snap+

PHOTOGRAMMETRY

Deciding when and why to employ photogrammetry in architectural surveying depends on the specific objectives of the project, the available resources, and the expertise of the surveyors involved. This handbook aims to assist in such decision-making by providing practical guidance. In practice, photogrammetry is most effective when used in combination with classical surveying techniques, either as a preliminary data-capturing phase or as part of a hybrid approach to create a comprehensive and detailed representation of a building.

# photure
## EDUCATIONAL HANDBOOK

SNAP + | Photogrammetry Aided Surveying in Heritage Management

PROGRAM: ERASMUS+

ACTION: KA220-ADU - Cooperation partnerships in adult education

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## EDUCATIONAL HANDBOOK


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Drone navigation, Tés

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# 1| SUMMARY OF THE PROJECT

## 1.1 | Framework and objectives

Joana Quintela & Gábor Palotás

### ERASMUS+ PARTNERSHIP

The 'Photogrammetry Aided Surveying in Heritage Management' (SNAP+) is an Erasmus+ KA229 Cooperative Partnership Project for Adult Education. It was called into being by a diverse consortium consisting of Universidade Portucalense (as coordinator from Porto, Portugal), two non-governmental organisations: the Institute of Vernacular Architecture (Ljubljana, Slovenia) and EK Association (Gyömrő, Hungary) and two small-scale enterprises: Aleron IT (Budapest, Hungary) and Tektum Architectural Studio (Cluj Napoca, Romania).

### PHOTOGRAMMETRIC SURVEY RESULTS

The programme was created in a response to the great need for new educational materials in the field of photogrammetric surveys of buildings. The consortium of the programme therefore planned to survey four historical monuments with the help of photogrammetric methods using cameras and drones, collecting digital data on both the interiors and the outer facades of these buildings. The 4 surveyed objects were a Tennis court in Porto, Portugal, a windmill in Tés, Hungary, a wooden church in Chidea, Romania and a sawmill in Trenta, Slovenia. Having finished these surveys, the members of the partnership generated and assembled different types of useful outputs from the collected data: 2D architectural plans, interactive spherical panoramas and 3D models of the buildings. All these results were paired with the historical and artistic description of the surveyed monuments to be shared on the educational platform of the programme to demonstrate the effectiveness and usefulness of the surveys aided by the most up-to–date form of photogrammetry.

### EDUCATIONAL MATERIALS

The main objective of the programme however was to provide digital form teaching materials with the help of these exemplary resources:

- a digital-form educational handbook, titled PHOTURE (this publication) and
- a series of INTERACTIVE QUIZZES,

both added to the educational platform of the programme (https://snap-plus.eu/), providing an online resource of learning together with the illustrative results of the afore-mentioned exemplary surveys.

PHOTURE provides a short introduction to the theory and history of a small-scale photogrammetry, advises on the suggested method of photogrammetric survey and describes the ways of generating final outputs based on the raw materials of the survey data, which are essentially photos and panorama photos (both digital) and also some longitudinal measurements for scaling, this way sharing a lot of best practices for the most effective way of photogrammetric surveying. The suggested methodology involves all the preparations ahead of visiting the plot of the survey and all the computer processes that are required to reach the final results. These intermediary and final outputs are the following:

- **Point cloud models** with different types of representation (basic, textured etc.)
- **Orthomosaics / Orthophotos** (dedicated 2D views of the point cloud model)
- **3D Mesh Model** with different types of representation (basic, textured etc.)
- **3D CAD / BIM models** built from the point clouds,
- **2D Architectural Drawings** from BIM models
- **Explorable 360 degree panorama environments**

For the case of the exemplary surveys and the description of the digital processes the authors selected two pieces of software: Agisoft's Metashape for the photogrammetric calculations and ARCHICAD for the creation of 3D CAD / BIM models. Both tools have free test versions and provide free educational licences. The two programmes can be exchanged with any of their alternatives, the selection of them was only required to be able to provide a proper and detailed explanation on the use of such pieces of software and to be able to show a full path of the photogrammetric work.

- Alternative pieces of software for photogrammetric calculations: Pix4D, DroneDeploy, RealityCapture, OpenMVG, Meshroom, Photomodeler, 3DF Zephyr and ContextCaptureeels.
- Alternative pieces of software for 3D CAD / BIM modelling: Archicad, Autocad, Revit, Solidworks, SketchUp, Microstation, Allplan.

The Handbook also contains the case studies of the exemplary surveys and parallel to this it also summarises the history and connecting artistic concepts of the surveyed monuments, providing a full-scale understanding of the best practice solutions, showcasing the complete background of architectural surveys.

INTERACTIVE QUIZZES are to help measure the knowledge on both the photogrammetric studies and on the history and description of the surveyed objects. They are conceived as True or False, Multiple Choice and Drag & Drop quiz types and can provide an instant feedback on the rate of success of the gained knowledge, also serving as a useful way of consolidating the learning processes.

### TARGET GROUP

The educational materials are intended to be especially useful for architects, heritage managers and learners of these professions and basically for anyone who would like to get acquainted with photogrammetry as a creative and modern technology-supported way of surveying. During the realisation a special focus was given to adult learners, especially in disadvantaged regions where job possibilities are fewer. The materials of the programme can provide a useful solution and a helpful introduction to a prosperous lifetime occupation for which the entry knowledge is relatively low, which does not require any special skills, but mainly a precise and diligent work following the most basic principles of the discipline. Working with photogrammetric surveys does require the purchase of different types of tools (cameras, measuring devices) and pieces of software, these are long-term, but certainly profitable investments and they can be also gradually improved from a low level to high proficiency as the incomes are getting higher and higher.

During the realisation of the programme the partnership involved the representatives of the afore-mentioned target groups: adult learners, VET and university students, architects and heritage professionals. Learners were invited to take part in the surveys at the 4 locations: Porto, Tés, Chidea and Trenta, in the online lecture on the photogrammetric calculations, the multiplier events of the programme organised in 4 countries of the partnership and also in the testing of the educational materials.

The open-resource sharing of the results allows even for the wider audience to get acquainted with the explorable world of the the interactable 3D models as achievable final results of any photogrammetric survey. Representing the historical buildings with high precision and realistic outcomes can also bring the wider audience closer to the proper understanding of the outstanding values of these monuments.

Trenta´s field survey

Drone survey, Trenta

Gilberto Duarte Carlos & Gábor Palotás

### What is Photogrammetry?

Essentially, Photogrammetry is the process of creating two or three-dimensional replicas of real physical objects through the processing of photographic data. It is so rapidly developed and so widely applied that it can already be considered a science, combining specific fields of physics, geometry, topography and, obviously, computer programming. As a technical tool, photogrammetry has a wide range of applications and a large spectrum of users. Nowadays, it can be used resulting from a modest smartphone app to a luxurious Artificial Intelligence drone robot.

Photogrammetry is centred around perspective and its interpretation. It can be considered as a reversed action compared to photography. While photography transforms 3D information to 2D images, photogrammetry transforms the 2D representation of the objects to their 3D model. The mediating language for this transformation - in both ways - is perspective itself.

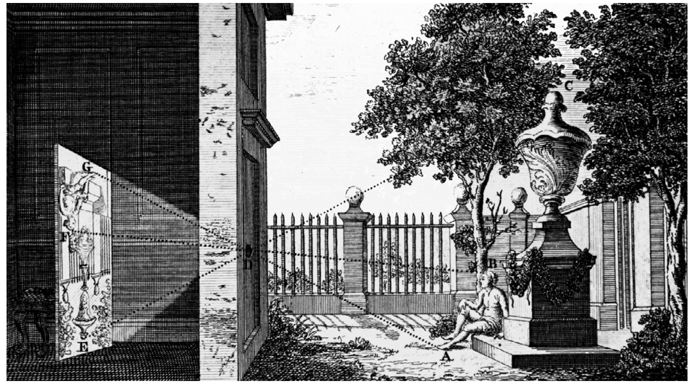
### Camera Obscura

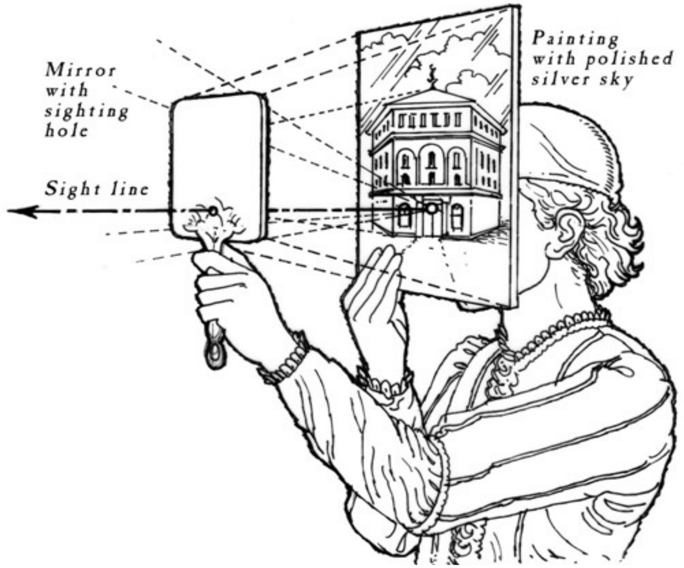
There is a natural phenomenon called camera obscura that significantly helped humankind in the proper understanding of perspective projection while also has been the main initiating idea for photography. This special occurrence of light had been with mankind for thousands of years, accidentally appearing indoors, painting some parts of the interior with a smaller, upside-down representation of the outer world. With time people learned how to artificially copy and induce this phenomenon, which also allowed to copy the perspective image and transform it to a drawing at place. We can already call this process the ancestor of all later cameras.

Leonardo da Vinci in his Codex Atlanticus described the functioning of the camera obscura (dark room) in the following way: “If the facade of a building, or a place, or a landscape is illuminated by the sun and a small hole is drilled in the wall of a room in a building facing this, which is not directly lighted by

Portrait of Leonardo da Vinci

The Camera Obscure demonstration





Brunelleschi’s method to rediscover linear perspective

Baptistery, Florence, Italy

Historical images, the foundations of perspective

Ideal City: Urbino, Italy

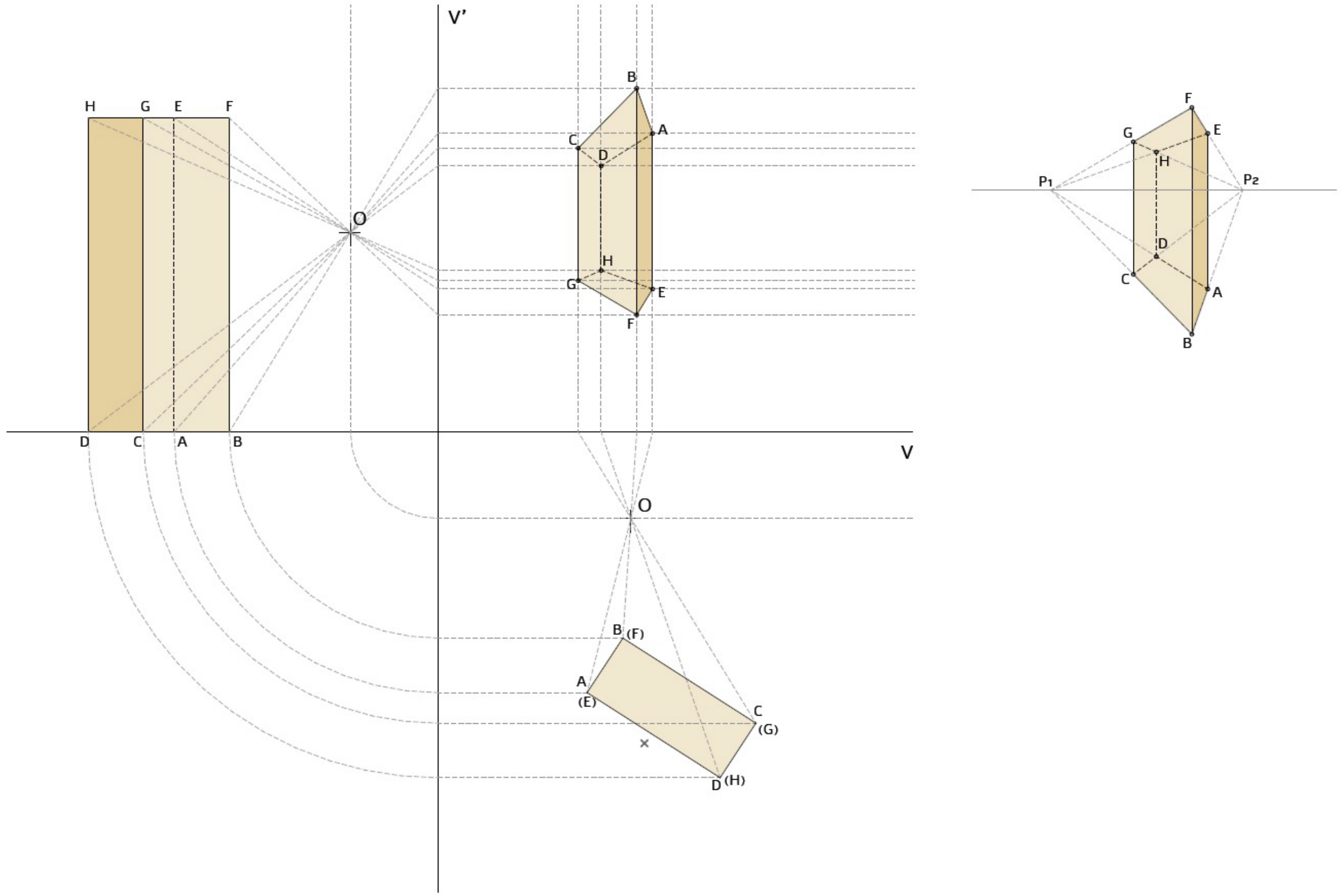
the sun, then all objects illuminated by the sun will send their images through this aperture and will appear, upside down, on the wall facing the hole. You will catch these pictures on a piece of white paper, which placed vertically in the room not far from that opening, and you will see all the above-mentioned objects on this paper in their natural shapes or colours, but they will appear smaller and upside down, on account of crossing of the rays at that aperture. If these pictures originate from a place that is illuminated by the sun, they will appear coloured on the paper exactly as they are. The paper should be very thin and must be viewed from the back."

