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Photogrammetric Techniques for 3D Documentation

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NARRATE
Needs for Digital Recording and Documentation of Ecclesiastical Cultural Treasures in Monasteries and Temples

Workshop on Documentation of Ecclesiastical Heritage
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Istanbul, Turkey

CIPA Heritage Documentation

Introduction

NARRATE

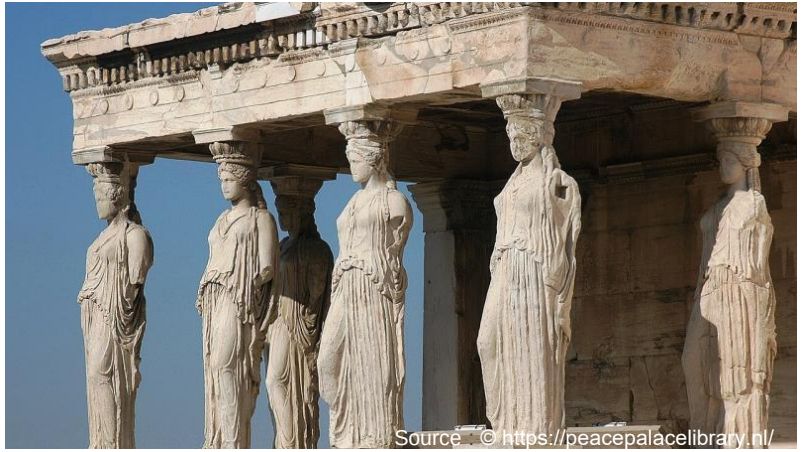
Needs for Digital Recording and Documentation of Ecclesiastical Cultural Treasures in Monasteries and Temples

What do we mean when we say Cultural Heritage?

According to UNESCO:

Cultural heritage refers to the legacy of physical artifacts and intangible attributes that a group or society inherits from the past and considers valuable enough to preserve for future generations.

- It encompasses both tangible and intangible aspects, reflecting the identity, traditions, and history of communities or societies.



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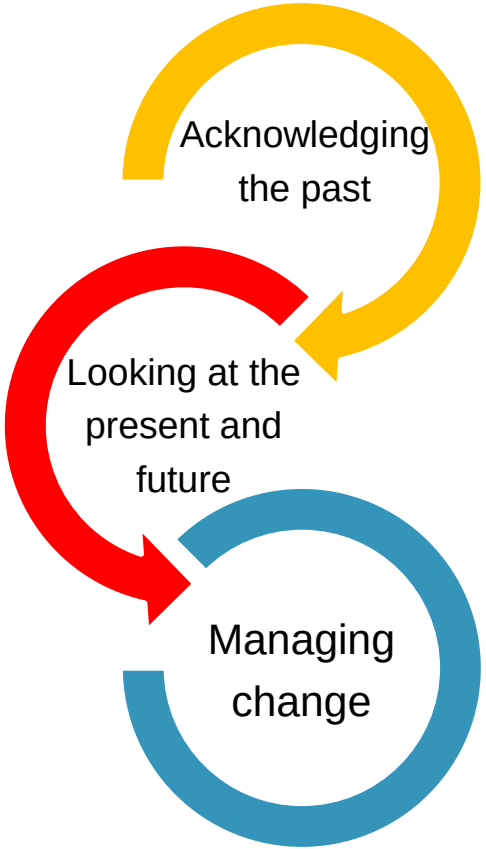
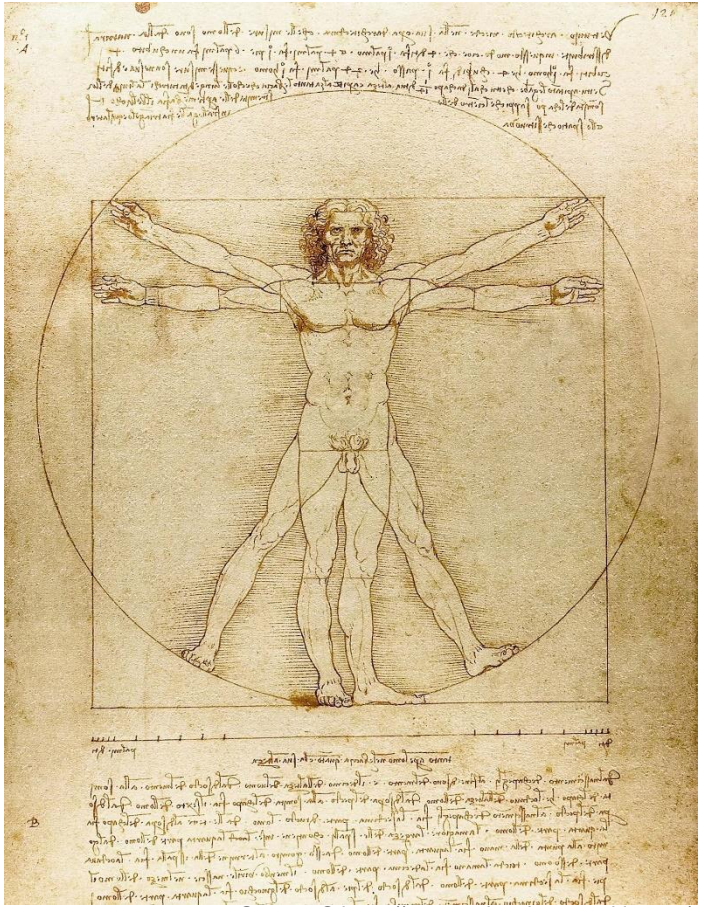
Why Conservation of Cultural Heritage is important?





Source: © https://www.nationalgeographic.com/

Documentation and Conservation of Cultural Heritage

"As a prerequisite for informed conservation, documentation and recording is a prime responsibility of everybody involved in conservation processes.

- All those involved with the *understanding, care,* and *management* of a heritage place or object must have access to existing information and will generate records, which must be preserved and made available to others."

obin Letellier, The Getty Conservation Institute, Los Angeles

Source : © https://digitalheritagelab.eu/

Documentation and Conservation of Cultural Heritage

We must make certain that future generations know what was done to a heritage place, why, when, and by whom.

- Producing adequate records of our actions, (such as research, investigation, or treatment) not only is an ethical obligation for future generations but also implies immediate benefits in terms of interdisciplinary communication and evaluation of results.


Source : © https://peacepalacelibrary.nl/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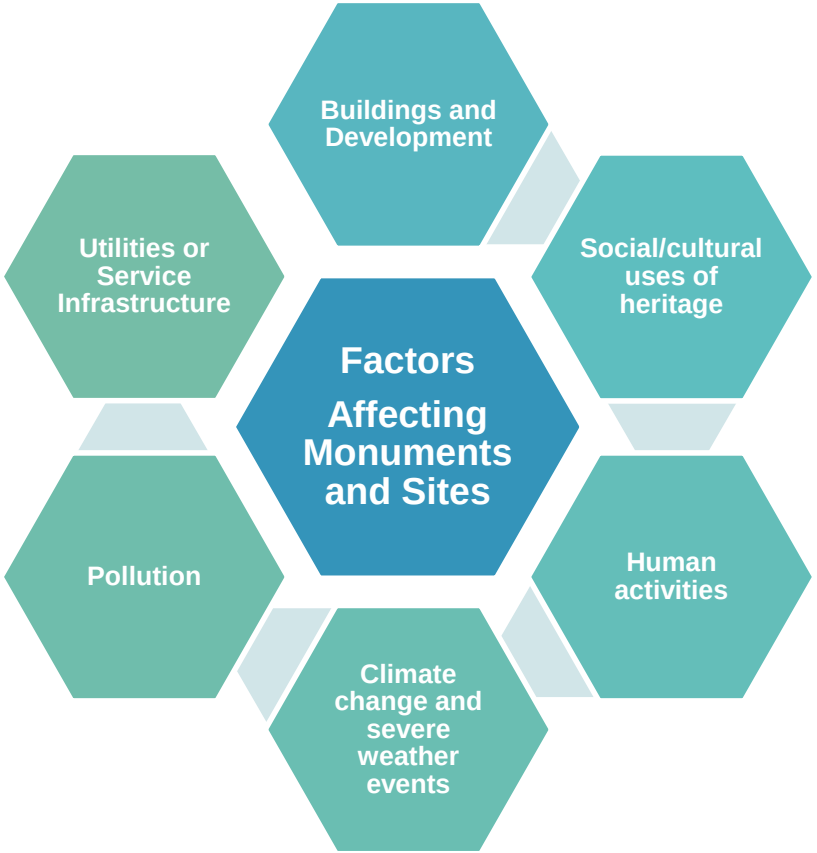
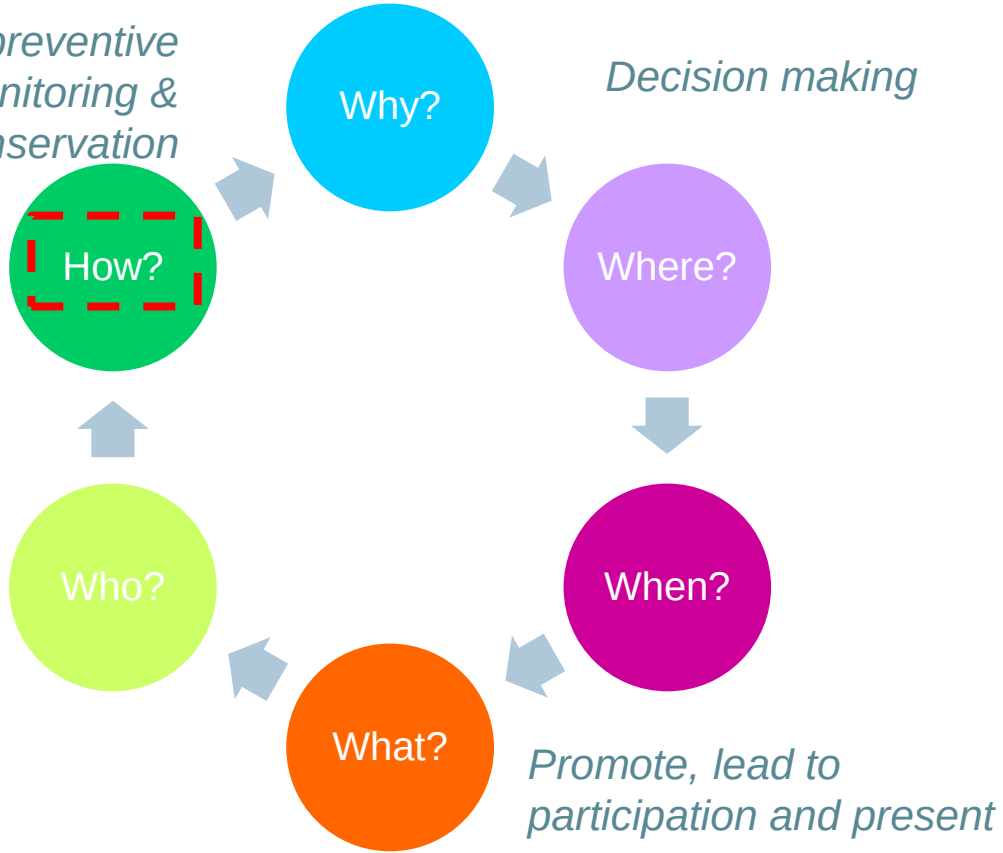
Documentation and Conservation of Cultural Heritage

