usable for diagnostic purposes?	-Well-experienced experts -Catalog of lightweight products of companies that produce lightweight sensors -The website of companies that manufacture sensors -Scientific publications	- Studying research and scientific resources related to the application of innovative technologies for the pathology of cultural heritage - Interview with the remote sensing experts and architectural heritage conservators - It may be necessary to conduct interviews with experts in physics and chemistry.
			What are the complementary acquisition methods for UAV photogrammetry in its application for the conservation of architectural heritage?	-Research and projects carried out to inspection of cultural heritage through interdisciplinary applications of innovative technologies	- Studying the available resources to address the requirements for complimenting methods and according to the requirements find the best solutions to respond.
2	Second	Data Processi	How the cultural artifact features and acquisition parameters can affect the generated 3D model?	-Well-experienced experts - Architectural Heritage 3D modelling related scientific publications	Extract the relevance between mentioned variables according to answers from the specialists and scientific records studied.
3	Third	Data post-processing	What are the challenges of parametric modeling of Architectural Heritage using UAV photogrammetry data?	- HBIM Experts - HBIM researches - BIM developers - BIM managers	Interview with the specialist to be aware of the latest solutions and respond to existing and possible challenges.
			How can use UAV captured data in Training Machine Vision Algorithms for architectural heritage parametric modeling?	-Well-experienced AI experts -Related scientific publications	-Studying AI application cases in Cultural Heritage

Table 6 Analysis

Phase 2: Analysis				
No.	Questions	Categories	Alignment	Findings
1	How it's possible to describe a complete and reliable workflow to 3D model Architectural Heritage through UAV Photogrammetry?	Acquisition planning		-Considering characteristics of the work area and the purposes of UAV Photogrammetry such as Identification, Mapping, Documentation, Diagnostics, and management then: 1. Selection of a sensor and UAV suitable for the purpose 2. UAV Regulations must be taken into account. 3. Flight plan design 4. Assessment of factors to be controlled during the flight mission
		Data processing		-Direct and Indirect Georeferencing -Dense point cloud extraction -Mesh building - Texture projection on the mesh
2	Which parameters and considerations have to be taken into account for 3D modelling Architectural heritage using UAV photogrammetry?	Acquisition planning		- GSD: The more accurate the digital terrain model, the more the GSD is respected - Overlap & sidelap: Generally, traditional longitudinal overlap values range from 70% to 90%. The overlap between adjacent parallel strips, called side laps takes on values ranging from 50% to 80%. GCPs: Target sizes are variable depending on the design GSD; Their size must be such to ensure that they can be identified at the flight height from which they are detected. GCPs should be distributed evenly over the area to be surveyed and, depending on the terrain morphology, positioned at different altitudes. -Motion Blur: It is possible to reduce it considerably to obtain better results in postprocessing by setting a correct drone speed beforehand to minimize this effect. - Camera information
		Data acquisition		- Before starting a good GNSS satellite configuration and suitable weather conditions must be checked. - UAV Regulations must be taken into account.
		Data processing		-The internal orientation (IO) and exterior orientation (EO) of each image (Camera calibration, GCP identification). -Hardware specifications of the system that is going to do data processing. -The specifications of the software which supposed to perform the photogrammetric process.
3	How do the various applications of architectural heritage 3D models (identification, change detection, diagnostics, management) affect the UAV photogrammetry workflow?	Acquisition planning		-The acquisition scenarios (nadir, oblique, horizontal, or combination of them), parameters (GSD, GCPs, overlap, and side lap), and sensor types (Visible, IR, GPR, etc.) in diagnostic cases vary in different applications.

Table 7Analysis

Phase 2: Synthesis				
No.	Questions	Categories	Alignment	Findings
1	How it's possible to describe a complete and reliable workflow to 3D model Architectural Heritage through UAV Photogrammetry?	Acquisition planning		By knowing the accuracy and details required of the 3D model of architectural heritage at each stage of the conservation process, a general and flexible framework can be defined that can be adapted to different artifacts. For example, to identify the scale of 1:200, to map the scale of 1:100, to document the scale of 1:50 to 1:10 (for artifacts with sophisticated decorations and details), the defined general acquisition framework and taking into account the geometry and features specifics of each work applied the necessary changes. In some cases, complementary or auxiliary methods may also be defined.
		Data processing		Photogrammetric processing using software based on SfM and MVS algorithms usually have a defined and fixed process. When there is a need for the combination of different types of data, such as point clouds obtained from laser scanning and thermography, the generated 3D point clouds have to be registered and merged before creating meshes, and then texture is applied.
2	Which parameters and considerations have to be taken into account for 3D modelling Architectural heritage using UAV photogrammetry?	Acquisition planning		The characteristics of the artifacts, UAV regulations in the area, the access conditions, available equipment, and the status of the artifact`s site are the main factors that play a role in defining the parameters and flight design considerations. On the other hand, the purpose of UAV photogrammetry and the use of the 3D model produced from it has a direct effect on the determining parameters of the acquisition.
		Data acquisition		Weather conditions and equipment performances affect the data acquisition operation and have to be taken into account.
3	How do the various applications of architectural heritage 3D models (identification, change detection, diagnostics, management) affect the UAV photogrammetry workflow?	Acquisition planning		The data acquisition accuracy and details respectively increase for identification, mapping, documentation, pathology, and change management applications. The 3D model`s required precision and detail, have a direct effect on acquisition planning. These effects are reflected in the selection of the type of sensor and the platform, and data acquisition parameters. For example, it may be necessary to obtain visible aerial photography with 2 cm GSD for identification purposes. While to detect the amount of moisture damage in a facade, thermal imaging may be required in addition to visual imaging with an accuracy of better than half a centimeter.
		Data processing		For single-sensor acquisitions, there are some clearly defined processing workflows. But in some architectural heritage maybe there is a need to use different sensors to acquire complete data. The diverse and heterogeneous data require more advanced and professional processing to be integrated into a single 3D model. Currently, data integration is one of the most challenging subjects of architectural heritage data processing. For example, it may be necessary to use more than one type of sensor to identify an unknown architectural heritage. In this case, the visible sensor will be used to acquire the data related to the artifacts on the ground and the Ground Penetrating Radar will be used to acquire the data related to remains left underground.