### Perspective Representation

While there had been several promising signs and attempts from earlier times in history, the first great steps towards the complete understanding of perspective representation appeared in the Italian Renaissance. We can track this development process in the linear perspectives appearing on the works of masters such as Piero della Francesca, Giotto or Raphael. Brunelleschi, the architect and builder of the Dome of Florence, was the one who finally developed a precise mathematical concept on the realisation of such a perspective graphic, with its one vanishing point lying on the horizon and a series of orthogonals illusionistically receding to this point. Through an interesting experiment he could even prove the accuracy of his theory. First he drew a one-point perspective drawing of the baptistery building of Florence cathedral and then he drilled a little hole in the middle of it. Then, standing in front of the baptistery building, he looked through the hole from the back of the picture while he held a mirror in his other hand, facing the picture and obscuring the building. By moving the mirror towards the building and back he was able to scientifically compare his theoretical image with the real view. A few decades later, it was another great Italian architect, Alberti who wrote a manual on this discovery, helping other painters and other artists to use the method in the proper way.

### (R)evolution of Photography

The next important steps in the proper and realistic representation of the real world arrived with the rapid evolution of photography in the 19th century. The new developments introduced a lens to the place of the former pinhole of the camera obscura and a copper plate to the place of the canvas. This was called the daguerreotype after its inventor, the French photographer and artist, Louis Daguerre (1837). With all these changes the physics behind the concept remained the same and soon after photography started developing in an even more revolutionary way. Cameras became smaller and smaller, lenses turned to more and more precise. The first photographic films, the celluloid appeared in 1885, while the first digital cameras in the 1970's. But much earlier to these achievements, photogrammetry was also born in the second half of the 19th century and this happened thanks to the development and more and more widespread use of photography.



Perspective and orthogonal projection, correlation diagram

### Birth of Photogrammetry

The French officer Aimé Laussedat (1819–1907) is often considered as the “father of photogrammetry”. He used aerial photography to create topographic maps and he was the first to use photographic images for topographic surveys in 1861. He named the technique metrophotography, which he had already implemented with hand-drawn perspective views of edifications and mountainous landscapes. Among Laussedat’s many achievements was a new mathematical analysis that converted overlapping perspective photos into orthographic projections on a single plane. However, the development of analog photogrammetry is not a direct evolution of Laussedat’s method, which were hallmarked by stereocomparators.

### The Origin of the Term Photogrammetry

If we break down the word created by Laussedat, metro - photo - graphy, we will see that the different parts derive from the following Greek words:

Métron - “measure”

Photo - prefix from phôs, “light”

Grapho - to write, draw, paint, scratch

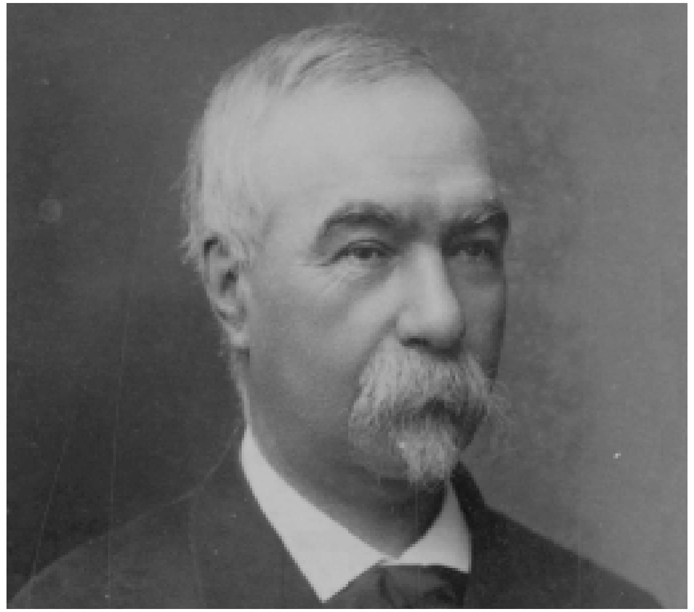
The combination of these words simply means measuring or surveying through photography.

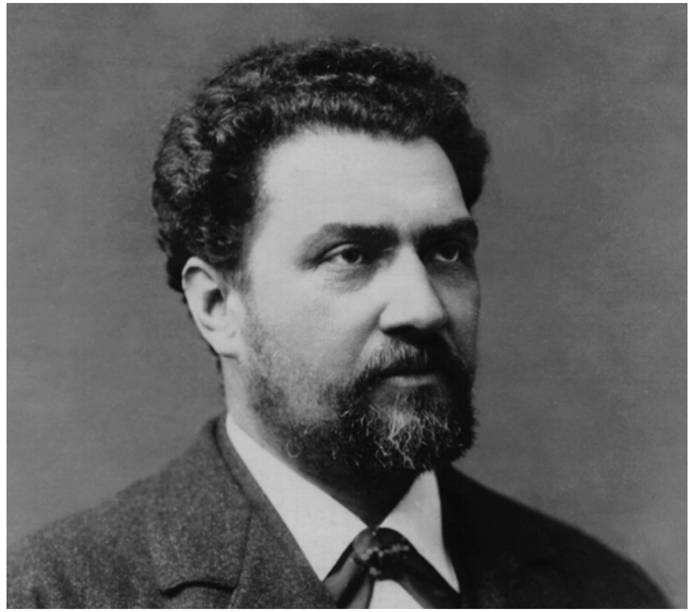
Parallel to Laussedat’s efforts, Albrecht Meydenbauer, architect and building surveyor of the Prussian government, also made experiments with surveys through the use of photography. In September 1858, while he was working, he had an accident and almost fell down from the side-aisle of the cathedral of Wetzlar. Following this dramatic episode, it occurred to him that the direct measurements at the facade could be replaced by indirect measurements in photographic images. In 1860, he wrote a memorandum about the documentation of buildings through photography to the curator of cultural heritage in Prussia. He described how photographic images can store the object information in great detail and with high accuracy. In an article published in 1867, he used the term ‘Photometrographie’ for the process, but for the recommendation of Dr. Otto Kersten, a geographical explorer he changed it to the expression ‘photogrammetrie’, as ‘photometrographie’ seemed to be far too complicated to use.

### What is it for?

Photogrammetry has an extensive range of applications. Because of its realistic appearance, it is widely used in the visual recording and documentation of historical objects, permitting the digital archive of cultural assets. It is compatible with dynamic data integration, enabling the use of augmented reality within the information databases, and promoting a more intuitive comprehension compared to other conventional record systems.

Due to its geometric accuracy and shape simulation capacities, photogrammetry is also applied on architectural and urban fields. It allows the reconstitution of build structures, from a simple building component to an entire city. Besides the digital


Aimé Laussedat (1819-1907)


Albrecht Meydenbauer (1834-1921)

historical images, explore the foundations of photogrammetry

Susse Frères Daguerreotype camera, 1839

Camera FKD 13x18: Lens Industar 51

Camera developed by Albrecht Meydenbauer

record of the object, it also consents the virtual manipulation and immersion of the observer, expanding the sensorial experience of the surveyed reality. It plays an important role in the recording of potentially dangerous structures, such as unstable ruins or toxic environments.

One of the most direct and simple applications of photogrammetry was in topographic mapping, determining a revolutionary impact on the land surveying equipment. The velocity of execution and processing automatism determines its preference in large scale and complex areas, that otherwise would consume a great deal of human and technical resources, to provide the respective technical drawings.

Nevertheless, besides these cultural features applications, it is also important to mention that the development of photogrammetry technology is also associated to the military sector, namely the production of georeferenced cartography, aiming the identification and comprehension of security menaces in enemy territories.

We can also categorise Photogrammetry based on the distance from the object, inducing different technologies based on the same general concept. On the level of a single building we usually talk about Close-Range Photogrammetry while urban scale and topographic surveys can be achieved through Aerial Photogrammetry or Satellite Imagery.

### How does it work?

Photogrammetry resorts to an ancient geometrical calculation technique called triangulation which is a method to determine the location of specific points in space by forming triangles between known points and the point itself.

### Historic examples of triangulation

One simple example for triangulation is the technique by which we can determine the height of an object with the help of two similar triangles.

From Point O, the top of Object A should be seen under the same angle (α) as the top of Object B.

If we know the distance of OA (l1) and AB (l2) and the height of Object A (h1) we can calculate the height of Object B (h2).

If we know the distance of OA (l1) and AB (l2) and the height of Object A (h1) we can calculate the height of Object B (h2).

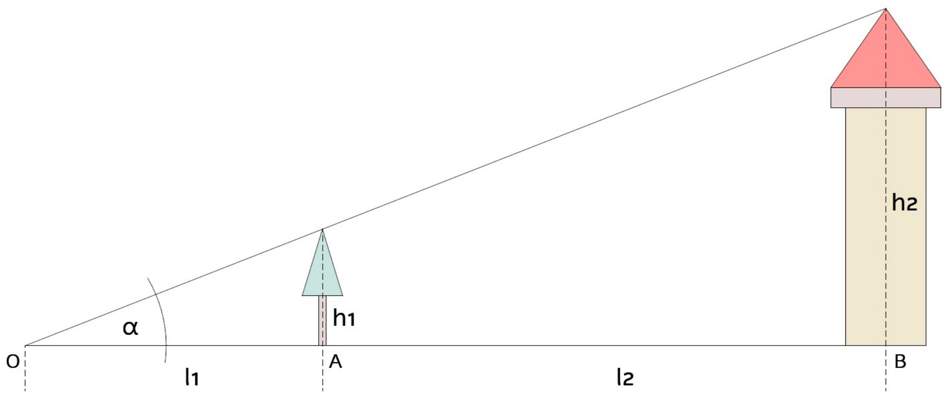
We can also get the desired result if we can measure two angles (α and β) under which the top of the object can be seen from Point A and Point B and also measure the distance between Point A and Point B (l1).

As a final example, with the help of two right triangles we can calculate the distance of an object from a line defined by A and B points.

For this, we need to know two angles (α and β) and the distance between Point A and Point B (L).

### Triangulation in photogrammetry

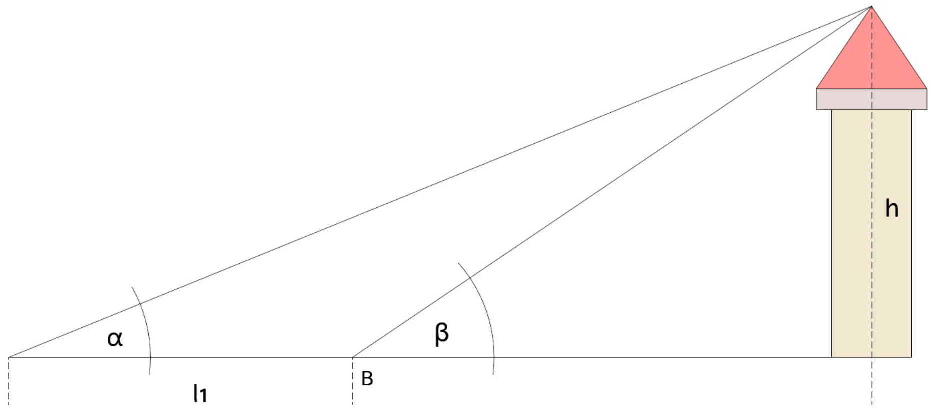
Photogrammetry uses similar techniques to these calculations



$$tg\alpha = \frac{h_1}{l_1} = \frac{h_2}{l_1 + l_2}$$

$$h_2 = \frac{l_1 + l_2}{l_1}\, h_1$$

Triangulation 1, correlation diagram



$$h = \frac{l_1}{\left| \dfrac{\tan \alpha}{\tan \beta} - 1 \right|}$$

Triangulation 2, correlation diagram

but on a different scale: instead of using only a few viewpoints and coordinates to calculate, it deals with thousands of points and coordinates with the help of hundreds of overlapping photographs at once. By analysing different images of the same object it is possible to identify the same points of the surveyed object in different positions.

Through prospective principles and taking into account parameters like the camera's position and orientation for each photograph, its focal length, lens distortion, and other variables, the computer will calculate and define lines of depth between them and the position of the camera, enabling the acquirement of the XYZ coordinates for each selected point. With enough points, we can construct a model of the scene.

From the resulting points system it is possible to generate three basic levels of digital replicas.

Usually, these levels represent a progressive and complementary evolution of a more detailed and complex model, although, depending on the objective, each level can be perceived as a distinct photogrammetric simulation.

### How to generate three-dimensional entities?

The cluster of points responsible for the object's basic geometric configuration is called Point Cloud.

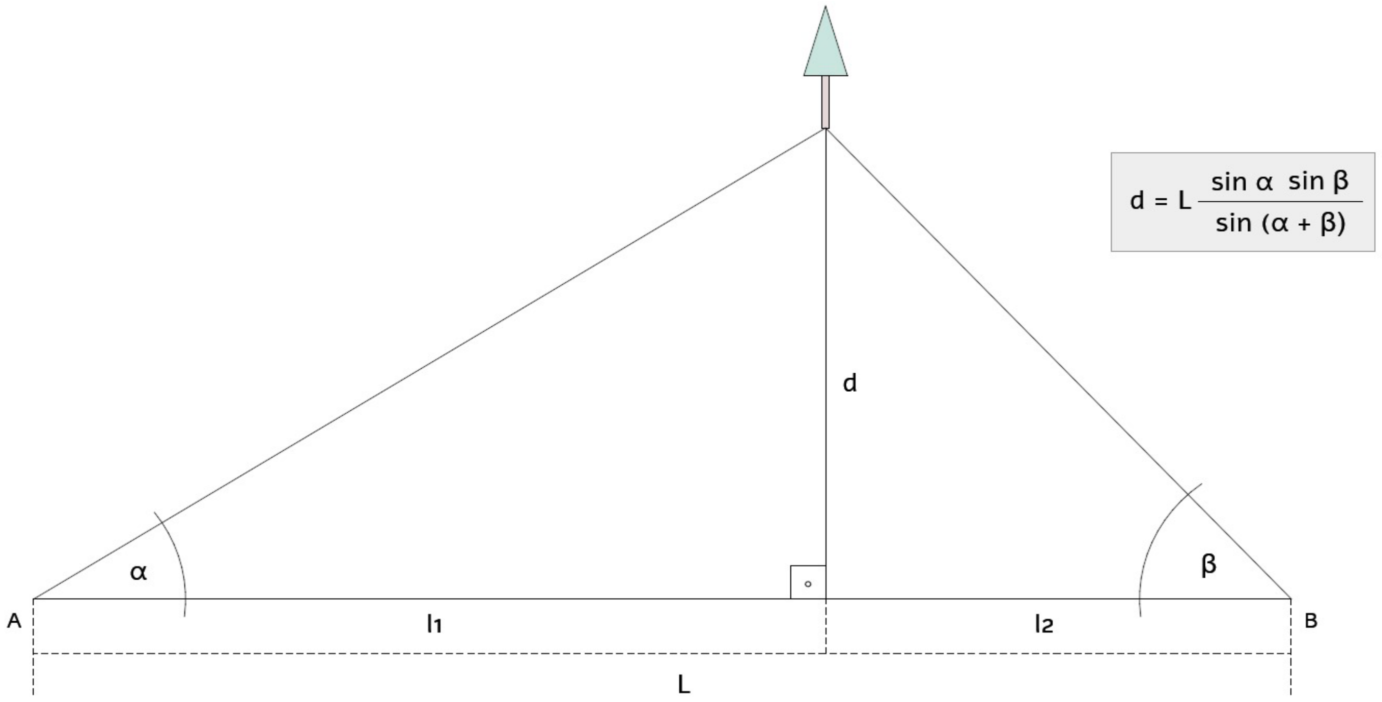
The Point Cloud consists of the aggregation of multiple coordinates into a single digital entity. The number of points is, in theory infinite, so the number of determined points will influence the accuracy and the operability of the entity. One may summarise the point cloud as the spatial grid of the surveyed object.