In 2008, the World Heritage Committee adopted a standard list of *factors affecting* the Outstanding Universal Value of World Heritage properties:



Documentation and Conservation of Cultural Heritage

The ICOMOS-*International Council of Monuments and Sites*- guiding principles (1996) for recording and documentation.



Create a Posterity Record

Source: © Recording, Documentation, and Information Management for the Conservation of Heritage Places, Robin Letellier, (2007)

Documentation and Conservation of Cultural Heritage

Digital heritage recording workflow

Documentation and Conservation of Cultural Heritage

To sum up, the digital heritage recording is important as we are able to:

- ✓ gain knowledge, comprehend meaning and values
- ✓ foster public interest and engagement
- ✓ enable informed management, and ensure the long-term preservation and conservation of heritage sites.

And most important:

It serves as a safeguard against loss and acts as a legacy record for future generations.

Photogrammetry as a tool for recording and documentation

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What is photogrammetry?

The word **Photogrammetry** originates from the Greek words ***phos - grammi – metro:***

- ***phos*** **-** in Greek '*φως*' that means ***light***
- ***grammi*** **-** in Greek 'γραμμή' that means ***line***
- ***metro*** **-** in Greek 'μετρώ' that means ***measure***

and is defined as:

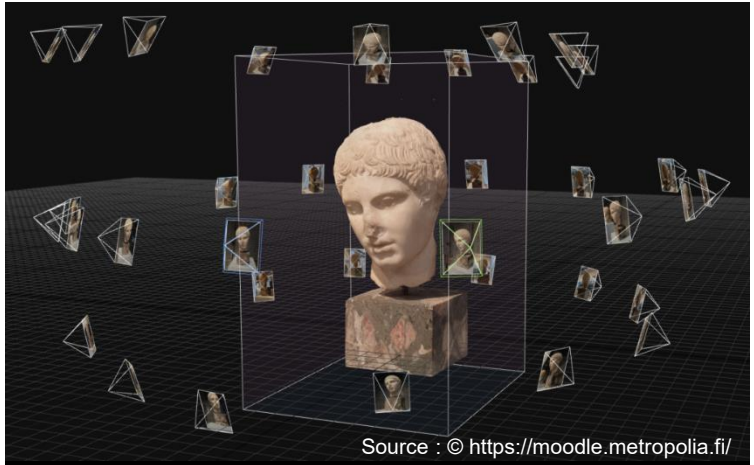
'The ***art, science, and technology*** of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images as well as patterns of electromagnetic radiation.' (ASP, 1980)

What is photogrammetry?

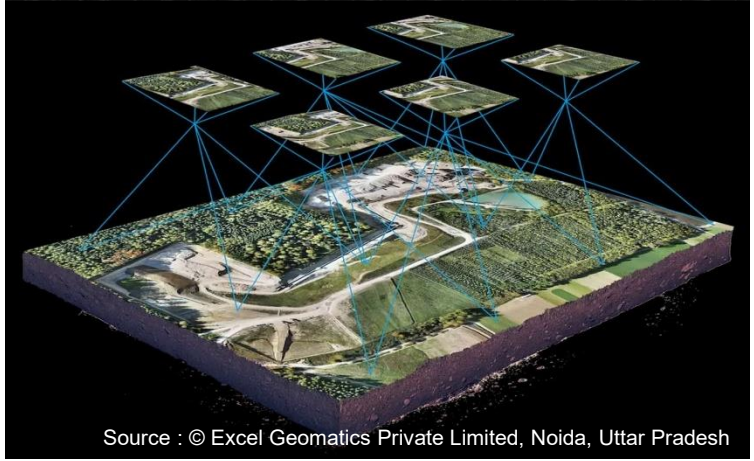
Photogrammetric techniques are *indirect methods of recording* the characteristics of objects such as:

- **their position**
- **their shape**
- **their dimensions**

Since they do not use direct measurements on the object, but rather use the metric information collected from a photographic image.

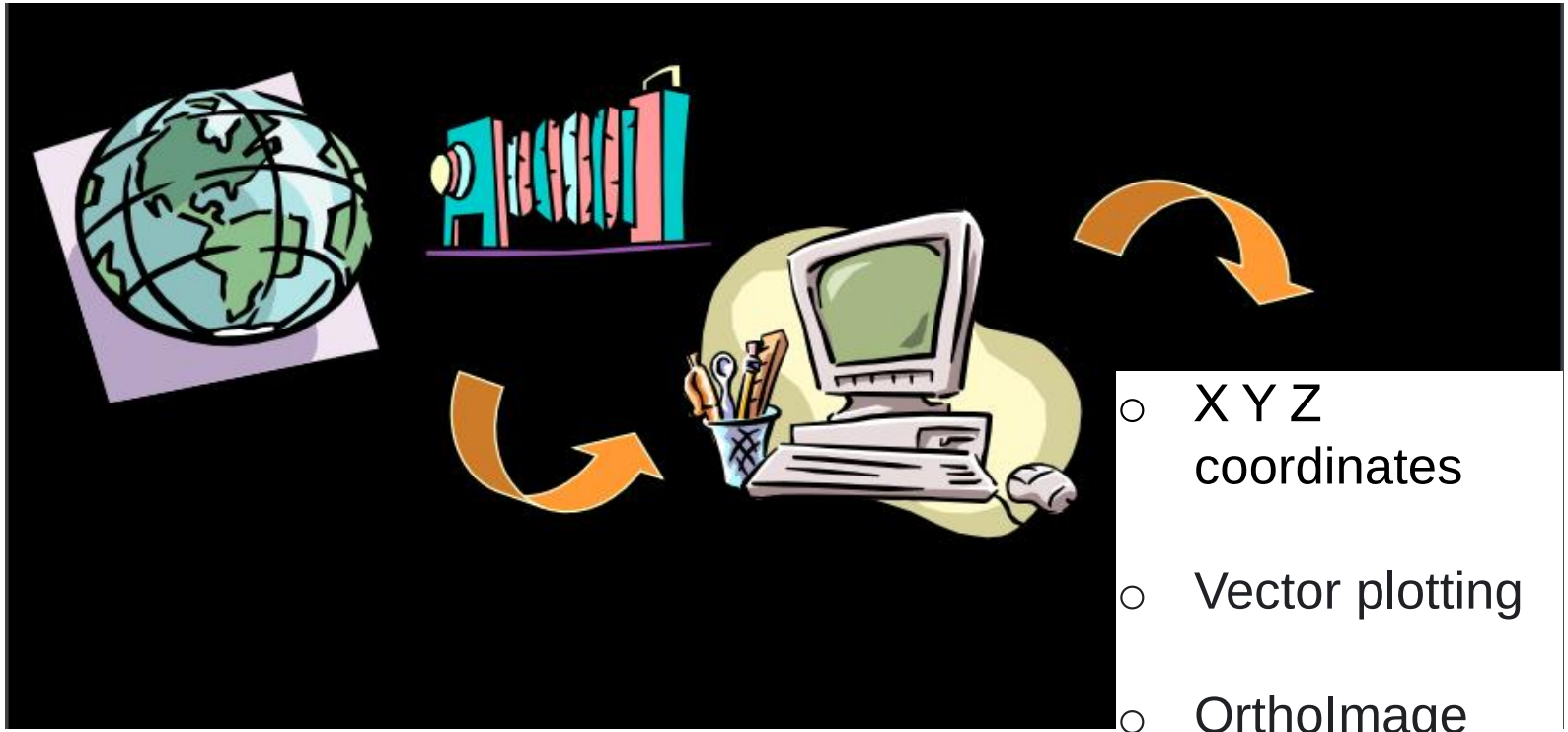


Source : © https://moodle.metropolia.fi/



Source : © Excel Geomatics Private Limited, Noida, Uttar Pradesh

What is photogrammetry?