To achieve a more realistic effect, the digital entity can be developed in a subsequent stage. This next level consists in the filling of the area between 3 coplanar points, constituting an isolated surface. The combination of the different surfaces bound to the previous point cloud will generate a Mesh Model. The mesh model can be compared to a skin, it replicates the external configuration of the surveyed model, but the generated envelope has no thickness. Despite the visual effect, one cannot forget that it is only a surface record, which means that the digital simulation, by default, is not composed of geometric solids.

When necessary, to bypass that situation and depending on the object nature, it is possible to combine internal surveys to the outside configuration, creating the illusion of a single block entity, constituted by matter. Nevertheless, we need to remember this tool is based on optical records, which means that the internal composition of all geometric elements is not registered, nor simulated.

Combining other software of Computer Aided Design (CAD), it is possible to integrate or combine with the mesh model information regarding the material and density of the surveyed elements, but this is a procedure external to the photogrammetry capacities.

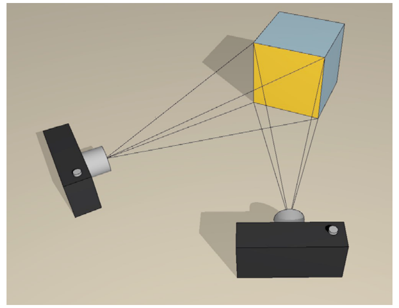
In the final stage of the process, depending on the objective of the replica, it is possible to render every generated surface of



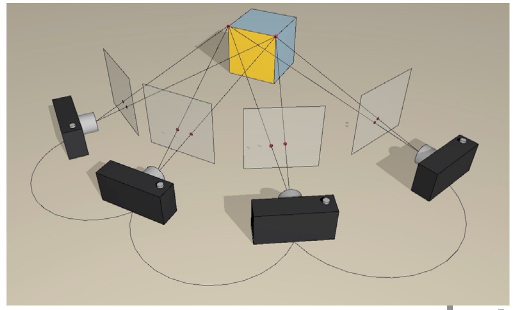
$$d = L\,\frac{\sin\alpha\ \sin\beta}{\sin(\alpha+\beta)}$$

Triangulation 3, correlation diagram

stereography, camera display



photogrammetry, camera display



the model. The present generation of photogrammetric processing software allows the use of the initial images as texture archives for each surface of the mesh models. The procedure, using powerful logarithms, optimises the available images with the configuration, positions, and scale of the model surfaces, creating a layer that overlaps the topologic figure through a Photorealistic Render.

### What do you need to know?

Always remember that photogrammetry is based on optics principles, the fundamental element for visual perception and recording is light. The light conditions are important to achieve a proper result. In every survey, if possible, one must try to capture images with the most neutral and homogenous light. Different intensities of light will compromise the final model.

High contrasts, creating strong shadow areas, are perceived in this system as voids, since there is no mechanism to calculate the depth of the occult surfaces. Therefore, the subsequent models frequently present anomalies like fragmented configuration or incomplete structures.

On the other hand, fine scale cast shadows on material can reveal material texture, such as fine or coarse mortal, state of decree on wooden surfaces etc. Especially on historic or vernacular buildings this “additional” layer of visual information is welcomed and can outweigh possible structural inconsistencies in three dimensional model generation.

Another important feature is the systematisation of the photo survey. The distance, angle and amount of planned views should be balanced on every side of the surveyed structure. The image capture should rely on a spatial scanning grid involving the object, whose density is adjustable to the pretended accuracy and final complexity. All visual interferences between the cameras and object should be avoided or considered, to allow a more efficient post photo manipulation.

Always remember to adjust the number of images to the survey purpose and to the digital equipment capacity. A very common error is to exaggerate the photo captures, creating excessive data. Don’t forget photogrammetric processing is based on digital files accessing and combination. Excessive heavy data will compromise the operability of the information, harming the model generation and preventing a fluid access to the respective record.

Finally, don´t forget that image records can be framed within privacy and security regulations. When surveying nearby public spaces, private properties or conditioned security facilities, the national competent authorities must provide special authorization. Some countries already developed strict criminal penalization regarding these issues. Before starting any photo survey procedure, one must confirm these circumstances and assure the appropriate measures.

### What do you need to have?

Besides a digital camera, photogrammetry requires software for image processing. This computer programme will be responsible for the selection, systematisation, overlapping and combination of all the fragment views resulting from the photographic survey. Recently, the biggest survey equipment labels started to provide processing computer software, exclusively compatible with their commercial products in combined packages. Evidently, the product range will determine the sophistication of the programs. The cheaper it is, the more basic the program will be. On the other hand, some of the already implemented big scale digital drawing companies are making an effort, realising the commercial potential of photogrammetry, to provide transversal programs or plugins to allow the extension and compatibility of their existing products with this phenomenon.

The quality and speed of the result is deeply linked to the computer characteristics, therefore the memory, the processor and the graphic card of the machine can be a key factor to develop speedy and good results. Although specific technologic hardware for survey already exists, it is very rare even for professionals and academics to adopt such equipment. The uprising of the gaming industry and the massification of digital devices, creating one of the wealthiest sectors of the actual economy, allowing greater access to high level computers or mobile devices for commercial purposes that have more than enough capacity to allow quality photogrammetric labour.

Remember that the photogrammetric survey also depends on the scale and the environments of the reality you want to replicate. Therefore, large scale elements or even territorial areas implies the use of aerial manoeuvring and scanning devices, which can range from simple drones to space satellites. Due to the scale and the operational simplicity of architectural surveys, small-scale commercial drones are very common complementary equipment, even for beginner level.

Although not so common, there are a few specific environments that will need special conditions to allow a proper photographic record. Dark environments are one of the most problematic situations to execute photogrammetric procedures. Without light, places like crypts, archaeological excavations or underground infrastructures are impossible for photo recording. In these cases sensible and appropriate artificial illumination equipment are necessary to provide a proper assessment. Underwater surveys are another of these situations. Waterproof cameras and appropriate lighting systems and filters are mandatory to allow clear recording through water.

Finally, the movement or dynamic context is also an important factor. Nowadays, most cameras already incorporate image stabilisation systems or resolution sharpen options, nevertheless in some situations, the utilisation of special extenders, supports, gimbals, cranes and shock absorbers is advisable to guarantee the image quality necessary for the viability of executing the respective model.

Gábor Palotás & Maj Juvanec

**Surveying a building for photogrammetry involves several distinct phases, commencing at the building site and concluding with computer processing, which generates spatial (3D) information of the building.**

### How to Prepare the Scene?

Photogrammetry relies on visual information, photographs, as input data. Consequently, everything visible to the human eye within the surveyed building is also captured in the photographs and later processed during computer calculations. All processed data (visible elements) generates a 3D model of them, in the form of a point cloud or a mesh model. In contrast to other architectural surveying techniques, preparing the scene for surveying is a crucial and often time-consuming phase of the process. Since buildings are designed for specific functions, their interiors (rooms) typically contain numerous objects. While these objects are essential for the building's functionality, they are often undesirable in photogrammetry surveying, as they are not integral parts of the building itself and obstruct visual surveying. To ensure visual access to all the structural elements of the surveyed building, these items usually need to be temporarily removed. Although some elements can be also removed from 3D model during computer processing, they may still obscure parts of the scene in photographs, resulting in a lack of spatial information behind these elements. However, some removable objects are inseparable from the building itself.

They create an indivisible whole with the building, and their narrative role often outweighs the fact that they visually obscure part of the building's construction. Examples include pictures hanging on the wall, tables, benches in a room, and similar elements. Selecting which objects are essential for architectural understanding of the building's 3D representation is a crucial decision that must be made at the outset of the process, before preparing the scene. This decision depends on the purpose of the survey and the nature of the building itself.

Historical and vernacular buildings tend to have more meaningful "removable" elements than modern buildings. Deciding what to include in the survey is typically more challenging for interior spaces (rooms) than for exterior building surveying. In these cases, the presence of greenery is often a debated issue. Questions arise about its proximity to the building, how much greenery to trim for a clear view of the facade, and, more importantly, how much greenery is an essential part of the building as a whole.

### What is Scaling (Calibration)?

Photogrammetry is the process of translating visual information from numerous photographs into 3D spatial information (point cloud, 3D model) of a surveyed building. As photographs themselves lack information on scale, the reconstructed 3D model must undergo scaling/calibration. The simplest method involves placing targets (markers) at strategic points on the building, measuring the distances between them, and inputting this information into the computer to calibrate the spatial model. Targets are special symbols that can be printed to sheets of paper in advance of the survey and that the photogrammetric software can later recognize. They are the most useful if they are evenly distributed around the entire building or room. The measured precision of distances between targets plays a crucial role in the precision of the point cloud and the final result of the photogrammetry survey. Distances are measured manually, either using a tape measure or a laser metre. Precision error is minimised when targets are positioned as far apart as possible. Errors for building-scale measurements are typically within a centimetre.

Metashape Workflow - As in this handbook we will be showing how to build photogrammetric outputs (point clouds, textured models, orthomosaics ...) using Agisoft's Metashape professional software. Let's see now how to print the markers within this software - in advance of the photogrammetric survey itself. Press Print Markers accessed through the Top Menu's Tools / Markers pathway. Smaller the markers are, less intrusive they are on captured photographs and later on 3D models. For architectural buildings surveyed with a high resolution camera, usually 6 markers per A4 page are optimal (Marker type: 12 bit, Center point radius: 10 mm, Targets per page: 6). The software will generate the series of markers as a pdf file and offer you to download the file. Having done this, you can anytime print the required amount of markers for the next survey you plan to take. Typically around 5 to 10 markers are placed in each room/chunk surveyed. Each of these markers represent a number from 1 onwards. When later analysing the collected data through the software again, it will easily identify these targets (markers) and name them accordingly from 1 to the highest number used during the photogrammetric survey.

Targets (markers) serve multiple purposes, primarily for scaling and calibrating the model, as well as aligning the 3D model with the water level. Any three targets aligned to the water level (for instance using a laser leveller or water hose) can be used to correctly level the building. This is particularly useful for vernacular and historic buildings with irregular floor levels or walls surfaces. Targets are also employed to align different segments of the building, allowing faster and simpler 3D reconstruction for smaller parts or so-called "chunks" for the computing work. These separate 3D models are then aligned or assembled together for accurate positioning, facilitated by at least three non-coplanar targets, usually placed at doors or windows.

Placing the targets on building is the only potentially intrusive part of photogrammetric survey as they must somehow be fixated on the building itself. Choosing appropriate clear adhesive tape (sellotape/Scotc Tape) that doesn't damage building material when removing is important epecialiy in monument buildings.

#### Alternatives to using targets for calibration

It is possible to conduct a photogrammetric survey without targets, calibrating distances between visually prominent points can be also acquired through alternative means, such as laser measurements. However, this completely diverges from traditional photogrammetry. Another option is to equip photographs with global positioning system (GPS) coordinates, but this is more suitable for open spaces, as the satellite signal might struggle to reach indoor locations. Precision in distance of GPS coordinates is also crucial for the reliability of such calibration. If precision has to be within a few centimetres, even nowadays it would require professional grade (RTK) GPS systems. Some drones are equipped with position devices of that kind of accuracy, providing exact location on where each photograph was taken.

### How to take Photographs?

In photogrammetry photographs are essential for capturing visual information of a scene or a building, forming the foundation for a credible spatial representation or a 3D model. In a technical sense, high-resolution photographs are paramount as the computer algorithm relies on numerous pixels constituting digital photography to create spatially located points in the 3D space (point cloud). Photographs should be sharp to enable the precise location of tie points in each image. Achieving sharp and well-lit photographs is facilitated by quality lenses, a good light-capturing chip (CCD) in the camera, and proper adjustments to aperture, shutter speed, sensitivity, and other photographic parameters. SLR cameras are commonly used for photogrammetry due to their superior lens quality, less distortion, and better light capture. However, even simpler cameras, such as those found on high-end smartphones, can produce adequate results.

Taking photographs for photogrammetry requires capturing shots of every part of the surveyed building (or room) from at least three different angles. To create a credible point cloud, multiple photographs of each specific part are taken, usually around 10 pieces, each photo from a different standpoint. Photographer needs to slightly move for each shot he takes. Each photograph overlaps the previously taken one. The diffuse lighting conditions provide homogeneous results, eliminating shadows. Strong unidirectional light (sun, interior lights) casts “micro” shadows on materials’ textures revealing material textures effectively.

This helps real life representation, especially in vernacular and heritage buildings where material texture is significant. Thaw allows experienced observers to read material texture, material deterioration and so on, later even from the 3D model.

**What are the main Equipments?**

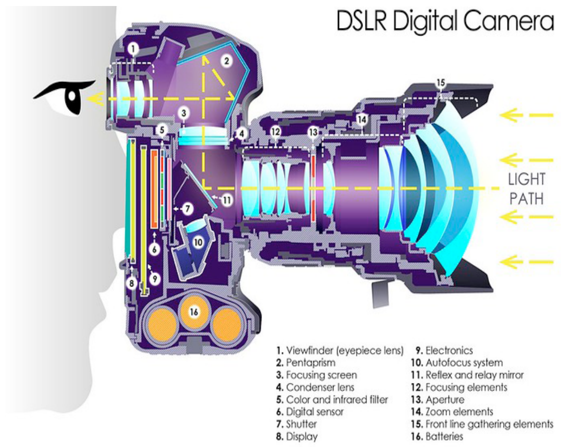
Cameras

The most common instrument for photogrammetry is the DSLR camera, especially for indoor surveying. When lighting conditions allow, holding the camera by hand and slightly adjusting the position for each shot is practical. In low-light situations, a tripod with longer exposure can be also used, but changing the standpoint for each photograph is time-consuming. Technical aids, like simple monopod sticks and remote shutter systems, or more complex giraffe systems can extend the reach of the camera, when the human hand is insufficient.

Before the exposure of a DSLR (digital single-lens reflex) camera takes place, the photographer is able to see through the lens with a help of the reflex mirror and the pentaprism letting the light beams through the eyepiece to reach the eye. This allows the photographer to compose the picture starting from focusing to choosing shutter speed, aperture (f-stop), ISO etc. In the moment of the exposition the reflex mirror and the focal-plane shutter get off the way of the light which then reaches the sensor at the back of the camera.

Let’s now get acquainted with a few important terms that can define the quality and exact content of a photograph:

Focus (focal point) - The sharpest area of the image based on the setting of the lens group. Most digital cameras have autofocus options built-in, but can be also operated manually, using the focusing ring. Turning the focusing ring moves the focusing lens group inside the lens (either mechanically or electronically), which changes the focus.



Section Diagram of a DSLR Digital Camera

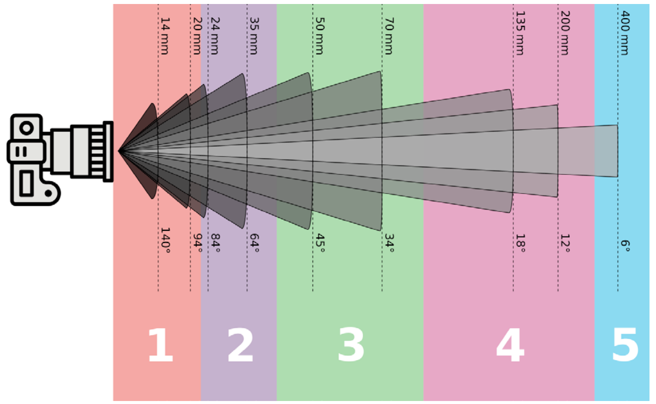
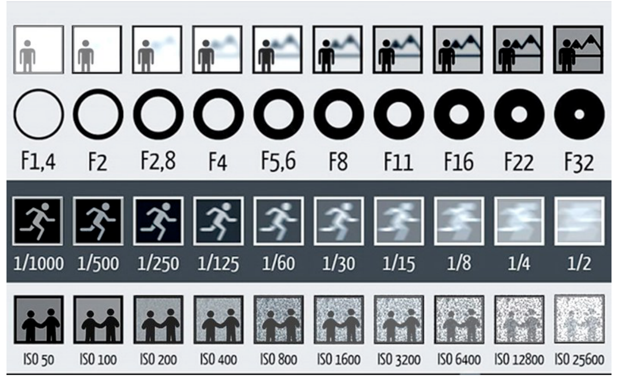


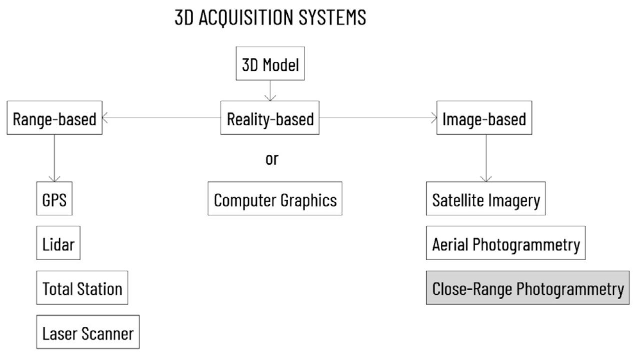
Photo lenses, focal length and angle display

Camera operability, examples and diagrams

Parameters for focusing lenses



3D acquisition system diagram



**Focal length** - The focal length of a lens is the distance between the plane of the sensor and the optical centre (nodal point) of the lens. This determines both the lens's angle of view and field of view. The smaller the focal length is, the greater the angle and field of view are and reversed. Focal length can be adjusted by the zoom ring of the camera and is determined in mm. Examples: 15 mm - fisheye: 180° angle of view, 35 mm: most generic setting, 63° angle of view, 400 mm: 6° angle of view.

**Shutter Speed** – The length of time a camera shutter is open to expose light into the camera sensor. Slow shutter speeds allow more light into the camera sensor and are used for low-light and night photography, while fast shutter speeds help to freeze motion. Examples of shutter speeds: 1/15 (1/15th of a second), 1/30, 1/60, 1/125.

**Aperture** – it means the hole through which light travels into the camera body. The larger the hole, the more light reaches the sensor of the camera. Aperture also controls the depth of field, which is the portion of a scene that appears to be sharp. If the aperture is very small, the depth of field is large, while if the aperture is large, the depth of field is small. In photography, aperture is typically expressed in "f" numbers (also known as "focal ratio", since the f-number is the ratio of the diameter of the lens aperture to the length of the lens). Examples of f-numbers are: f/1.4, f/2.0, f/2.8, f/4.0, f/5.6, f/8.0.

**ISO** – a way to brighten your photos if you can't use a longer shutter speed or a wider aperture. It is typically measured in numbers, a lower number representing a darker image, while higher numbers mean a brighter image. However, raising your ISO comes at a cost. As the ISO rises, so does the visibility of graininess/noise in your images. Examples of ISO: 100, 200, 400, 800, 1600.

For photogrammetry high ISO values (above 400) are not welcome, as graininess lowers the accuracy/sharpness of information captured.

Sharp photographs are essential as good "input" information for photogrammetric software. Correctly set shutter speed / aperture are crucial to achieve that. Unless you are a very seasoned photographer, shutter speeds in un-aided handheld photography should not be below 1/30.

**Depth of Field** - Depth of field is the distance between the closest and farthest objects in a photo that appears acceptably sharp.

For photogrammetry depth of field on photographs can reduce time and resources needed for point cloud calculation. If just the object of interest is in focus (sharp) and surrounding (background) is blurred, then identifying tie points on blurred parts of photographs is not possible. As we are not interested in this information (background information) they don't "weigh down" the whole calculation process that can be done faster. However we need to be careful not to put parts of our "object of interest" out of focus, as then we are losing valuable information.

### RAW files

DSLR cameras usually have the ability to capture pictures in RAW format. This is information as they are captured on a CCD chip in camera and are not processed yet. Manually adjusting RAW pictures and saving them to workable TIFF or JPEG format allows to adjust/modify photographs qualities in post-processing. Usually allowing to compensate for not optimally set parameters on camera when the photograph was taken.

Working with RAW format allows faster photographs shooting on the scene and requires more work in adjusting photographs on computer as photographs posprocessing (before photogrammetrical calculations begin). As conditions and accessibility on the scene (ot time available) are often not optimal, this is a viable way of doing this task in arhitectural projects.

### Drones

Drones prove to be incredibly useful when conventional methods for positioning a camera fail. These unmanned aircraft, equipped with cameras, can fly with precision using satellite navigation. Drones can change viewpoints smoothly and quickly by taking photographs every few seconds from different positions, capturing otherwise inaccessible perspectives. This ability is particularly valuable for surveying for photogrammetry, as one of the main characteristics of shooting for photogrammetry is changing standpoint for every single photograph. Drones are perfect for this purpose, as they can fly by a building and take photographs every couple seconds - every couple metres. Speed of capturing consecutive photographs of building exteriors in sunny conditions also minimises the impact of moving shadows.

### 360 Lens

360-degree cameras capture the surroundings in all directions, either by stitching numerous photos (taken with special tripods heads) into one 360-degree image or using two fish-eyed cameras. For photogrammetry, this offers new possibilities, ensuring a lower chance of missing parts of the building during the capture phase. 360-degree cameras are always used with some sorts of tripods, allowing longer exposures and working in low lighting situations as well. That comes handy in indoor photography of remote vernacular buildings with no artificial lighting (or electricity). On one hand it is time-consuming to move the 360-degree camera between the different viewpoints, but on the other hand as the offset is greater due to the larger capturing area, this solution requires much fewer shots in general. However, there is also a compromise with the lower resolution, CCD and lens quality. It is worth mentioning that future developments in 360-degree cameras may address these limitations, making them even more useful for photogrammetry.

Drone: DJI Mini 3 Pro RC

Gábor Palotás, Maj Juvanec & Radu Stoica

### What is Computing?

After completing field work - obtaining numerous photographs of surveyed buildings (several hundreds, several thousands) and measuring distances between targets, the process moves to second phase: the actual photogrammetric calculations. The magic, well mathematics, happens on computers with a special piece of software. There are a handful of commercial photogrammetric software available that generally work the same way, but have some differences and their own specifications. All case studies presented in this material were made by using Agisoft's Metashape professional photogrammetric software. This, to some extent, also has an influence on the explanation of the processes and the terminology used.

Calculations for photogrammetry use a lot of processor power to conduct a huge amount of mathematical operation to generate 3D space representation from photographs. More powerful computer can do this task faster, on a slower computer or even smartphone, calculations take more time. In most cases, classical personal computers are good enough to calculate photogrammetry of any building, if processing is divided into small enough segments - so-called chunks.

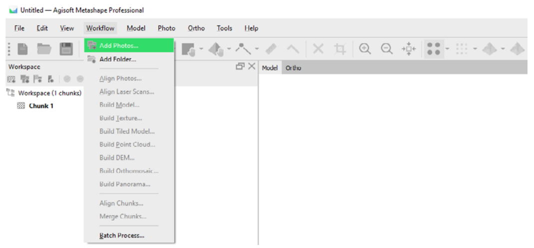
Metashape Workflow - The default work area of Metashape consists of the following parts: Commands at the top, organised as menu items and buttons, the Workspace area, which provides links to each generated model of the different chunks switchable to Reference pane with setting, the Photos area which shows the photos imported to the chunk actually selected and finally the Model area which shows the model selected in the Workspace area.

### How to Align the photographs and calibrate camera distortions?

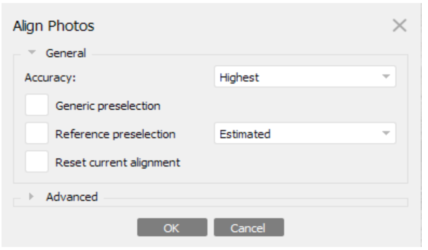
The first step towards the assembly of the 3D model by the photogrammetric software is aligning the photographs. On multiple photographs, same tie points are identified and distance between them is measured. This are basic input information for complex set of mathematical operations that first calculate the exact standpoint where each photograph was taken (relative to the surveyed building). This process is called aligning the photographs. In this first step, a sparse point cloud of a surveyed chunk is already generated.

Metashape Workflow - The process is started with importing the computable photos for the first chunk. By default this is titled Chunk 1 in the Workspace area on the left side of the screen. To start this process you need to select Chunk 1 and then choose the upmost command from the Workflow item of the top command menu: Add Photos... Once