- X Y Z coordinates
- Vector plotting
- OrthoImage

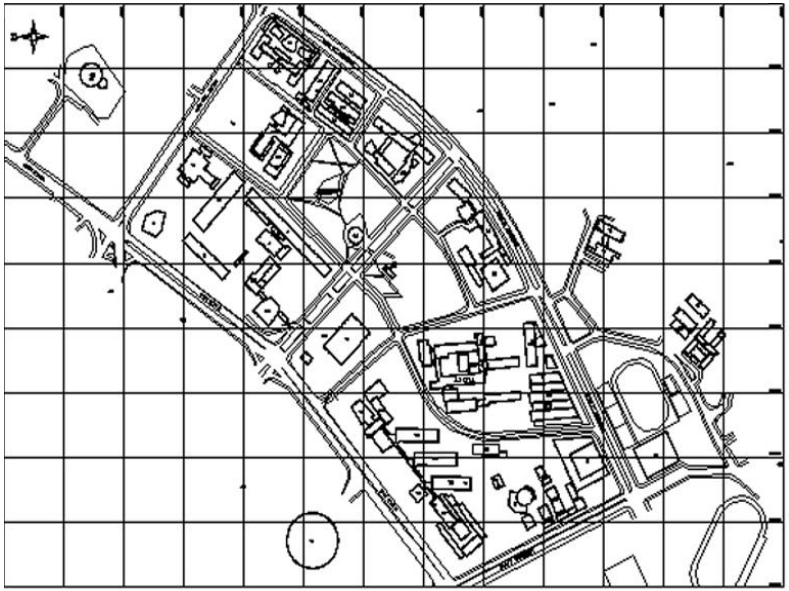
Source : © http://ecourses.dbnet.ntua.gr/

Some examples

Aerial photo of Aristotle University of Thessaloniki Campus, Greece

Aerial Photo 1:5.000

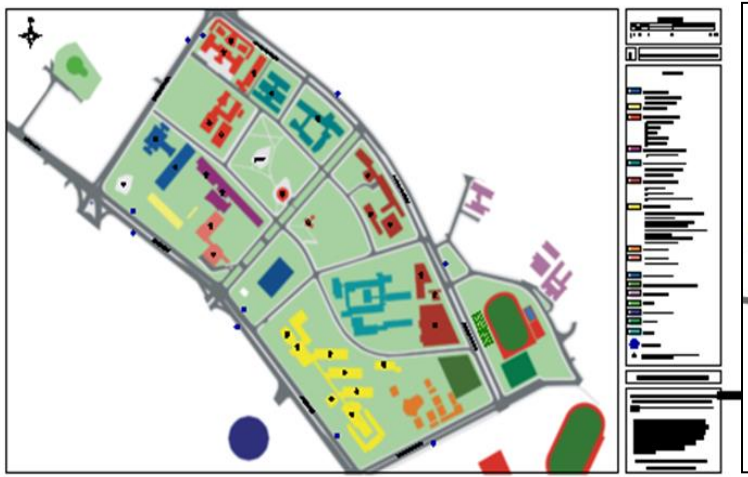
Photogrammetric design 1:1000



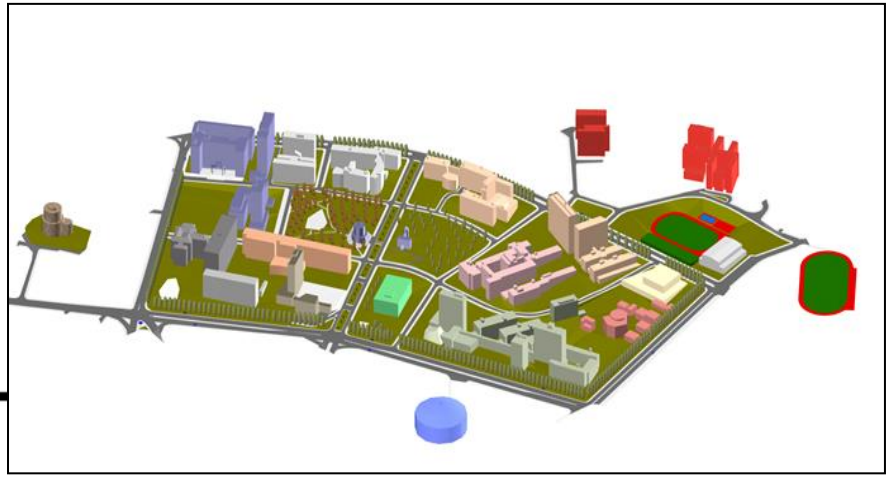
Source : © Δρ. Α. Σταμνάς, ΤΑΤΜ

Some examples

Thematic map

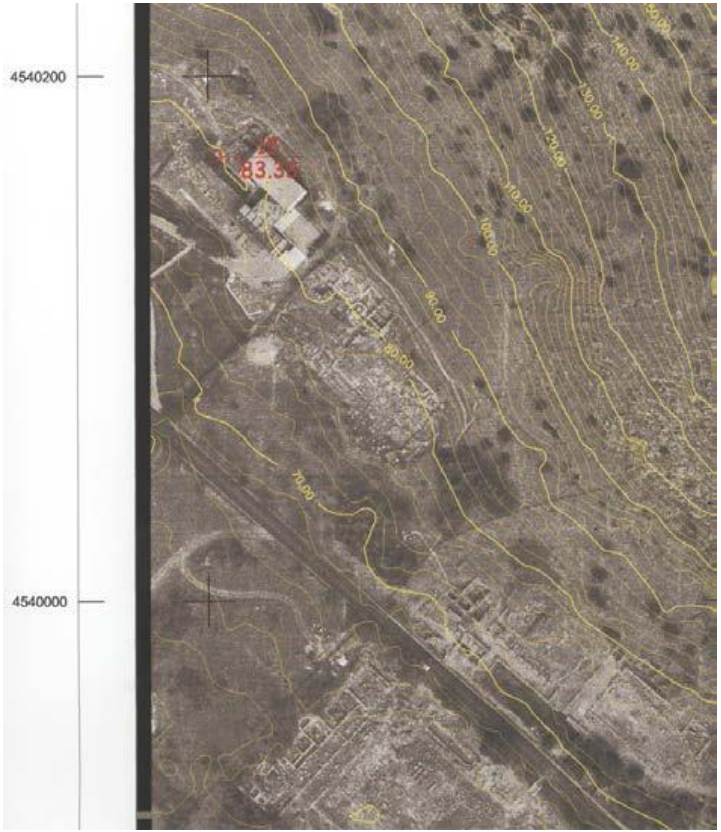


3D Thematic map



Source : © Δρ. Α. Σταμνάς, TATM

Some examples



Orthophoto

Source : © Δρ. Α. Σταμνάς, ΤΑΤΜ

Some examples

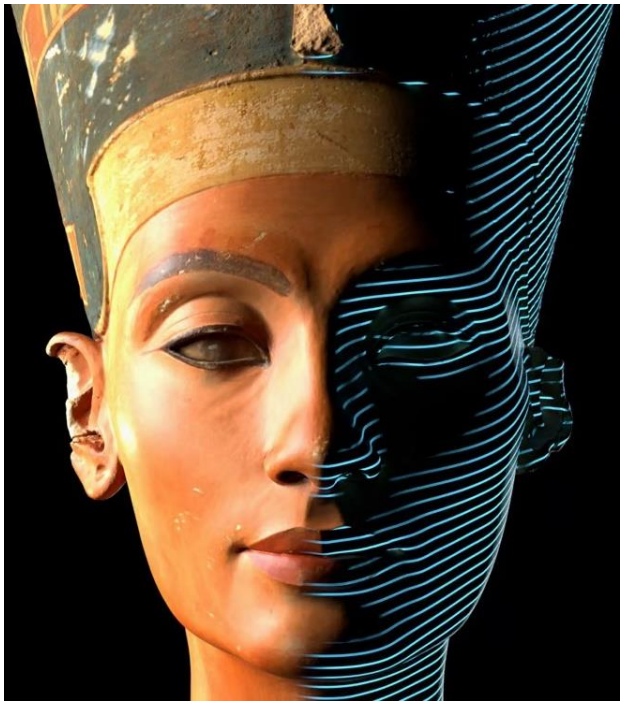
Key advantages of using photogrammetry

Accuracy: Captures intricate details of structures and artifacts.

Cost-Effectiveness: Requires minimal equipment (camera and software).

Accessibility: Creates sharable digital models for education, tourism, etc.

Preservation: Offers a non-invasive method to document fragile details.



Source : © https://kottke.org/

Key advantages of using photogrammetry

Documenting Complex Heritage Elements:

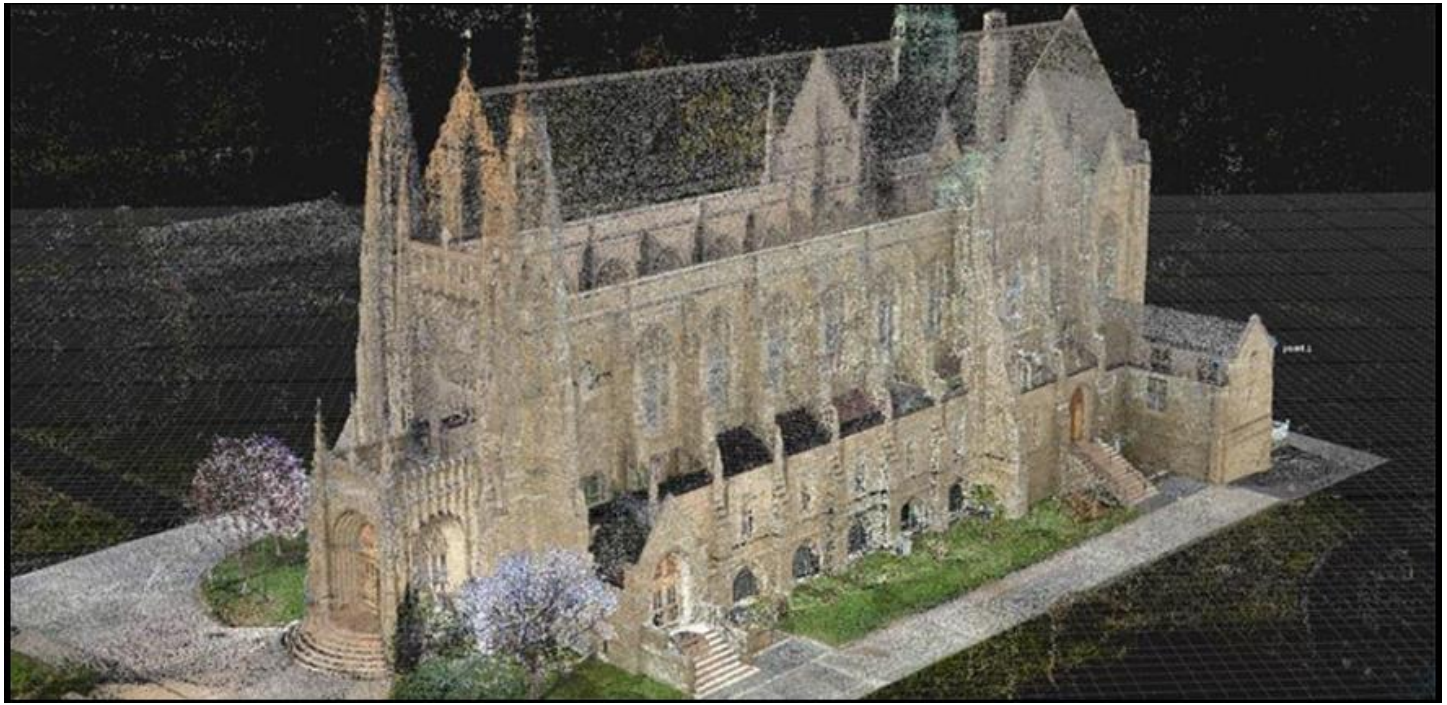
Church Facades: Maps intricate carvings and architectural details.