Metashape's screenshot 01



Metashape's screenshot 02



Align Photos

General

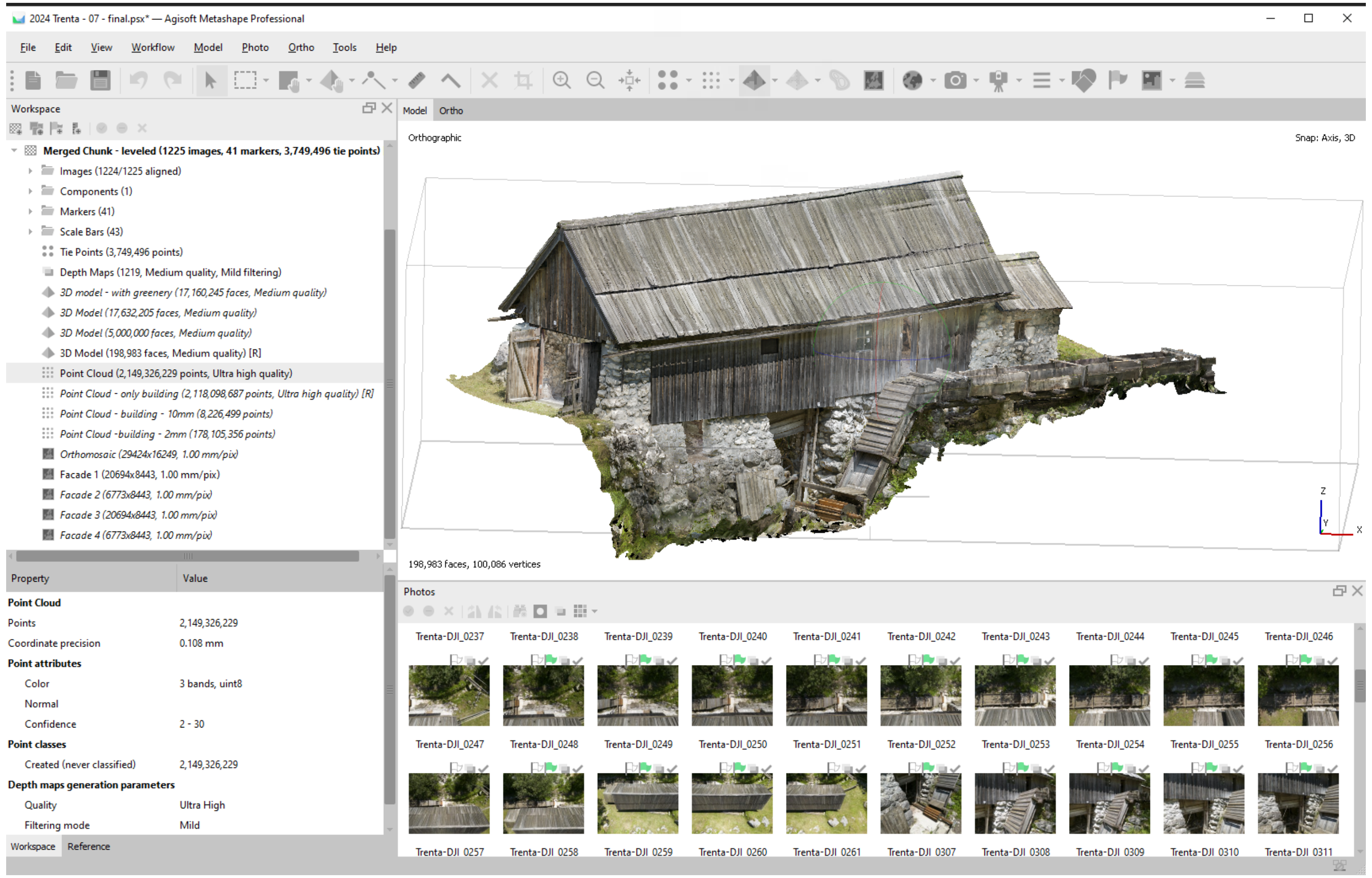
Accuracy: Highest

☐ Generic preselection

☐ Reference preselection: Estimated

☐ Reset current alignment

Advanced



2024 Trenta - 07 - final.psx* — Agisoft Metashape Professional

Merged Chunk - leveled (1225 images, 41 markers, 3,749,496 tie points)
- Images (1224/1225 aligned)
- Components (1)
- Markers (41)
- Scale Bars (43)
- Tie Points (3,749,496 points)
- Depth Maps (1219, Medium quality, Mild filtering)
- *3D model - with greenery (17,160,245 faces, Medium quality)*
- *3D Model (17,632,205 faces, Medium quality)*
- *3D Model (5,000,000 faces, Medium quality)*
- 3D Model (198,983 faces, Medium quality) [R]
- Point Cloud (2,149,326,229 points, Ultra high quality)
- *Point Cloud - only building (2,118,098,687 points, Ultra high quality) [R]*
- *Point Cloud - building - 10mm (8,226,499 points)*
- *Point Cloud -building - 2mm (178,105,356 points)*
- *Orthomosaic (29424x16249, 1.00 mm/pix)*
- Facade 1 (20694x8443, 1.00 mm/pix)
- *Facade 2 (6773x8443, 1.00 mm/pix)*
- *Facade 3 (20694x8443, 1.00 mm/pix)*
- *Facade 4 (6773x8443, 1.00 mm/pix)*

| Property | Value |
|---|---|
| **Point Cloud** | |
| Points | 2,149,326,229 |
| Coordinate precision | 0.108 mm |
| **Point attributes** | |
| Color | 3 bands, uint8 |
| Normal | |
| Confidence | 2 - 30 |
| **Point classes** | |
| Created (never classified) | 2,149,326,229 |
| **Depth maps generation parameters** | |
| Quality | Ultra High |
| Filtering mode | Mild |

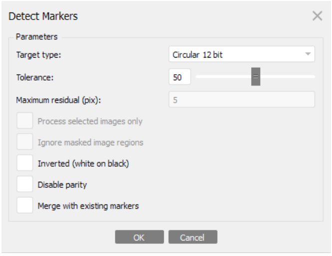
198,983 faces, 100,086 vertices

Metashape screenshots, data processing

they are added to the chunk, the next step is the alignment of these photos, which will be the first thing to calculate by the software. To initiate the process you need to select the Align Photos... command from the Workflow menu. In the appearing pop-up window the most important thing to set is Accuracy. It is recommended to work with the Highest value even if it can take significantly greater amount of time for the computer to make the calculations compared to all the other options, but only this option is not downsampling photographs and thaw losing information.

There are numerous mathematical calculations and approaches already behind the alignment of the photos, including many processes for optimisation and decreasing the margin of errors. One of the most important thing to do is the calibration of camera lens distortion. To create a photograph, the light must travel through camera lenses, where it is collected and directed to a small CCD chip (or film) for capturing the image. Small imperfections in lenses create local distortions on photographs, normally not seen to the human eye. But in the precise world of photogrammetry, they are considered as significant errors and can be eliminated in the computing process. The software calculates lens distortions for each camera/lens and corrects them for more precise 3D model reconstruction.

Metashape's screenshot 03


Detect Markers

Parameters

Target type: Circular 12 bit

Tolerance: 50

Maximum residual (pix): 5

☐ Process selected images only

☐ Ignore masked image regions

☐ Inverted (white on black)

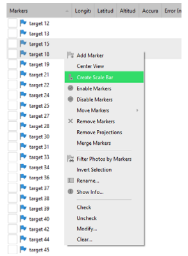
☐ Disable parity

☐ Merge with existing markers

How to set the size of the Model (Scaling)?

Assuming processed photographs don't contain GPS information or they are not precise enough (they are not created with professional grade accuracy - RTK GPS), the photogrammetric software will not know the size of the created 3D model: whether it's a real castle or just a castle in a nutshell. Targets (markers) and measured distances between them will put the model into the correct scale, which is crucial if measurements are to be taken from the 3D models generated in some later processes. As the distances between targets are precisely measured and considered trustworthy, the whole 3D model is calibrated based on these. That's why it's important to have targets evenly distributed throughout the whole surveyed object and within every single chunk. After calibration, the errors or inaccuracies will arrive from two factors: the inaccuracy at the measuring process (between targets, within the range of a centimetre), and the errors of the photogrammetric calculation which is influenced by many factors. But in general, the precision in case of smaller buildings is within a centimetre margin, if conditions are unfavourable, maximum a few centimetres in more demanding conditions. Precision is comparable with the accuracy of classical architectural surveying, but the level of details is incomparably higher in case of a photogrammetric survey.

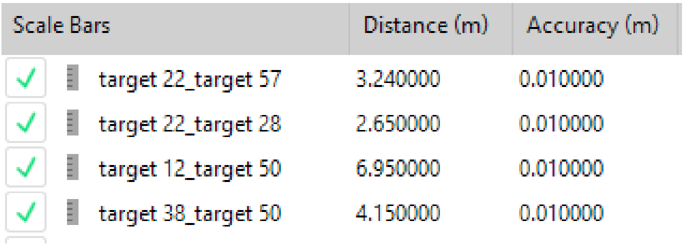
Metashape's screenshot 04



Metashape Workflow - From Tools / Markers initiate Detect Markers... command. In the settings select the marker type you used during the photogrammetric survey (by default: Circular 12 bit) and keep the default tolerance value (50). This command will identify all the markers appearing on your photographs and assign the relevant number to each of them. The imported markers (targets) can be seen listed in the Reference view of the Workspace area (Markers: target 01 - target xy).

Having pressed the Show Markers button in the Top Menu bar, the markers (targets) even appear within the 3D space of the spare point cloud (Model area). For performing the scaling process, our next task is to create Scale Bars between as many pairs of markers as possible, based on the measurements we made during the survey. To achieve this we need to select two of the markers and press Create Scale Bar button from the context menu of Reference / Markers (press right mouse button over the selection to get the context menu opened). The operation will create a new scale bar in the Scale Bar list of the Reference window (below Markers). Next to the name of the scale bar (e.g. target 01_target 10) you can now set the Distance value measured at the plot (in metres). For architectural building surveys it is advised to set the Accuracy to 0.01, that is 1 cm.

Metashape's screenshot 05

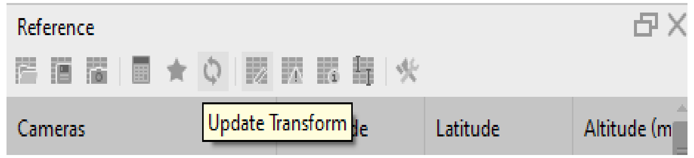


| Scale Bars | Distance (m) | Accuracy (m) |
|---|---|---|
| ✓ target 22_target 57 | 3.240000 | 0.010000 |
| ✓ target 22_target 28 | 2.650000 | 0.010000 |
| ✓ target 12_target 50 | 6.950000 | 0.010000 |
| ✓ target 38_target 50 | 4.150000 | 0.010000 |

Having set multiple measured distances for the different scale bars, press Update Transform button in the top menu bar of the Reference window. This command will regenerate the point cloud, scaling the 3D view of the surveyed object in the Model view. If a measurement is not precise enough, it will turn out very soon as based on the generated new coordinates of the 3D information will show how much a measurement goes along with all the others. Based on these calculations the Error value will highligh how much a newly set scale bar fit to the complete system of all collected data (both photogrammetric and manually measured data). If the error value is high, it is advised to check the notes and if it still cannot be corrected, then it is better to erase that scale bar (or set it inactive). Unselected scale bars are called "check" scale bars and are not included in model calibrations. They serve just as a control information on how precise the generated (and calibrated) model is.

If all scaling data are given with no significant errors between any of them, we can finish the calibration process by pressing the Update Transform button for the last final calibration of the model information.

Metashape's screenshot 06



### How to generate a Point Cloud?

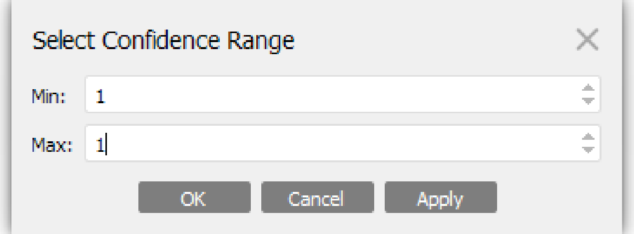
After photograph positions are determined (aligned) and model is optimised and calibrated, the main work begins: so the generation of the point clouds, which are called Dense Point Cloud models in the Workspace area of Metashape. The requested final resolution, the quality, quantity and size of the input information (number of photographs, number of pixels in them) will define the computing time needed for the creation of the final point cloud. On high-end personal computers this process usually takes a couple of hours for every chunk. The result is a point cloud consisting of millions of points allocated to the right position in space (X, Y and Z coordinates) and with information on the corresponding colour for each point within the point cloud.

Metashape Workflow - Initiate Build Point Cloud... from the Workflow menu to generate the Dense Point Cloud model. This point cloud model can be already used as a final output and as an ultimately useful resource for a new BIM / CAD 3D model. For both purposes often we might want to clean up the data and delete those points which are not that important for us or which are not confident enough. This cleaning can make the point cloud much easier to work with as the computers will be able to handle the smaller model with a much greater ease.

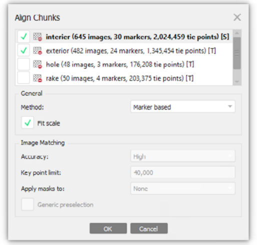
For the cleaning we can manually select those points which are simply not interesting enough for us (like background). For filtering the points of low confidence we can set the Point Cloud representation to Confidence (from the list of Solid / Colors / Classes / Elevation etc.) and initiate Filter by confidence... from the Tools / Point Cloud menu. In the pop-up window we can set an interval with a Min. and Max. value based on confidence. For architectural building surveys with high enough information to work with (hi resolution photographs) it's suggested to discard (erase) all points with confidence value of 1. This means the point cloud is cleaned up or made lighter not by randomly discarding points (information), but by discarding the points that are less accurate. The filtering will allow us to select these points and delete (discard) them with ease.

It is always advised to keep the original Dense Point Cloud as a separate chunk too and perform the cleaning process only on a copied instance.

Metashape's screenshot 07


Select Confidence Range
Min: 1
Max: 1

Metashape's screenshot 08


Align Chunks
☑ interier (645 images, 30 markers, 2,024,459 tie points) [S]
☑ exterior (482 images, 24 markers, 1,345,454 tie points) [T]
☐ hole (48 images, 3 markers, 176,208 tie points) [T]
☐ rake (50 images, 4 markers, 203,375 tie points) [T]
General
Method: Marker based
☑ Fit scale
Image Matching
Accuracy: High
Key point limit: 40,000
Apply masks to: None
☐ Generic preselection

### How to work with Chunks?

As the principle of photogrammetry is comparing multiple photographs to each other and trying to identify matching points on all different photographs (tie points), it makes sense to narrow down the number of photographs the software has to work with at once. When surveying architectural objects (buildings), they are usually made up by different rooms in it. Photographs from two (or more) different rooms won't have much, if any identical points in them, so the photographs taken in one room will not help the calculations required in the other room. Therefore splitting the architectural object to smaller parts (usually each room separately plus the exterior) can speed up the calculation process substantially and is usually employed. These smaller parts of the building are called chunks. As chunks have less information for the computer to work with, even less powerful computers can do the job, calculating one chunk after the other. As a result of this process for each chunk a separate point cloud is created. As point clouds are "machine-made" some work in checking the accuracy, removing noise and other unwanted objects is usually required to be done "by hand" and with awareness to what the final outcome has to be.

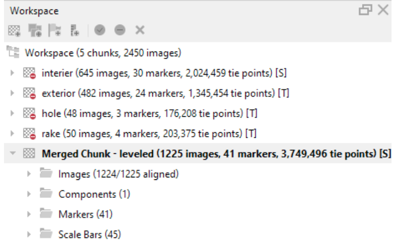
Metashape Workflow - Each chunk has its own set of photos, tie points, markers, depth maps, generated point clouds, 3d maps and orthomosaics organised under its own name within the Workspace area of the software screen. These separate chunks can be switched on and off based on what we would like to work with and see in the Model view.

### How to Align the Point Clouds?

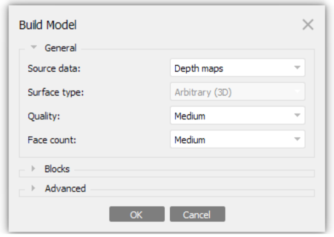
Having separate point clouds created for each chunk (e.g. each room, exterior, facades, roof...) does not mean that the whole building model is already truthfully created. To achieve this the chucks have to be aligned to each other with correct positions. The easiest to reach this is with the help of the targets that are visible on both of the corresponding chunks. In general we can say that three identical non-linear targets are sufficient to correctly align one chunk to another. Usually the chunk of a room to the chunk of a hallway connecting multiple rooms. And doors are, in architectural surveying, usually matching points for different chunks. That's way targets for chunk alignments are usually located at the doors. For aligning exterior chunk with interiors, glass windows are practical, as targets are seen from inside and also outside. Allowing to correctly align chunks and form point clouds of the whole building.

Metashape Workflow - In the Workspace window of the software screen we are able to switch on and off the different chunks either to show them in the Model window or not. When we already have more chunks in our model view, it is a basic need to clarify their relation to each other. The correct positioning of the connecting chunks, each

Metashape's screenshot 09


Workspace
Workspace (5 chunks, 2450 images)
interier (645 images, 30 markers, 2,024,459 tie points) [S]
exterior (482 images, 24 markers, 1,345,454 tie points) [T]
hole (48 images, 3 markers, 176,208 tie points) [T]
rake (50 images, 4 markers, 203,375 tie points) [T]
**Merged Chunk - leveled (1225 images, 41 markers, 3,749,496 tie points) [S]**
Images (1224/1225 aligned)
Components (1)
Markers (41)
Scale Bars (45)

Metashape's screenshot 10


Build Model
General
Source data: Depth maps
Surface type: Arbitrary (3D)
Quality: Medium
Face count: Medium

containing a point cloud already, can be initiated from the Top Menu's Workspace / Workflow / Align Chunks command. First let's select two (neighbouring) chunks and press Align Chunks. In the pop-up window it is advised to select Marker based as Method. If the Fit scale check box is checked, the secondary chunk will be recalibrated to match the primary one (its matching markers). As matching makers are usually placed on doors, one or two metres apart and and if secondary chunk is already calibrated to scale bars (markers) set wider apart (and thaw more precise) it makes sense to unthick "Fit scale" option to tell software not to rescale secondary chunk, but just to align it. It's also important to choose primary chunk wisely (usual hallway), that is the central chunk, that has correct alignment in space (water levelled). The markers connecting the two chunks will help to create the proper alignment between the two parts.

Having finished a series of alignment processes, we can decide to merge these chunks as one. To start the merging process, press Merge Chunks... in the Workflow menu. In this case too, it is advised to perform this action to create a new instance and to keep the original parts intact.

### What is a Computer derivative?

The basic result of a photogrammetry survey is the point cloud of a building. This is the most accurate 3D representation, but because of its visual complexity it is not the most practical representation. For different uses other computer calculated derivatives of this point cloud can be more useful. Let's see what these alternatives are:

#### a) Mesh

A Mesh is, instead of just points allocated to correct positions in space, a spatial model made of polygonal surfaces. A wall, for instance, is not formed by an array of points anymore, but is represented as a composition of different surfaces. Surfaces are derived from the points of the point cloud and they follow their shape more or less accurately. As this mesh is made up of many small triangles, we call it a triangular mesh. Because this is already a computer interpretation (following different sets of rules) of point cloud the credibility is lower, but understanding a mesh of a building is for humans much easier.

Metashape Workflow - The creation of a Mesh model can be achieved by selecting Workflow / Build Model... menu item from the Top Menu. First we need to select our Source data. Here it is recommended to choose either Depth maps or Dense cloud. Surface type: Arbitrary (3D) . As Face count, let's set High. If calculation takes too much time for you though, you might want to lower the quality. By hitting OK, the 3D mesh model is generated. As a result of the process a 3D Model item will appear under the tree of the active chunk in the Workspace Window.

#### b) Textured mesh

As we discussed in the previous paragraph, a mesh is a 3D geometrical model, constituted of many small triangles. The downside of this is that the edges of the triangles can be seen in the visual representation of the model. This differs from how we can "see" spatial objects. If the picture of a flat surface (texture) is applied to these 3D shapes, the visual representation will have a real-life look. This is called a Textured Mesh model. The 2D image textures of the mesh are generated from the input photographs.

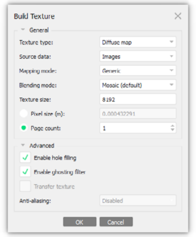
Metashape Workflow - A further step to create a proper model is to build the textures for the mesh. You can start the process by selecting Workflow / Build Texture... in the Top Menu. Typical setting of the panel is the following: Texture type: Diffuse map, Source data: Images, Mapping mode: Generic, Blending mode: Mosaic (default), Texture size / count: 8129. For architectural buildings it's advisable to thick Enable hole filling and Enabling ghosting filter options to generate more consistent results and correct small errors (holes). As a result the previously created 3D model entry in the Workspace Window will be updated.

#### c) Orthophotos

Photogrammetry in the past was developed to overcome "lens" caused distortions in classical photography - so to remove perspective. Omitting perspective from photographs allows representation of objects in "real" scale, so measurements can be taken directly from the photographs. This is what we call orthophotos or orthomosaic. Based on the 3D model the computer software can generate rectangular views or "ortho" views of the objects. In architectural surveys such orthographic views are the elevations, so the perpendicular side views of the facades and site views, which are the perpendicular top views of the buildings and surroundings. Orthomosaics are very useful as they feature numerous details of the building otherwise almost impossible to catch through any other facade/roof representing techniques. As part of an architectural survey the different parts of orthophotos are just useful as textures are for 3D meshes.

Metashape Workflow - We can initiate the process by selecting Build Orthomosaic... in the Workflow menu item of the Top Menu. For Projection we might want to select Planar over Geographic or Cylindrical as we are usually dealing with buildings and our intention is to get proper elevation or section views on the facades. Surface: Mesh is the recommended source. Blending mode: Mosaic is the default setting. We can either use the coordinate system of the 3D model view to choose the Projection Plane (Top XY, Bottom XY, Front XZ, Back XZ, Right YZ, Left YZ) or we can orbit the model to a desired view and apply Current View. To work with pre-defined projection planes building has to be properly align For Pixel size (that effective is the resolution) the recommended value is 0.01 (1 cm) or 0.001 (1mm). Round value makes it easier to set the correct size on post processing softwares. When all set, press OK and as the progress finishes, a new orthomosaic instance will appear in the Workspace and in the 3D Model view.

Metashape's screenshot 11



Build Texture

General

Texture type: Diffuse map

Source data: Images

Mapping mode: Generic

Blending mode: Mosaic (default)

Texture size: 8192

○ Pixel size (m): 0.000432291

● Page count: 1

Advanced

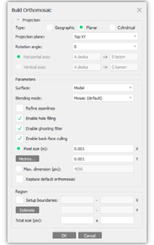
☑ Enable hole filling

☑ Enable ghosting filter

☐ Transfer texture

Anti-aliasing: Disabled

Metashape's screenshot 12



Build Orthomosaic

Projection

Type: ○ Geographic ● Planar ○ Cylindrical

Projection plane: Top XY

Rotation angle: 0

● Horizontal axis: A deska -> B beton

○ Vertical axis: A deska -> C kamen

Parameters

Surface: Model

Blending mode: Mosaic (default)

☐ Refine seamlines

☑ Enable hole filling

☑ Enable ghosting filter

☑ Enable back-face culling

● Pixel size (m): 0.001 X

0.001 Y

○ Max. dimension (pix): 4096

☐ Replace default orthomosaic

Region

☐ Setup boundaries: - X

- Y

Total size (pix): x

### What is a Human made derivative?

Humans comprehend our world in an abstract way. Millions and millions of points composing the building's point cloud are hard to read and even harder to comprehend. Computer generated meshes are easier to understand, but humans are adjusted to even more abstract presentations of buildings. In this type of presentation, for instance, numerous polygons forming a wall in a mesh are represented with a single block representing the wall. This has far less information and detail, but is much easier to understand. Though it has far less information, it has the most important piece of information. These are "classical" architectural 3D models.

The actual modelling stage of the object serves several purposes. Firstly, the model is processed in such a way that it can be used by all the specialists who will be responsible for the monument, engineers, architects, restorators, specialists in various fields. Secondly, it helps to understand the main elements that make up the building. In this context, we can speak of structural, architectural and artistic elements, since the great advantage of photogrammetry is that it accurately preserves all cultural and artistic traces.

Therefore, in order to create a proper 3D model we can mention two working methods. One is to make characteristic sections of the building in the point cloud software, import these sections into a 3D modelling program and develop the model based on the sections. Another method, which we have used in the following example, consists of importing the point cloud obtained from photogrammetry into a 3D modelling program, in this case Archicad from Graphisoft.

Within Archicad, the most efficient way to import the file is to select File / Interoperability / Import Point Cloud, so you will get the point cloud into the Archicad library. It should also be mentioned that the more points the point cloud contains, the more processing power the computer will need. In addition to the point cloud itself, orthomosaic images can be imported, these will be useful in the development of the next phase.

#### a) 2D plans

Ground plans, sections, elevations are the most common representations of architectural buildings. Photogrammetrically survey in the background, has similar influence to making classical 2D plans or 3D models. Underlying point clouds serve as a handy background for reading dimensions and allocation of elements, that had to be drawn (abstracted) by hand (actually by brain). This speeds up the process as no "hand" measurements on the site are necessary. And if the point cloud is credible, level of details can be much higher, as well as accuracy. Especially in historically and vernacular buildings, where perpendicular angles and straight lines are sparse. Photogrammetry based models have no problem registering all these, while disregards of exact geometry in abstract drawing can lead to higher inaccuracies of product.

Once point cloud is imported, the software allows several sections to be created. The characteristic sections will be made, (transversal, longitudinal) and also plans. And on top of these sections and on top of the orthomosaic images, the elements of the building will be drawn from lines and polylines in order to obtain clean sections, facades, plans.

#### b) 3D model

Techniques used for creating architectural 3D models are standard, the difference in having point clouds of a building available is, that 3D modeling can be made "over point cloud". When creating 3D element's, location and dimensions can be directly read from a point cloud. Allowing for much faster and accurate 3D model reconstruction.

Starting from the resulted drawings, we will use the 3D modelling tools of the software for the object. During modelling, we can overlay the point cloud with what we are building to constantly monitor the consistency of the model and to capture in the modelling imperfections, small deformations, details that can be captured especially by photogrammetry.

#### c) 3D renders

Making renders of buildings doesn't defer much in techniques and quality much if the survey is based on photogrammetry. The main advantage is, because of orthophotos available for surfaces, they can be used as textures. Renders can, instead of generical textures, have real object textures and be in this way more credible in representation.

Afterwards, 2D parts can be extracted from the model, which can be used as technical pieces, or presentation pieces.

Matosinhos site, Drone capture

Tennis Pavilion of Quinta da Conceição

# 4 | CASE STUDIES - SNAP+ Surveys

## 4.1 | Tennis Pavilion of Quinta da Conceição, Matosinhos, Portugal

### General description

Gilberto Duarte Carlos & Alejandro Lopez

The Tennis Pavilion at Quinta da Conceição (Lady of Conception's Farm) is a seminal work of contemporary Portuguese architecture. Built in 1958, it is regarded as one of the earliest examples of a critical revision of the Modern Movement. The Pavilion exemplifies a fusion of modernist design with principles rooted in local building traditions, notably referencing the vernacular architecture of Northern Portugal. According to most scholars, it represents the first fully realised expression of the paradigm shift pioneered by Fernando Távora, one of the most influential figures in Portuguese architecture.

The Pavilion forms part of the transformation of a private agricultural estate into a public urban park, acquired by the Municipality of Matosinhos in the early 1950s. Located adjacent to the country's largest industrial harbour, this new leisure space was intended to serve as a buffer between the expanding port activities and the growing residential area, driven by the rapid development of the Porto metropolitan region. Fernando Távora was commissioned to oversee the requalification of the estate, a project that spanned over a decade. His master plan encompassed a range of interventions, from the preservation of traditional structures to the introduction of new and innovative facilities, reflecting the evolving cultural landscape of Portugal at the time.

Under the direction of Architect and Professor Fernando Távora, the project team included recent graduates Rui Pimentel and António Meneres, both of whom had participated in the Inquiry into Portuguese Regional Architecture, as well as the young Álvaro Siza Vieira, who would gain significant recognition during this period.

The Tennis Pavilion is one such innovative intervention, introducing a foreign and sophisticated sport to a community experiencing economic growth and an increasing desire for urban sophistication, despite having no established cultural tradition of tennis.

The pavilion's design is articulated in two contrasting floor plans. The upper level is light and permeable, designed for unrestricted public use, functioning as a sports stand that overlooks the twin tennis courts. This level is composed of fragmented walls, arranged as detached orthogonal white planes that incorporate traditional structural elements, supporting a floating tiled roof. In contrast, the lower level is heavy and opaque, embedded into the sloping landscape. It serves as a private locker and shower room for tennis players and is constructed from granite masonry and exposed reinforced concrete, forming a retaining wall that blends with the terraced terrain, thereby highlighting the upper level as a distinct, elevated structure.

The pavilion's fusion of modernist design principles with vernacular building techniques, though unconventional, achieves a harmonious relationship with the farm's existing structures and reflects the broader ambition to introduce urban cultural advancements, influenced by foreign architectural trends.

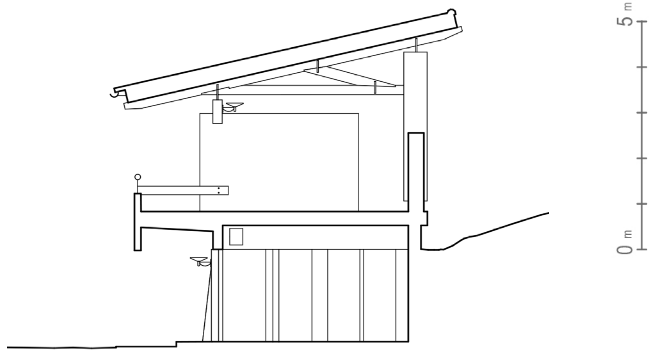
The pavilion's granite pillars and exposed wooden trusses evoke the image of a rural porch or water mill, with its single-pitched tiled roof following the natural slope of the land. At the same time, the detached structural elements, large spans, and systematic geometric alignments show clear influences from Mies van der Rohe's aesthetic, and even the more radical works of Gerrit Rietveld.

Another notable feature is the contrasting application of technology. The construction employs industrial materials, such as reinforced concrete and standard metal components, left in their raw form, alongside traditionally crafted elements, most notably the intricately detailed wooden ceiling. This interplay of materials contributes to the building's paradoxical sense of scale and atmosphere.

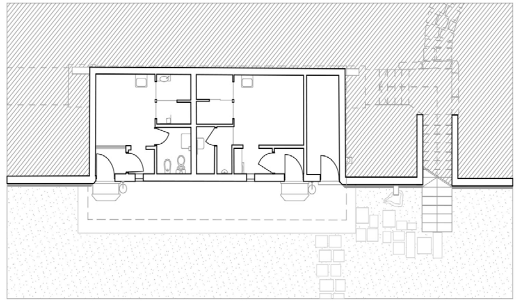
As an "in-between" building, the Tennis Pavilion acts as a conceptual bridge, exploring what Távora and his collaborators would later refine into a distinct identity: a contextual approach that honours traditional heritage while embracing industrial methods. This approach offered an alternative to the post-modernist trends that would dominate European architecture in the following decades.