Sculptures: Captures fine textures and contours for analysis.

Stained Glass: Creates detailed visual archives, preserving color and design. Example photogrammetry models of each type of structure.

Source : © https://www.wessexarch.co.uk/our-work/bath-abbey-photogrammetry-3d-modelling-medieval-stained-glass-flooring

Key advantages of using photogrammetry



Combining Laser Scans with Photogrammetry of St Mary's Church Facade (Stamford, CT)

Source : © https://myndworkshop.com/resources/photogrammetry-scanning-for-historic-preservation/

Key advantages of using photogrammetry

Source : © https://3dsurvey.si/

Key advantages of using photogrammetry

3D Modelling of Medieval Stained Glass, Bath Abbey, UK

Source : © https://www.wessexarch.co.uk/our-work/bath-abbey-photogrammetry-3d-modelling-medieval-stained-glass-flooring

Any disadvantages?

- ✓ Many sources of errors – For this reason, the methodologies for processing photogrammetric products are more complex.
- ✓ Control point requirements – Photogrammetry relies on existing information, requiring known Ground Control Points.
- ✓ Accuracy depends on the quality of the photogrammetric equipment – Along with the methodology for deriving measurements and the user's expertise.

Photogrammetric Techniques

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Needs for Digital Recording and Documentation of Ecclesiastical Cultural Treasures in Monasteries and Temples

Classification of Photogrammetric Techniques

- ❖ **Capture Station**
  - ✓ On the ground (terrestrial or close-range photogrammetry)
  - ✓ From the air (aero or aerial photogrammetry)
- ❖ **Number of Captures**
  - ✓ Single image
  - ✓ Pair of overlapping images
  - ✓ Multiple overlapping images
- ❖ **Based on the Equipment Used**
  - ✓ Analog photogrammetry
  - ✓ Analytical photogrammetry
  - ✓ Digital photogrammetry

Terrestrial photogrammetry

- ✓ Digital cameras (single or 360 degrees)
- ✓ 3D scanners, and surveying instruments

Source : © CIPA summer school 2023, Rhodes, Greece

3D Scanner

A **3D scanner** is a device that *captures the physical details* of an object or environment by collecting data on its shape and appearance.

These devices use various technologies to create highly accurate digital models, often referred to as "*point clouds*," which can later be processed *to form 3D representations*.

- ✓ **Laser Scanners:** These use laser beams to measure distances to the object's surface. The scanner records the exact location of each point in space based on the time it takes for the laser to reflect back.
- ✓ This is ideal for capturing detailed structures, such as architectural sites or sculptures.

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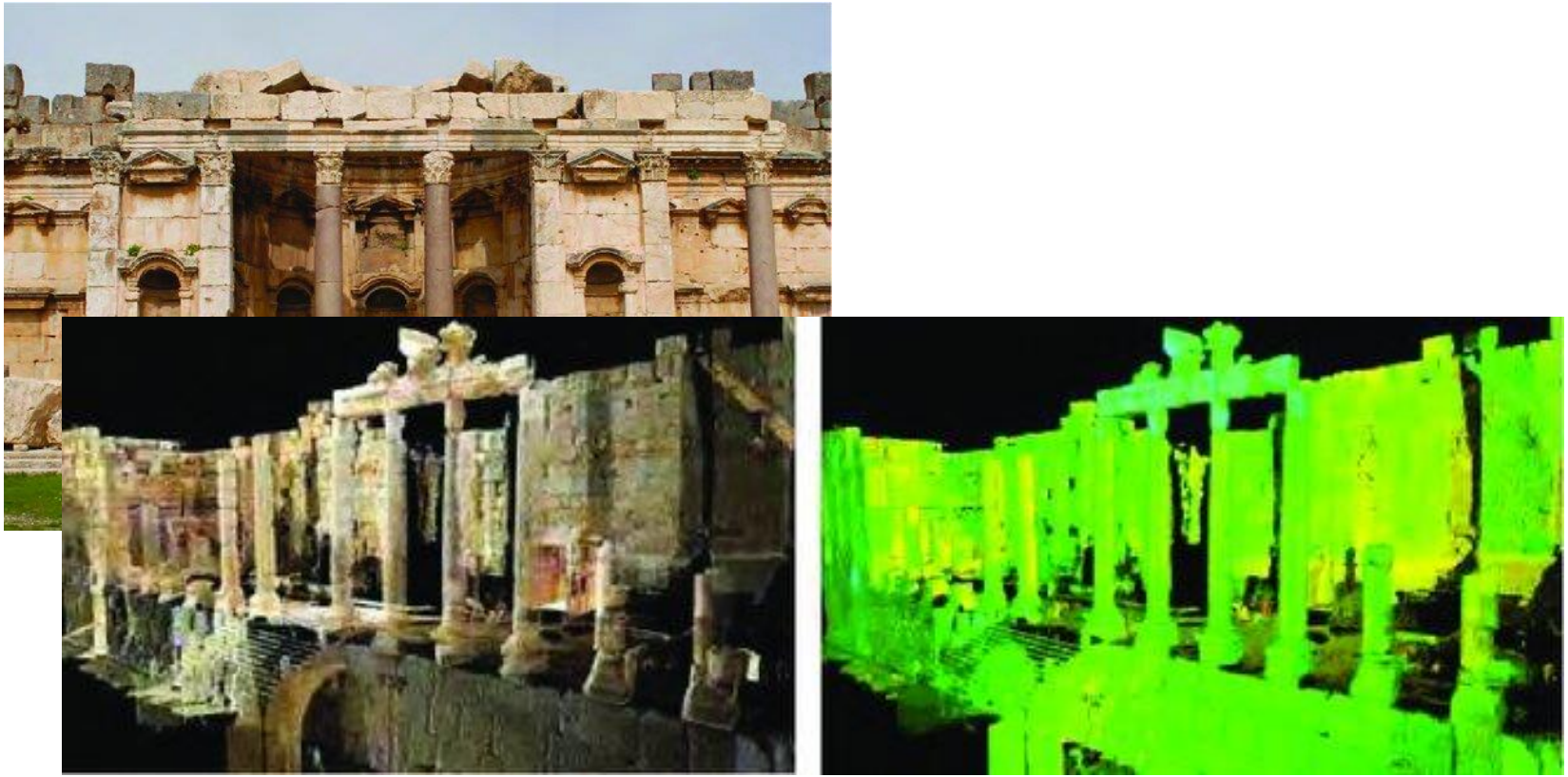
Needs for Digital Recording and Documentation of Ecclesiastical Cultural Treasures in Monasteries and Temples

3D Scanner

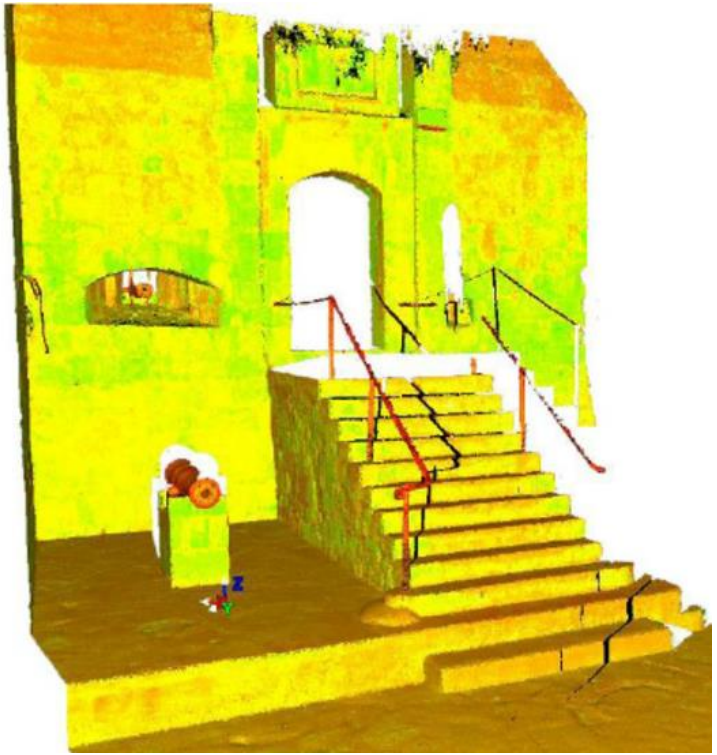
Source : © https://kb.worldviz.com/articles/2339

3D Scanner



Source : © Assaad Seif, 2016

3D Scanner



Source : © Kyriacos Themistocleous et al, 2010

Aerial photogrammetry

1918 portable camera

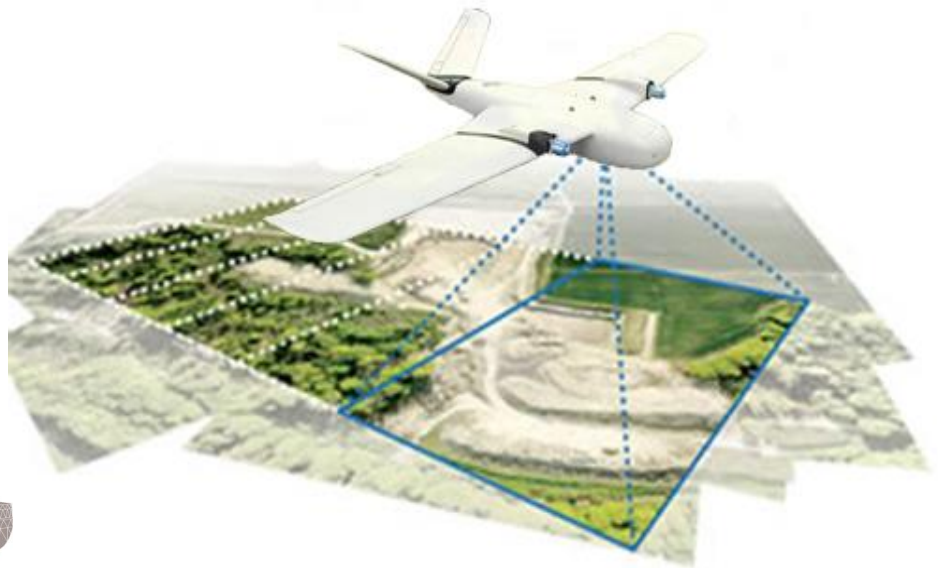
1922 : RMK C1

1956 : RMK

2001 : DMC

Source : © Σημειώσεις Φωτογραμμετρίας ΕΜΠ

Aerial photogrammetry



Source : © https://www.spectrum-drone-services.co.uk/

✓Modern platforms are equipped with inertial systems to provide information about the angles ω (omega), φ (phi), and κ (kappa) (orientation angles) at the moment of capture.