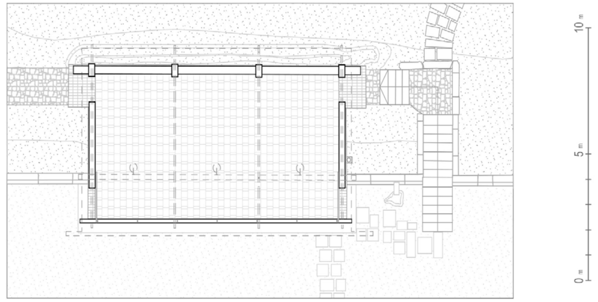
Despite its modest size—approximately 15 by 7 metres—the pavilion serves as a focal point within the park. It marks the eastern entrance to the farm, acting as a portal to the park's walking paths and providing a visual backdrop that mitigates the impact of the surrounding urban landscape. Situated at the highest point of the park, the pavilion also frames views of the harbour's cranes, offering an ironic reflection on the industrialisation that had contributed to the decline of the estate's agricultural use.

Today, the pavilion functions less as a sports facility and more as a belvedere, linking the garden to the city beyond. Rather than separating these spaces, it engages the local community with the site's history and memories, offering a vantage point to "watch the ships roll in," as if inviting contemplation of the area's industrial past.



2D Architectural drawings





### Survey report and data processing

Maj Juvanec

The Tennis Pavilion is situated within an urban garden park, where the surrounding greenery is an integral component of the pavilion's design and was consequently included in the photogrammetric survey. This introduced certain challenges, as it was not feasible to interfere with the vegetation, which partially obscured the view of the structure.

Trees positioned directly above the building cast shadows on parts of the roof, while well-maintained bushes encroached upon the building's perimeter. These factors account for the shadows visible on the otherwise uniform textures of this geometrically rectangular building. Owing to the surrounding greenery and the pavilion's relatively low height, all photographs were captured using a handheld camera, ensuring that no plants were damaged during the process.

In some instances, plants were gently moved aside to allow for camera access. To reach higher areas, the camera was mounted on a monopod and operated remotely. Drone photography was employed exclusively for the rooftop, as no other method could provide an unobstructed view of the roof.

In total, 1,370 photographs were captured on-site in compressed TIFF format, occupying 70 GB of storage space. The point cloud was divided into seven chunks: one main chunk representing both the interior and exterior, three chunks corresponding to each room in the basement, and a separate chunk for the roof, generated using drone imagery.

The wall of the observation deck was modelled in separate chunks to accommodate the high-contrast lighting conditions, while the west wall was isolated into a distinct chunk due to the dense vegetation growing adjacent to it. Thirty-two targets were strategically placed on the pavilion to facilitate calibration and ensure the accurate alignment of the chunks.

The post-processing "cleaning" of the point cloud was particularly challenging due to the pervasive presence of greenery. The final assembled and refined point cloud comprises 3,077,070,000 points, which is approximately equivalent to one point for every two people currently living in the world.

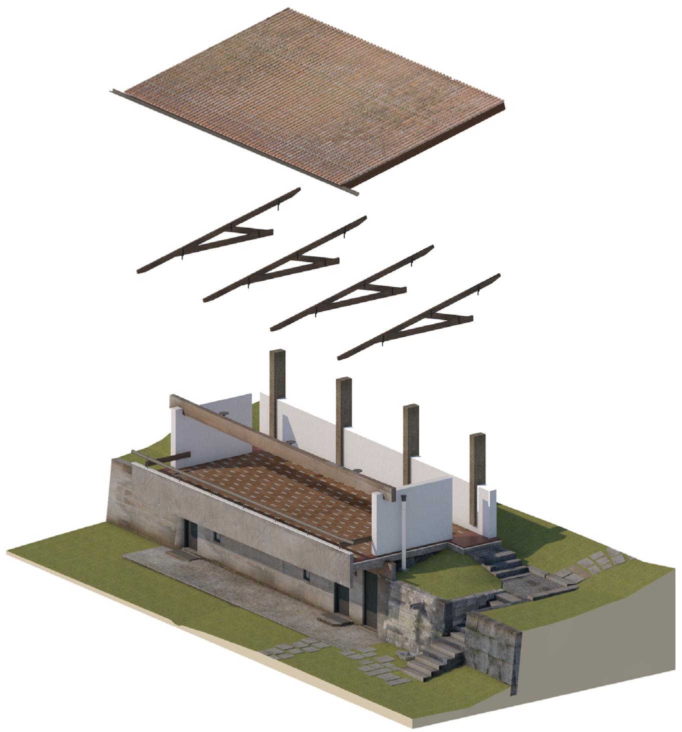
The on-site survey, including preparation of the scene and the acqui-

Matosinhos field survey

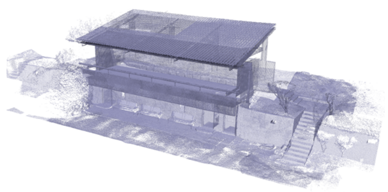
sition of photographs, can typically be completed within a day under favourable conditions, particularly with regard to weather. The computational time required for point cloud generation was 27 hours and 30 minutes on a high-end personal computer. This processing time does not include the human labour involved in preparing photographs, setting calculation parameters, aligning, cleaning, calibrating, fine-tuning, and undertaking the various tasks necessary to produce the final point clouds and models.

The time required for these activities is highly dependent on the specific circumstances of the survey site and the desired quality of the output. In this instance, the human time investment was approximately equivalent to the computer's calculation time. Human effort was distributed across phases that corresponded with the computational processes, carried out in multiple "chunks" as well. The generation of the 3D model (restricted to the exterior) took an additional 9 hours, with each orthomosaic requiring a further hour to produce.

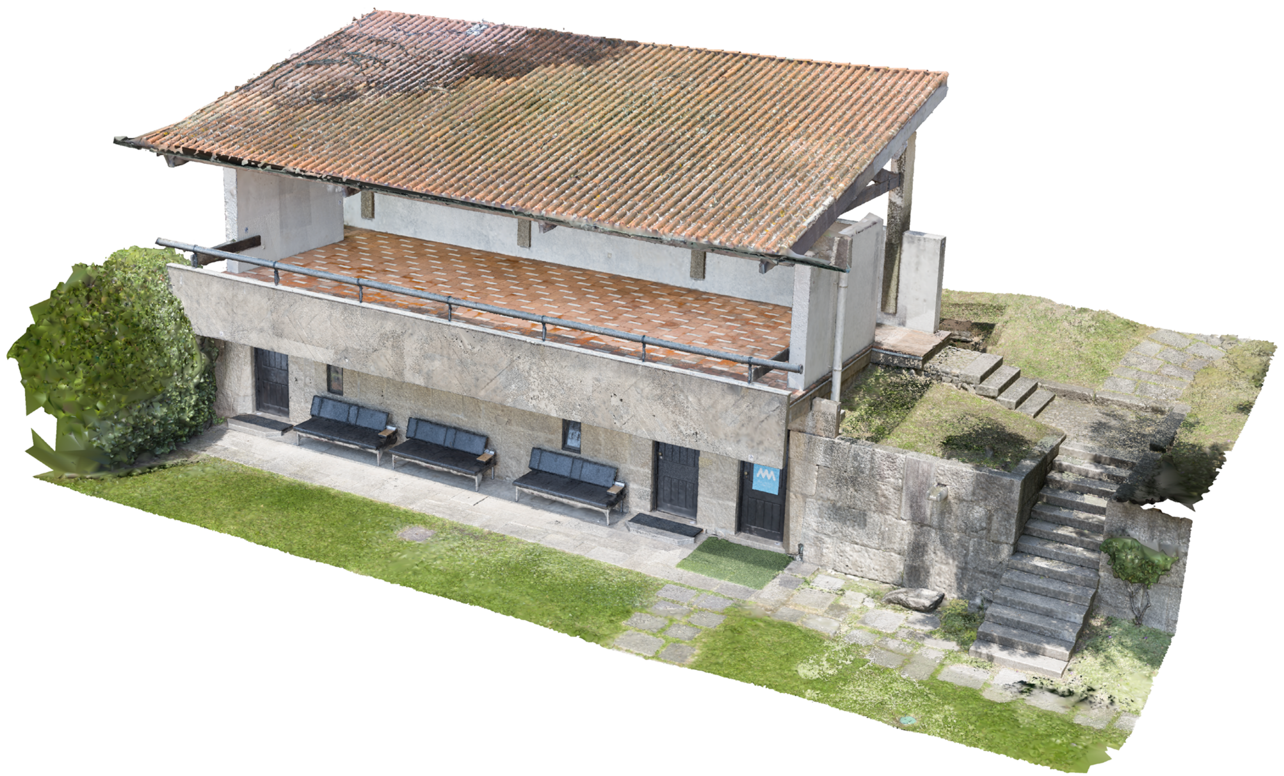
**Exploded axonometric model**

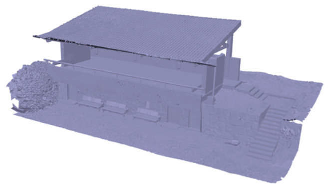


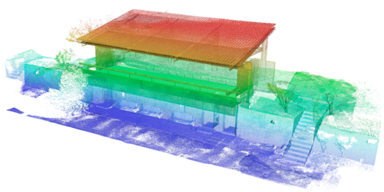
**3D model processing**

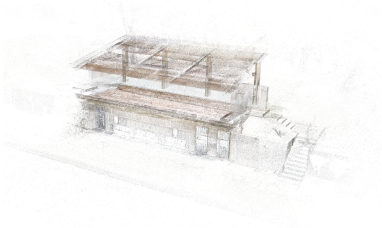


**Explore the 3D interactive model**









Tés site, Drone capture

Helt windmill in Tés

# 4 | CASE STUDIES - SNAP+ Surveys

## 4.2 | Helt Windmill in Tés, Veszprem county, Hungary

### General description

Gabor Palotas

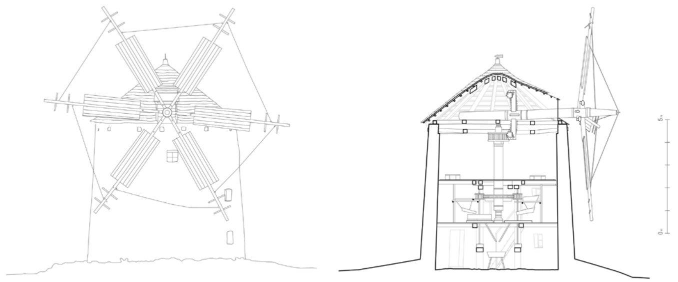
The Tés Plateau in Veszprém County, Hungary, has long been ideal for operating windmills due to its consistently windy climate and the lack of river water on its limestone surface. As a result, watermills were not a viable alternative, and with the advent of industrialisation in the 19th century, four windmills were built on the outskirts of Tés village, providing milling services for the local community. The prevailing wind direction on the ridge, which rises between 400 and 500 metres above sea level, is south-western (from Lake Balaton), but the windmill sails could be turned to face any direction, as the tops of the structures were designed to rotate around a vertical axis. This type of windmill is known as "Dutch" in Hungary, although by the time they were built, the "tower type" was no longer in fashion in the Netherlands, where "smock mills", a more economical and practical solution for wetlands, had become popular. However, tower windmills had been widely used across Europe since the 13th century due to their relative ease of construction and operation compared to older models like post and hollow-post mills. The windmills at Tés are unique in several respects. While most windmills have four sails, or eight in the Mediterranean region, the tower mills of Tés were equipped with six. The materials used in their construction are also distinctive. Instead of using a traditional frame to hold sails or a system of slats, the sails of the Tés windmills were made from simple straight boards. Additionally, the towers were built from stone, which is somewhat unusual compared to other Hungarian windmills, which were more commonly constructed from brick.

Of the original four mills, only two have survived: the Ozi and Helt mills. The other two, Rotter and Vaszlav, were demolished after World War II. Their destruction began during the war when the caps, along with the shafts and sails, were removed so the towers could be used as military observation points. After the war, there was little interest in restoring the buildings, as they were seen as outdated technology. Consequently, the towers were dismantled, and the stones were repurposed for other uses in the village.

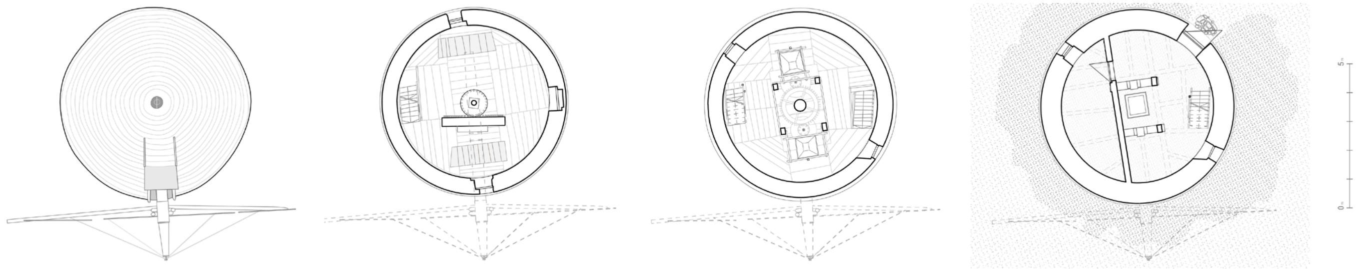
The Ozi mill, the youngest of the four, was built in 1924 by János Ozi, located 200 metres from the Helt mill. Though similar in appearance to the Helt mill, the Ozi mill is slightly smaller and has only one pair of grinding stones. It was primarily used for crushing nuts and grain to feed livestock and, to a lesser extent, for household consumption. Like the other mills, it was named after its last known owner and operated on a commission basis, with 8% of the milled grain being retained by the miller as payment for services rendered.

The Helt mill, built around 1840 by carpenter János Pircher, later came into the possession of József Helt, a master cartwright, whose family operated it for several generations, giving the mill its current name. This windmill could grind 400 kilograms of grain per day using two sets of grinding stones, although only one set was used at a time to prevent excessive vibration that could damage the mill's structure. The mill remained in operation until 1951 and, following recent restoration efforts, is still fully functional. It now operates as a museum and is registered as a vernacular industrial monument, owned by the State Asset Management Company (Állami Vagyonkezelő).