Source : © https://oceanservice.noaa.gov/

Aerial photogrammetry with Drones

Source : © https://www.bluefalconaerial.com/

Source : © Mapping the Unseen: Unveiling History with Drones for Archaeological Surveys and Cultural Heritage Preservation, LinkedIn

How do I choose the most appropriate method?

Key factors to take into consideration:

- **Type and Scale of the Object**
  - Small Artifacts: Use close-range photogrammetry for high-resolution and complex details (e.g., sculptures, pottery).
  - Large Structures: Employ aerial photogrammetry for landscapes or large buildings like churches or archaeological sites.

How do I choose the most appropriate method?

Key factors to take into consideration:

- **Purpose of Documentation**
  - Conservation and Restoration: Is high accuracy critical for your application?
- **Final Output Requirements**
  - Orthophotos: If you need high-resolution 2D maps, prioritize aerial or terrestrial photogrammetry.
  - 3D Models: For 3D visualization, ensure the chosen method can produce dense point clouds and realistic textures.

How do I choose the most appropriate method?

Key factors to take into consideration:

- **Environmental Conditions**
  - Lighting: Favor clear and consistent lighting for outdoor captures. Avoid harsh shadows that could obscure details.
  - Accessibility: For inaccessible areas (e.g., tall structures), aerial photogrammetry using drones is ideal.

How do I choose the most appropriate method?

Key factors to take into consideration:

- **Available Resources**
  - Budget: Digital photogrammetry software can vary in cost, so match the software to your project's scale and financial constraints.
  - Equipment: Choose cameras or drones suited for the resolution and coverage you need.

How do I choose the most appropriate method?

Key factors to take into consideration:

- **Accuracy Requirements**
  - Control Points: For high-accuracy outputs, ensure sufficient ground control points (GCPs) are integrated.
  - Camera Calibration: Use calibrated cameras for precise measurements if metrical accuracy is essential.

How do I choose the most appropriate method?

Key factors to take into consideration:

- **Experience and Expertise**

  Photogrammetric documentation often requires technical expertise, especially for complex structures..

Photogrammetric Workflow for Documenting Ecclesiastical Heritage

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Needs for Digital Recording and Documentation of Ecclesiastical Cultural Treasures in Monasteries and Temples

Photogrammetric workflow

1. Planning a photogrammetric survey
2. Image acquisition
3. Data processing: Converting 2D images to 3D models.

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Useful tips

- Choose the right time of day: Photograph during consistent lighting conditions, such as overcast days or early morning/late afternoon, to minimize harsh shadows and overexposure.

- **Weather conditions**: Avoid rain, fog, or strong winds, which can affect image clarity and camera stability (especially for drone use).
- **Camera choice**: Ideally use a high-resolution DSLR camera for detailed images.
- **Tripod**: Use a tripod for ground-level captures to reduce motion blur and ensure consistent framing.

Useful tips

- **Overlap**: Ensure at least 60–80% overlap between images to allow the photogrammetry software to align them accurately.
- **Angles**: Capture images from multiple viewpoints—straight on, oblique, and from varying heights—to cover all surfaces and intricate details.
- **Distance**: Adjust the distance based on the structure's size. For facades, take wider shots, and for details like carvings or statues, move closer for higher resolution.
- **Ensure vertical alignment** when photographing large facades to avoid perspective distortion.

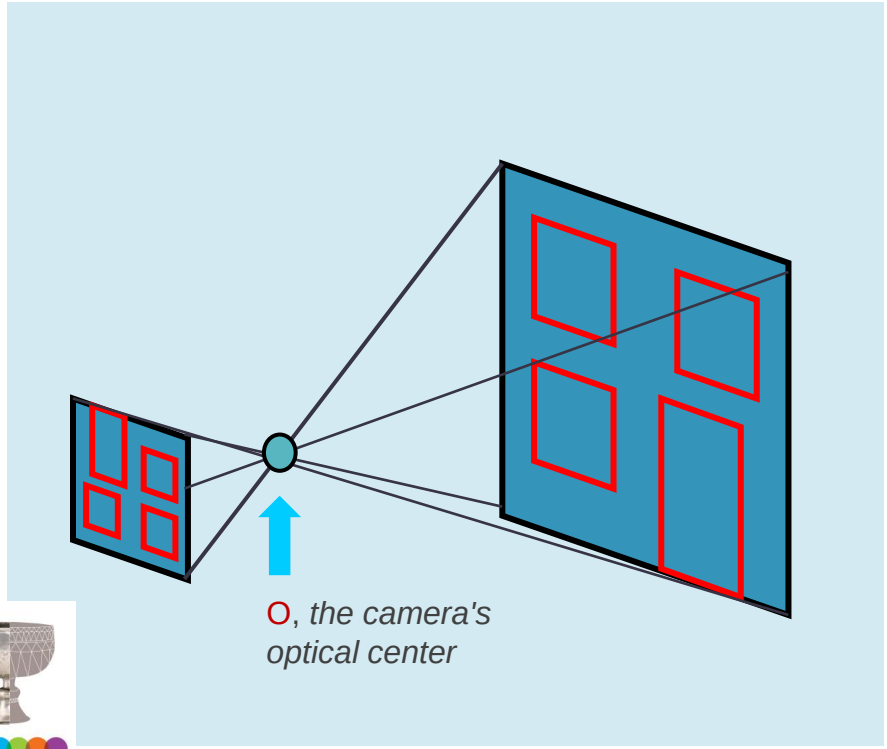
Useful tips

Pro Tip: *Practice redundancy* - take more photos than necessary, ensuring no part of the structure is missed.

This is especially important for ornate ecclesiastical objects with complex details.

Data Processing

Data Processing

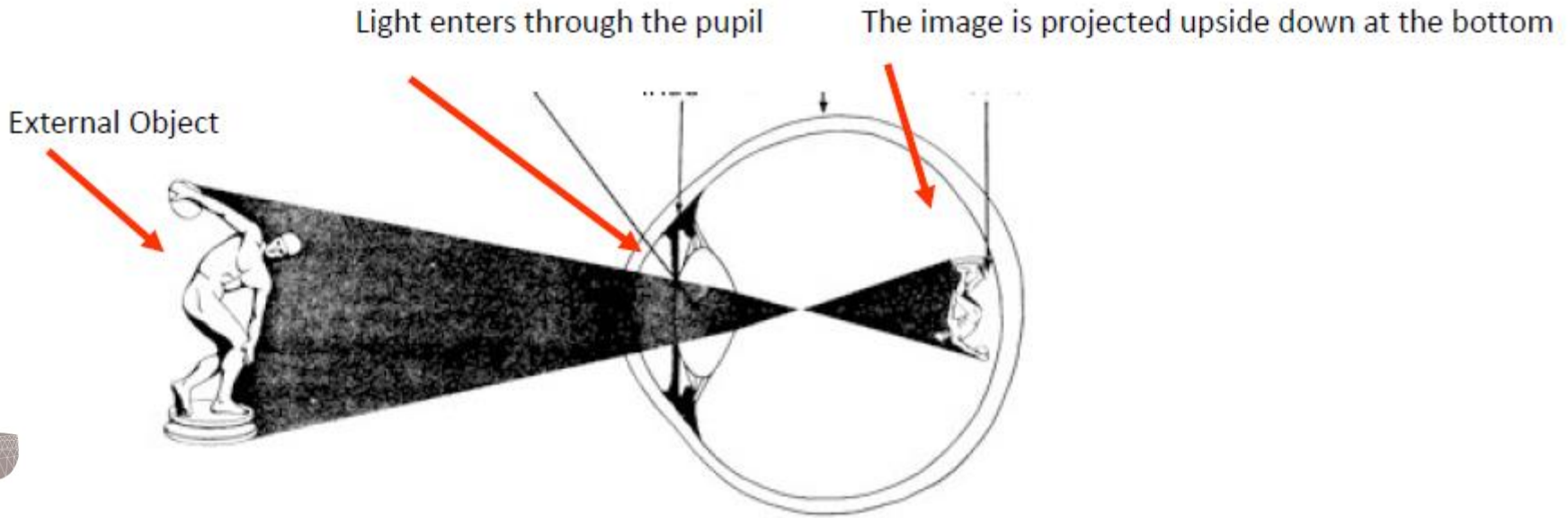


Central projection is a fundamental concept in photogrammetry, describing the geometric relationship between the object being captured, the camera, and the resulting image.

Central projection occurs when all light rays from the object pass through a single point, the **optical center** of the camera lens, before forming an image on the sensor or photographic plane.

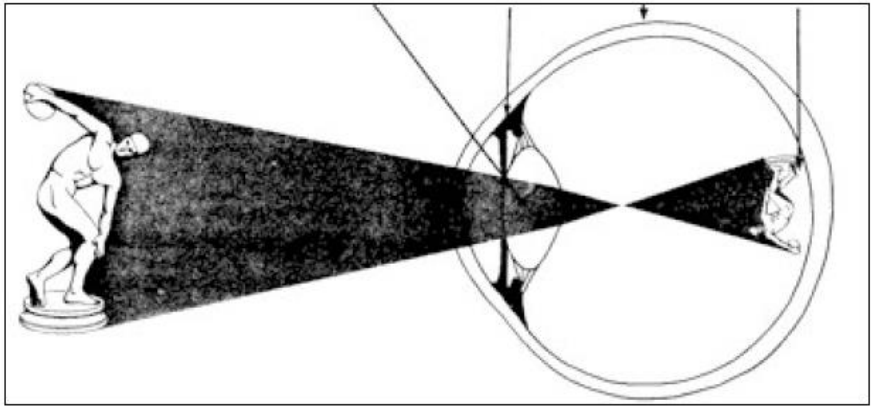
Data Processing

The same thing happens in the human eye:

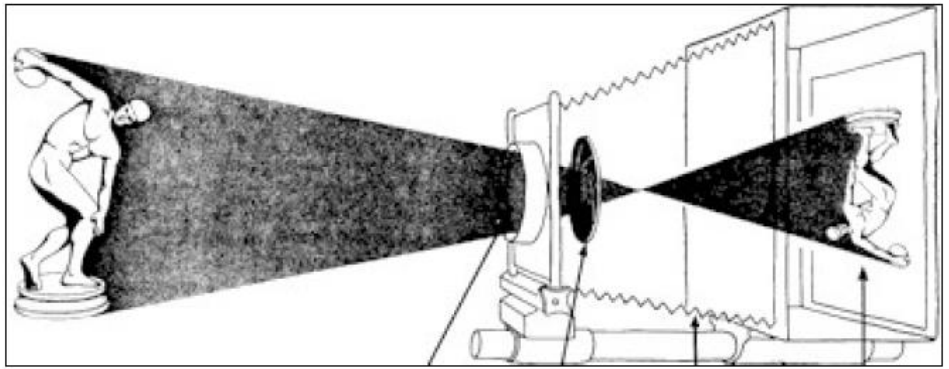


Source : © CIPA summer school 2023, Rhodes, Greece

How do I get reliable information from a photograph?



Eye

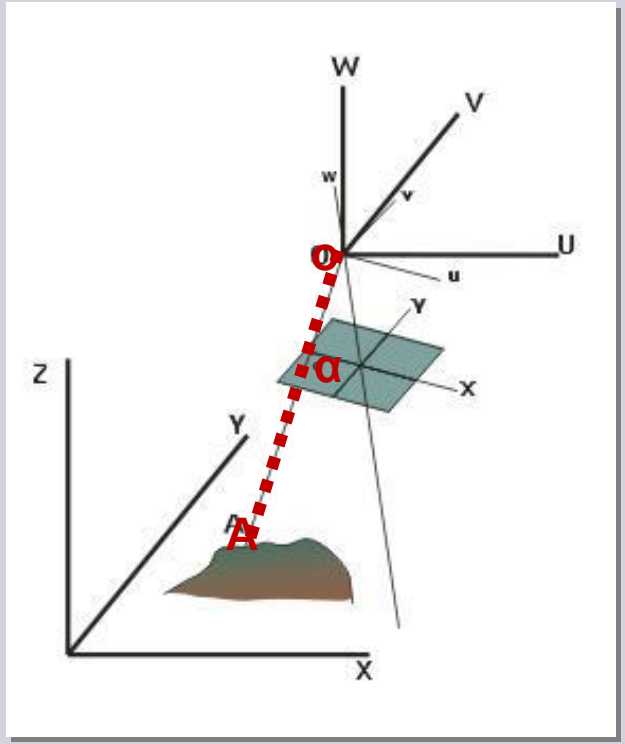


Photocamera

Source : © CIPA summer school 2023, Rhodes, Greece

Mathematical definition of Central Projection

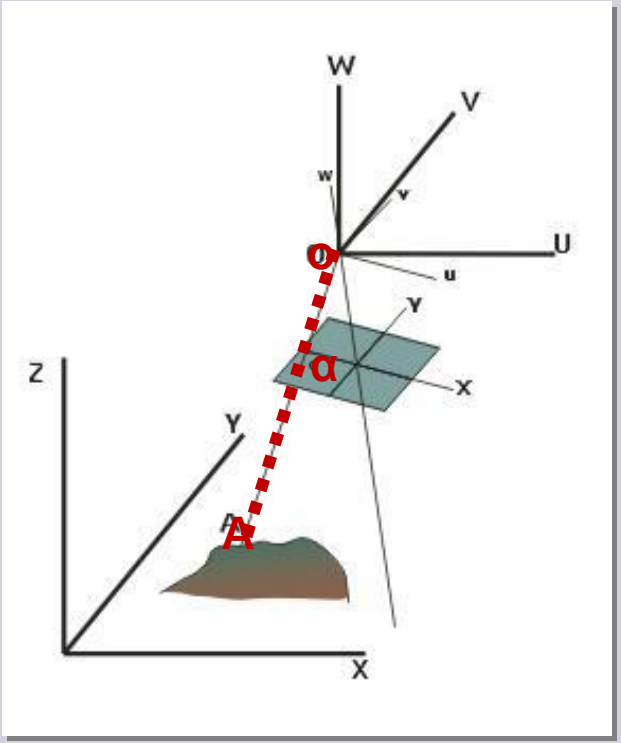
- ✓ For every point A on the ground, the corresponding point α in the image is defined such that the points A, α, and O-*the camera's optical center,* are collinear.
- ✓ This line represents the path of the light ray that starts at the ground point A, passes through the camera's lens (point O), and finally forms the image at point α.



Mathematical definition of Central Projection

- ✓ This collinearity condition of central projection is adopted by photogrammetry to define the relationships between the ground /object and the photo.
- ✓ The collinearity condition expresses central projection, and through this, the main photogrammetric problems are addressed.

It connects the elements of the image with those of the space as expressed in the corresponding coordinate systems.



Mathematical definition of Central Projection

- The general form of the collinearity condition:

$$\begin{bmatrix} x_\alpha - x_o \\ y_\alpha - y_o \\ -c \end{bmatrix} = \lambda * R(\kappa,\varphi,\omega) \begin{bmatrix} X_A - Y_o \\ Y_A - Y_o \\ Z_A - Z_o \end{bmatrix}$$

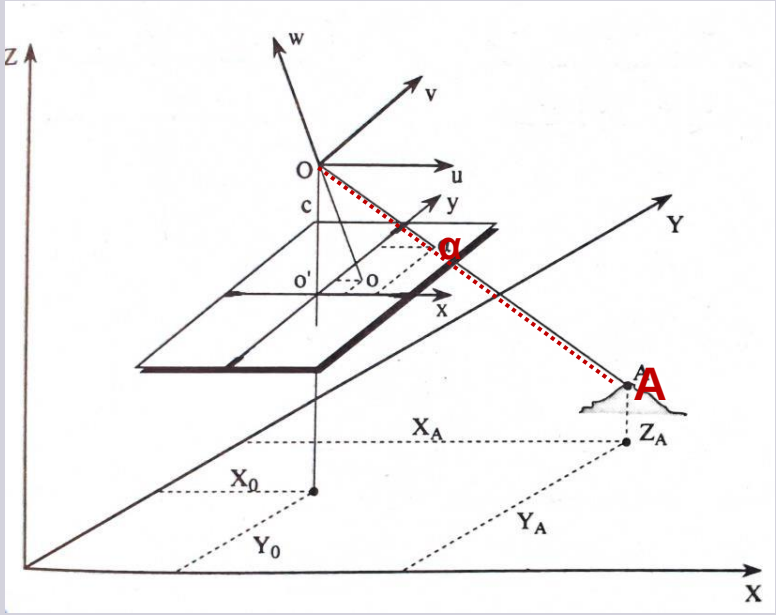
Scale and rotation parameters

x_α y_α : Coordinates of A in the photo

x_o y_o: Coordinates of the Optical center O in the photo

X_α Y_α : Ground Coordinates of A

X_o Y_o: Ground Coordinates of O

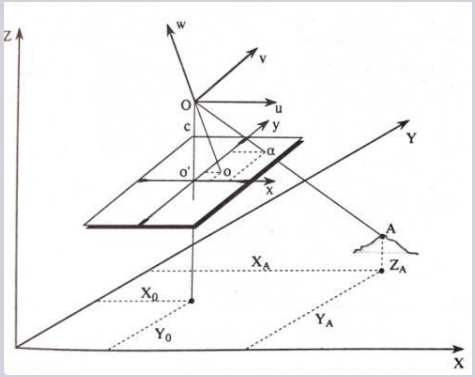


Mathematical definition of Central Projection

- The analytical form of the collinearity condition:

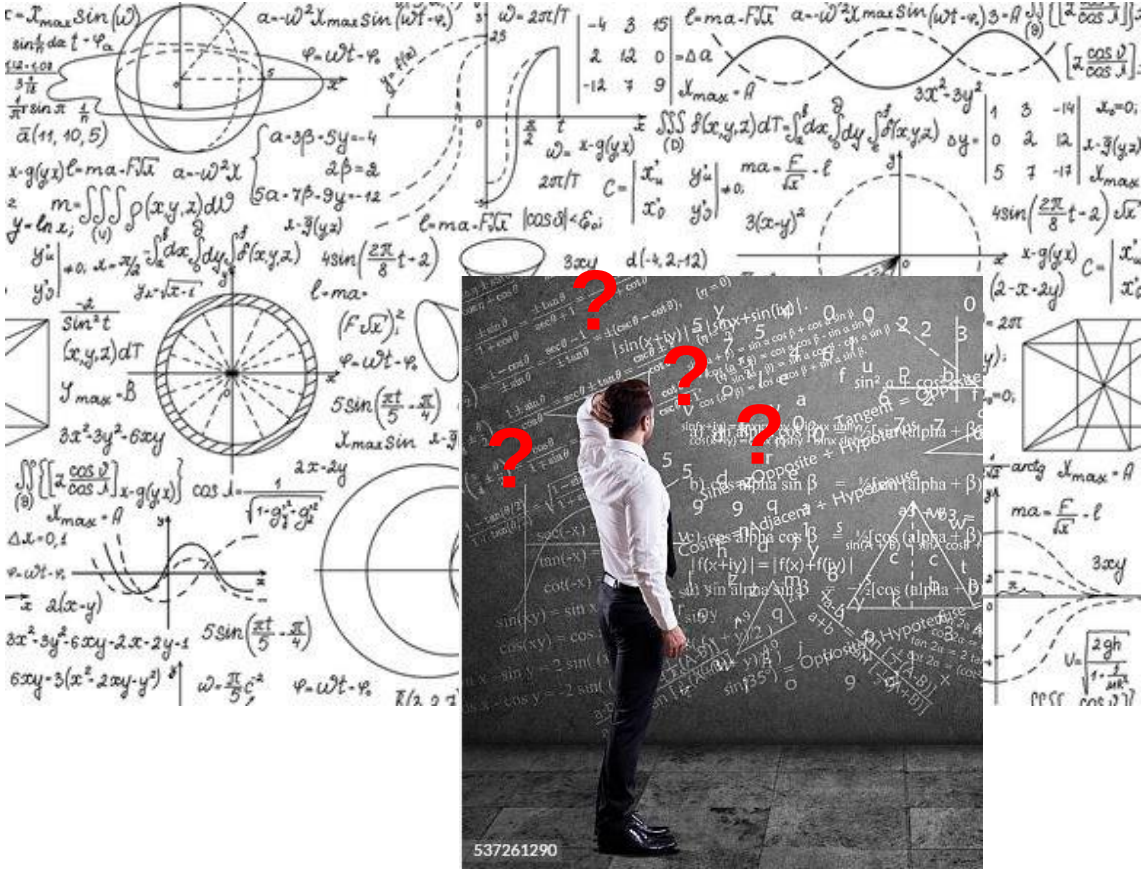
$$x_a - x_o = -c \cdot \frac{r_{11} \cdot (X_A - X_o) + r_{12} \cdot (Y_A - Y_o) + r_{13} \cdot (Z_A - Z_o)}{r_{31} \cdot (X_A - X_o) + r_{32} \cdot (Y_A - Y_o) + r_{33} \cdot (Z_A - Z_o)}$$

$$y_a - y_o = -c \cdot \frac{r_{21} \cdot (X_A - X_o) + r_{22} \cdot (Y_A - Y_o) + r_{23} \cdot (Z_A - Z_o)}{r_{31} \cdot (X_A - X_o) + r_{32} \cdot (Y_A - Y_o) + r_{33} \cdot (Z_A - Z_o)}$$



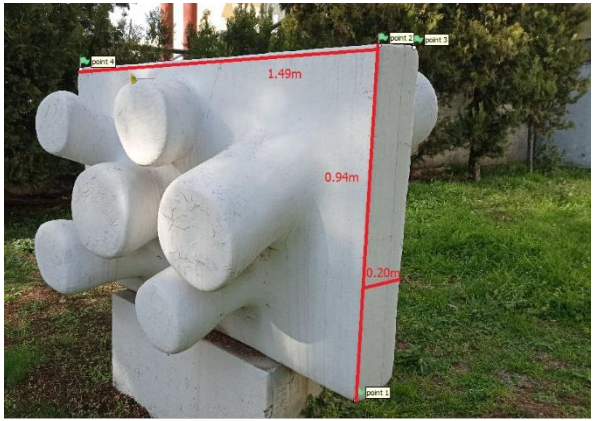
Going from the image to the ground

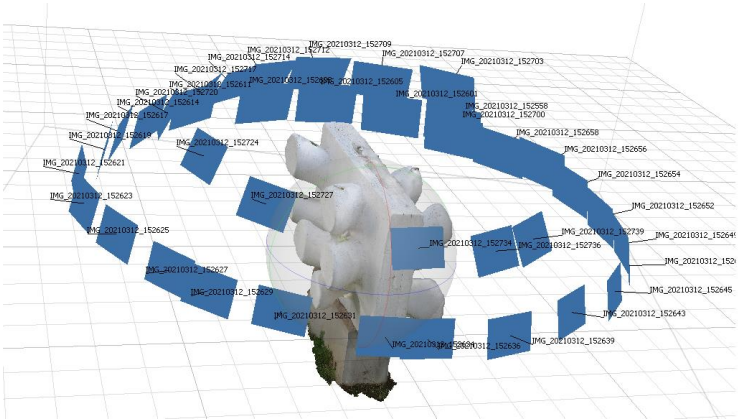
- ✓ Fortunately, all these complex mathematical procedures are being handled by the photogrammetric software!



Going from the image to the ground

- ✓ Our task is simply to take clear photos and identify points on the images whose ground coordinates are known.
- ✓ These are called Photo Reference Points.





Going from the image to the ground

✓ For aerial photographs:

- reference points can be obtained from a scale diagram of the area.

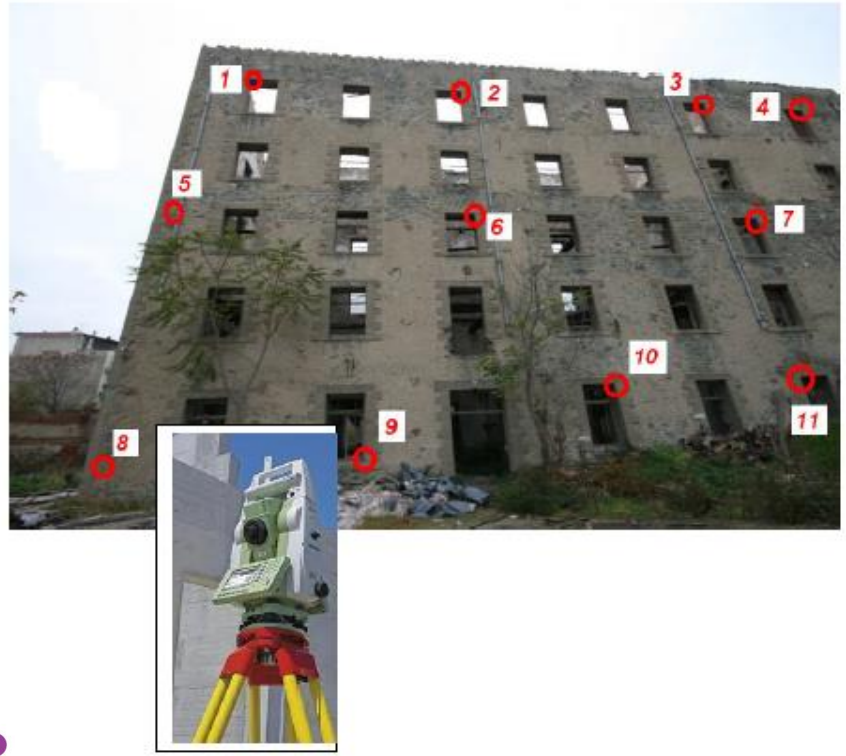
✓ In ground applications:

- marked or natural reference points can be measured using topographic methods.

✓ For easily accessible objects:

- known points can be defined by measuring the sides and diagonals of quadrilaterals or by marking them with horizontal and vertical threads, etc.

Going from the image to the ground



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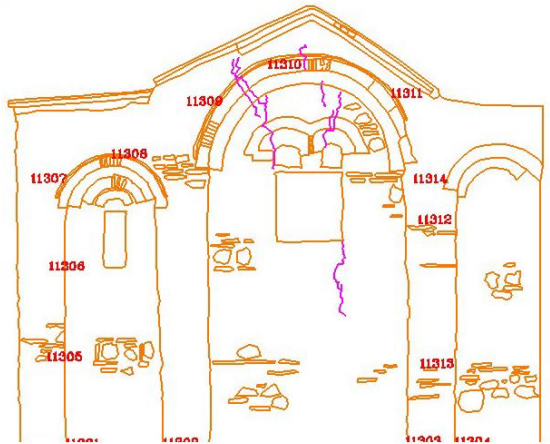
Going from the image to the ground

Source : © Γ. Καραποστόλου, ΔΠΕ

Single image photogrammetric procedures

Source : © Καραποστόλου Ε., ΔΠΕ



Single capture → 2D information

Single image photogrammetric procedures

Source : © Καραποστόλου Ε., ΔΠΕ

Single capture → 2D information

How about 3D information?

Stereophotogrammetry

Source : © Καραποστόλου Ε., ΔΠΕ

How about 3D information?

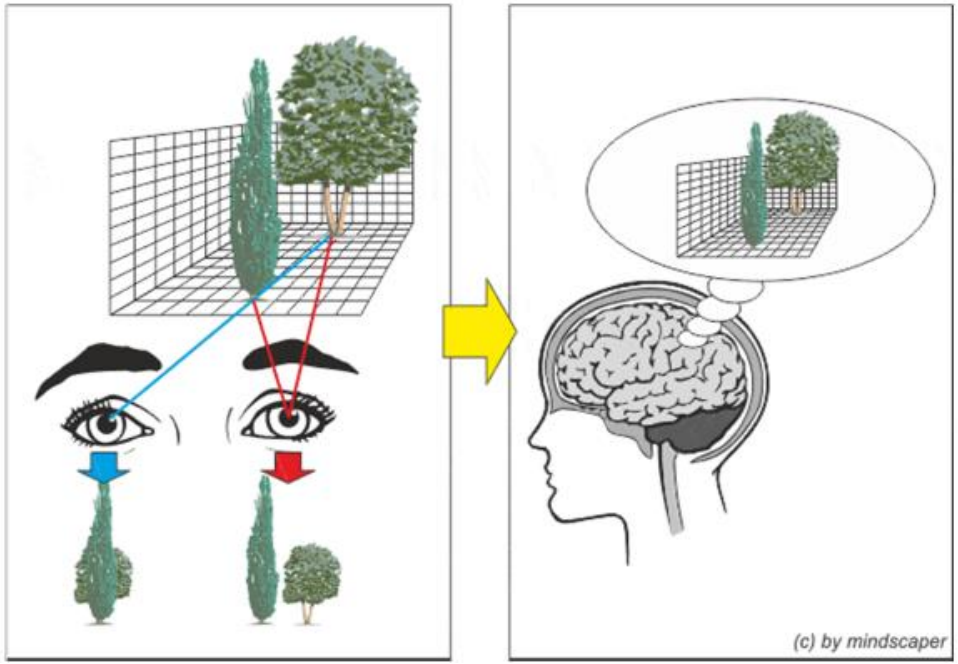
We are again inspired by the human vision:

Two eyes, slightly different views: Each eye sees the world from a slightly different angle. These two views are slightly different because of the space between our eyes.

Brain combines the views: The brain takes the two images from each eye and combines them into one single image. It compares the differences between the two views, using the depth and distance between the objects to determine how far away things are.

Depth perception: The brain uses these small differences (called "disparity") to figure out the distance and depth of objects.

This process gives us the ability to perceive depth, allowing us to judge how far or close something is in 3D space.



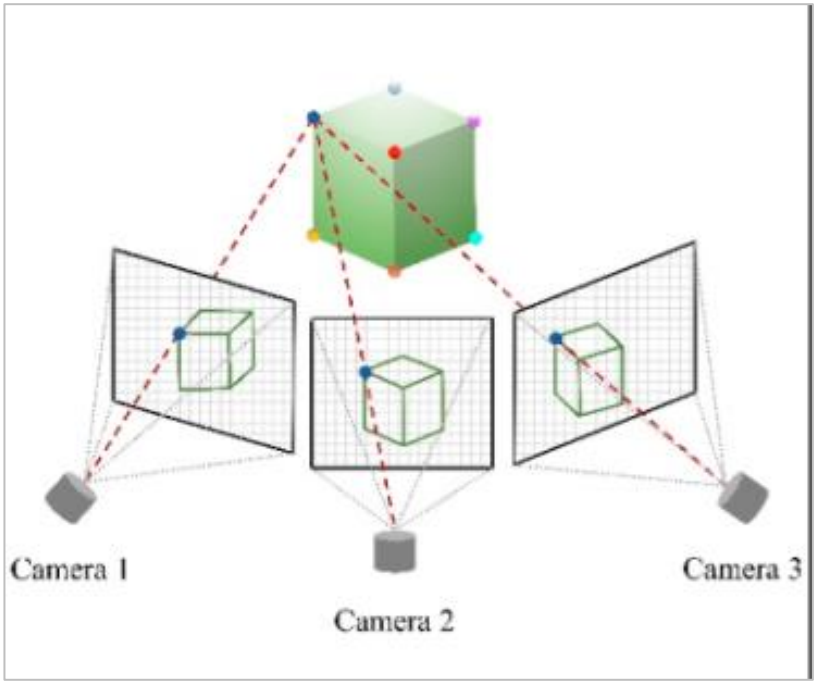
Source : © CIPA summer school 2023, Rhodes, Greece

How about 3D information?

Stereophotogrammetry is based on this notion:

It involves capturing two or more photographs of the same area or object from slightly different angles, just like how our eyes see the world in 3D.

Overlapping Images: At least one pair of photographs is taken from different positions or angles. The images must overlap in the area of interest.

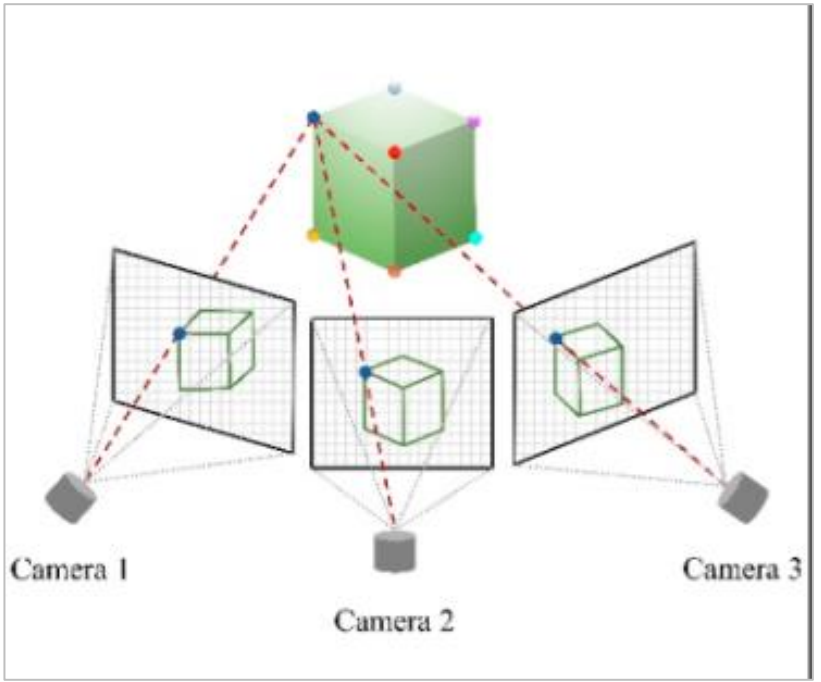


Source : © https://doi.org/10.3390/jpm12030490

How about 3D information?

Matching Points: In the overlapping region of the two images, reference points are identified. These are features like corners, edges, or specific objects that can be recognized in both images.

Triangulation: Using the differences in the position of these matching points between the images, the technique calculates their 3D coordinates.



Source : © https://doi.org/10.3390/jpm12030490

- This is similar to how our eyes judge depth by comparing the different views from each eye.

How about 3D information?

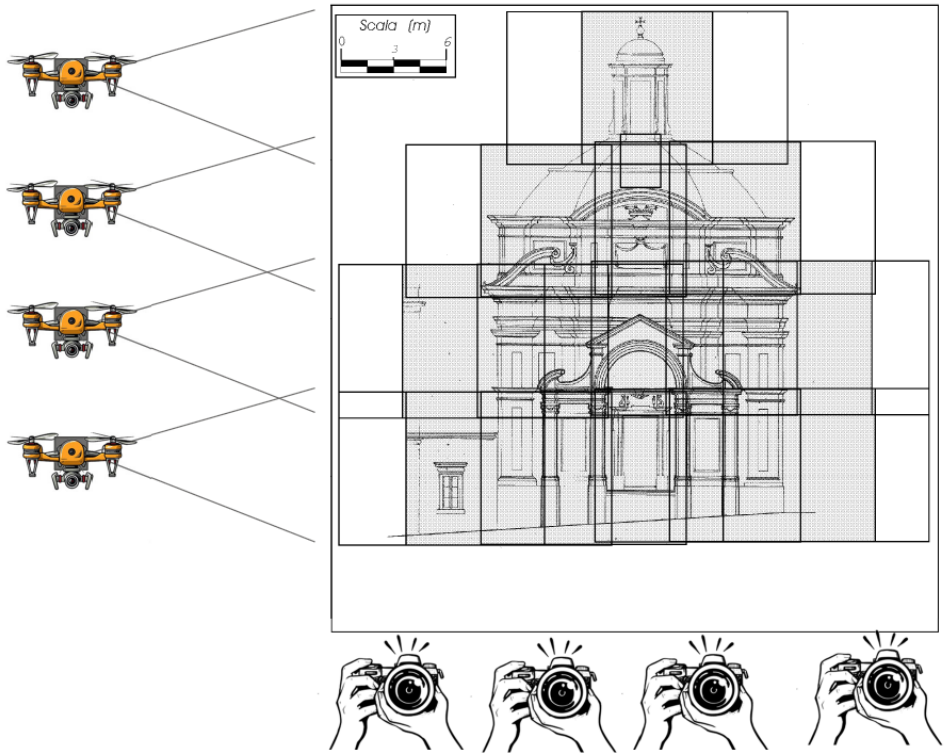
3D Model Creation: Once enough points have been measured and the 3D coordinates are established, a 3D model of the object or landscape can be created.

Source : © MIT Fab Lab

How about 3D information?

Again, our task is simply to take clear photos and identify matching points on the images whose ground coordinates are known.

And the photogrammetric software will do its magic..



Source : © CIPA summer school 2023, Rhodes, Greece

Photogrammetric workflow redefined:

1. Decide the representation scale of your object

2. Go on the field and study the object identifying the optimal acquisition schema in terms of :
   - ✓ Minor number of photos
   - ✓ Completeness of the acquisition
   - ✓ Overlap
   - ✓ Low costs
   - ✓ Identify the best organized way to proceed with the acquisition in order to not forget some parts!

3. Put markers on the objects if you don't have any other source for reference points.
   - ✓ Measure the reference points coordinates or at least take some distance measurements on the object to scale it.

4. Setup your camera:
   - ✓ Set up focal length (we need this for the central projection procedures!)

5. Go to your office and start working with your photogrammetric software!

NARRATE
Needs for Digital Recording and Documentation of Ecclesiastical Cultural Treasures in Monasteries and Temples

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Photogrammetric software

Photogrammetric software is essential for processing images into 3D models, allowing the extraction of *geometric and spatial data from photographs*. Key features of photogrammetric software include:

Image Processing: Converts 2D images into accurate 3D models using algorithms to detect common points across multiple images.

Point Cloud Generation: Transforms captured data into a dense point cloud, representing the surface of objects with high precision.

Mesh Creation: Generates detailed mesh models that represent the geometry of the scanned object.

Texture Mapping: Adds photographic textures to the 3D models, enhancing the realism of the digital representation.

NARRATE

Needs for Digital Recording and Documentation of Ecclesiastical Cultural Treasures in Monasteries and Temples

Photogrammetric software

Popular Photogrammetric Software:

Agisoft Metashape: Known for its high-quality 3D model generation from photos and laser scans.

Pix4D: Used widely in aerial surveying, with strong features for creating detailed orthophotos and 3D reconstructions.

RealityCapture: Combines images and laser scans to produce models with fast processing speeds and high accuracy.

Photogrammetry in action: A case study

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Needs for Digital Recording and Documentation of Ecclesiastical Cultural Treasures in Monasteries and Temples

Data sets

Small object

Building façade

..lets' continue with the hands-on case studies!

Thank you!