The windmill's tower is a three-storey structure built of limestone masonry, with its outer surface whitewashed. The cylindrical tower tapers towards the top, creating a truncated cone shape. The walls are nearly one metre thick at the base but become significantly thinner near the roof. The conical cap, covered in wooden shingles, includes a dormer that projects the wooden windshaft holding the six sails. The cap, made of pine wood, rotates 360 degrees on a steel track using 18 roller bearings. Initially, the cap could only be turned from outside, but a later modification allowed two people to rotate it from inside, standing on small platforms on the third floor. The miller could determine wind direction from inside with the help of a weathercock mounted under the roof. The floors are wooden, supported by beams and covered with planks. The windshaft and upright shaft are made of oak. The wind turns the sails and windshaft in an anticlockwise direction. If the wind was too weak, extra boards could be added to the sails to increase their surface area, while boards could be removed when less force was needed. With additional boards, the diameter of the sails could reach up to 12 metres. The windshaft drives the upright shaft through the cogged brake wheel and wallower, with a gear ratio of roughly 1:10, meaning for every 8-10 turns of the windshaft, the upright shaft rotates 110 times. On the second floor, the great spur wheel transfers power to the stone nuts, turning the grindstones at an even higher speed. However, only one set of stones would operate at a time, as using both would cause excessive shaking and require frequent repairs. The milling process involved pouring grain into a hopper that led the grain between the grinding stones. Once milled, the flour would pass through a hole in the floor to the ground level, where it could be bagged. If finer flour was needed, the distance between the stones could be adjusted, or the grain could be milled a second time. Regular maintenance was required to keep the stones rough and effective, with chiselling performed every 2-3 days.



## 2D Architectural drawings



## Survey report and data processing

Maj Juvanec

The windmills in Tes are located just outside the village, situated in open fields where wind is abundant. As these windmills are commercial vernacular buildings designed primarily for functionality rather than lighting, windows are both small and scarce, making the interior of the windmill quite dark. Additionally, the windmills' separation from the village and their reliance on wind as a power source means there is no access to electricity for artificial lighting within the building. The interior spaces are small, with many mechanisms centrally positioned. Consequently, interior photographs were captured using a 360-degree camera, which was mounted on a tripod. This setup allowed for longer exposures and reduced the need for additional lighting. Given the limited and circular nature of the space inside the windmill, the 360-degree camera offered a more comprehensive capture of the environment, minimising the risk of missing areas, which is more likely when using a conventional camera. The 360-degree field of view required fewer camera positions, which compensated for the additional time needed to move the tripod and ensure the photographer was not captured in the image.

The exterior of the windmill was ideally suited for drone photography, as there were no obstructions surrounding the structure. Even moderate wind conditions did not pose a challenge for the drone's operation.

The height of the building and the limited number of windows made it difficult to place targets for accurate alignment, posing additional challenges for integrating the interior and exterior chunks, as well as for calibration.

Control measurements on circular buildings, in particular, can be more complex. The exterior chunk was created from 399 drone-captured photographs. Internally, the windmill was divided into four chunks: one for the first and second floors, and two for the separate rooms on the ground floor. Using the 360-degree camera, 303 photographs were taken to cover all interior chunks—a significantly smaller number than would have been required with a conventional camera. The exterior point cloud consists of 29,987,000 points, while the combined interior point cloud contains 186,485,000 points after cleaning and optimisation. The final polygonal 3D model comprises 9,805,000 faces (triangles).

## Tés field survey

Exploded axonometric model

3D model processing

Explore the 3D interactive model

Chidea's site, Drone capture

Wooden Church of Chidea

# 4 | CASE STUDIES - SNAP+ Surveys

## 4.3 | Wooden Church of Chidea, Cluj-County, Romania

### General description

**Radu Stoica & Sorana Vlad**

Wooden construction was predominant in Romania until the early 20th century, with both secular and religious buildings following this tradition. From the 18th century onward, however, this method was increasingly abandoned, a trend that accelerated in the 19th and early 20th centuries. Several factors contributed to this shift, including the deteriorating state of wooden buildings, their small size, and the impact of invasions, occupations, and wars over time. As a result, wood was replaced by more durable materials like stone and brick, leading to the gradual loss of traditional woodworking knowledge and techniques. The understanding of wood's long-term performance as a building material also faded.

In rural Romania, the construction of churches was a communal effort, with all members of the community contributing to both the building and decoration. Churches were not only spaces of worship but also centres for community life, where the act of building together helped strengthen social bonds. Despite the decline in wooden construction, many wooden churches have survived, particularly in the Maramureș region, home to the most famous examples now listed as UNESCO World Heritage Sites. While these churches share certain similarities in appearance, regional variations in their plans and elevations reflect local traditions.

Architecturally, these wooden churches share several key features. The construction method typically involved horizontal logs stacked and joined at the corners using techniques that varied by region, craft, and tradition. The nave was often covered by a vaulted ceiling supported by wooden beams, though in rarer cases, plastered wattle was used. Inside, these churches featured artistic components such as religious furniture, service objects, an iconostasis, and murals, which contributed to their sacred atmosphere.

One such wooden church is located in the small village of Chidea (Kide in Hungarian), part of the commune of Vultureni in Cluj County. Chidea, first documented in 1332, is a small village that developed along a stream and extends along the northern side of a hill. The village is rich in architectural heritage, preserving a relatively homogeneous appearance with stone houses and stone boundary walls. Chidea's cultural diversity is further reflected in its four places of worship: a Calvinist Reformed Church, a Roman Catholic Church, a Unitarian Church, and an Orthodox Church, which was originally Greek Catholic.

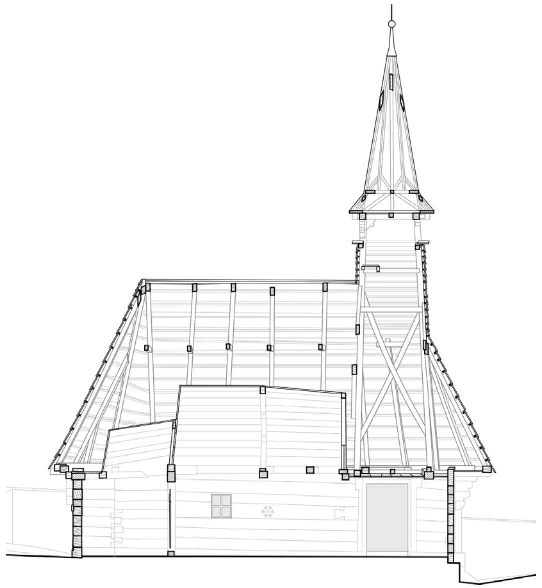
The Orthodox Church of Chidea, the subject of a photogrammetric survey, is listed as a historical monument. Dedicated to St. George, the church now stands on one of the village's main streets. However, it was originally located in the Orthodox cemetery and was later relocated to its current position. Community records from 1764 detail contributions toward the church's construction, suggesting this as the likely date of completion, with an inscription on the altar vault indicating a renovation in 1902.

The church's tall wooden silhouette is visible from the street, rising behind a stone wall typical of Chidea's landscape. The structure is accessed through a traditional wooden gate. Rectangular in plan, with a polygonal recessed apse—one of only 18 such examples in Cluj County—the church entrance is decorated with traditional elements and preceded by a porch that provides shelter for parishioners. The church's frame consists of beams intricately joined at the corners, with eaves that cover the notched cantilevers. Inside, the nave, encompassing both the pronaos and naos, is separated from the polygonal altar by an iconostasis. A vaulted porch leads to a narrow bell tower with a polygonal frieze, rising from the roof and adding to the structure's distinctive character.

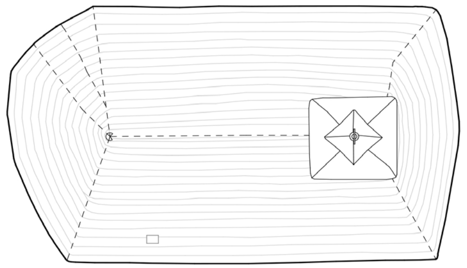
Several archaic elements further define the church's unique design, such as the altar with its two entrances and a skylight on the southern side shaped as a cross with six clover leaves. Decorative motifs, including the rope, wolf tooth, and rosette, are carved into the entrance frame, wall beams, vault supports, and the beam of the iconostasis, reflecting the artistic traditions of the time.

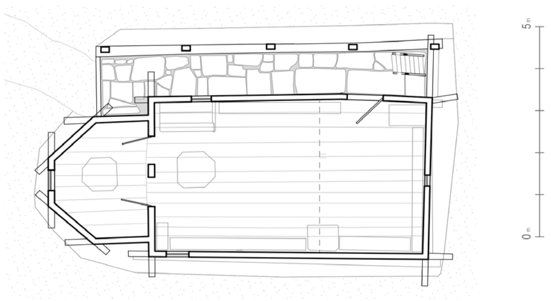
The church's furniture is particularly notable, especially a table carved by sculptor David Sipos. Distinguished by its carved vegetal motifs on the supporting column and the presence of holes, it may have originally been part of a pulpit.

In conclusion, the Orthodox Church of Chidea, with its modest yet intricate design, stands as a significant example of Romania's wooden architectural heritage. Its presence within the village, alongside other religious and secular buildings, preserves the legacy of communal craftsmanship and reflects the region's historical and cultural diversity.



2D Architectural drawings





### Survey report and data processing

**Maj Juvanec**

The church is located in the centre of the village, enclosed by its own stone wall. The focus of the photogrammetric survey was the church and its immediate surroundings, up to the boundary formed by the stone wall. The church is still occasionally in use, containing various small objects required for religious services, along with many traditional religious decorations. Preparing the site for the survey was challenging: all small objects not directly related to religious services were removed, while decorations, including numerous paintings, curtains, and similar elements, were left in place. Although these partially obscured views of the building, they were deemed essential to the church's authenticity and were therefore included in the photogrammetry.

The church of Chidea is entirely built of wood, with traditional joints. These joints are in fact the main feature of the building, therefore the model, in order to accurately reproduce the current state of the monument, was made element by element, highlighting the woodworking technique. (Chidea processes images).

Drone photography was used for the exterior, while a standard camera was employed for the interior. Due to the low light levels inside the church, reflectors were used to illuminate the richly decorated interior walls. Above the main space is a small utility attic, accessible via a steep ladder and a narrow hatch. The attic has no windows, and the space between the ceiling and the wooden roof is limited. The low light, confined space, and partially deteriorating materials posed significant challenges for photography. Consequently, some inaccessible areas, including parts of the tower's interior, are missing from the point cloud, leading to reduced accuracy in those sections compared to the rest of the church. A total of 1,885 photographs were taken, producing a point cloud with 2,215,971,000 points, of which 1,307,110,000 points are from the exterior. To align the various sections (exterior, main church room, back room, attic, and bell tower) and calibrate the model, 31 targets were placed on the building, and 37 scale bar measurements were taken on-site.

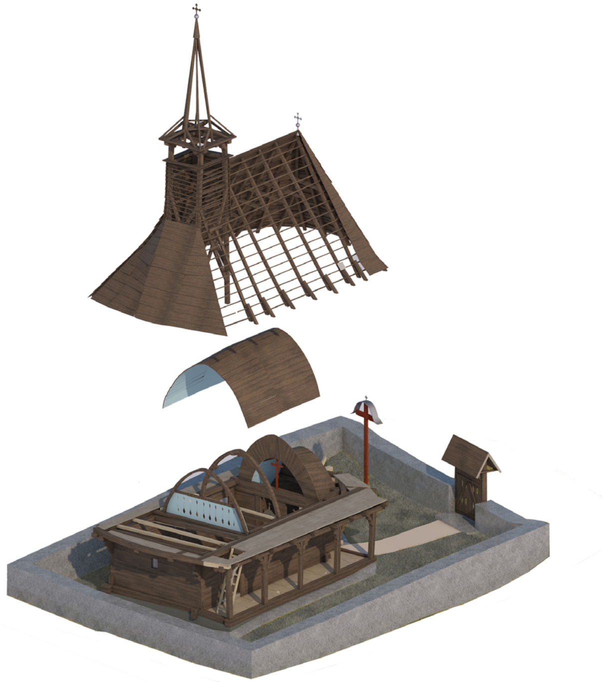
The maximum distance between targets was 9 metres. The error margin for the scale bars was less than 1 cm, corresponding to the typical inaccuracy of on-site human measurements for vernacular structures. Since the point cloud sections were relatively similar in size, and none were exceptionally large, the point cloud calculation took just over

Chidea's field survey

four hours. The church's exterior polygonal 3D model, consisting of 2,437,000 faces, took slightly more than six hours to compute from the previously generated point cloud. The entire project occupies 515 GB of storage. The photogrammetry software files (with a complete backup) take up 300 GB (including point clouds, depth maps, dense clouds, thumbnails, etc.).

The compressed TIFF photographs require 120 GB (excluding the equivalent amount of space for the RAW format images). The generated point clouds occupy 90 GB, while the 3D models take up an additional 100 MB. Each orthomosaic, with a resolution of 1 pixel per 1 mm, requires around 100 MB in lossless compressed TIFF format.

Exploded axonometric model



3D model processing

Explore the 3D interactive model

Trenta's site, drone capture

Saw mill at Trenta

# 4 | CASE STUDIES - SURVEYS OF SNAP+

## 4.4 |Saw Mill at Trenta, Slovenia

### General description

Radu Stoica & Sorana Vlad

A water-powered sawmill is a mechanical device used for sawing wood, requiring proximity to a stream with a strong current to generate the necessary power for operating the saw blades. These sawmills rely on water energy, harnessed through waterwheels, to drive the sawing mechanism. There are two main types of saws used in water-powered mills: the rotating circular saw and the 'Venetian saw,' which features longitudinal blades that move up and down.

The efficiency of the waterwheel depends on its type and the characteristics of the water flow. Undershot waterwheels are generally slower, while overshot waterwheels, which require a chute or millrace to direct water to the wheel, are more powerful. In regions where water flow is insufficient, water can be stored behind a dam to allow intermittent operation. For an overshot waterwheel, only a narrow wheel can be employed to maintain efficiency.

Circular saws are typically used for cutting smaller beams and planks, whereas 'Venetian saws' are more suitable for processing larger logs. Larger sawmills may be equipped with multiple blades—some using up to six blades—allowing them to cut seven boards simultaneously. Such large sawmills require extensive space for both the saw sheds and for handling logs, beams, and boards. The use of pulleys and transport mechanisms integrated into the mill's structure greatly assists the sawyer in moving heavy materials efficiently.

One example of a water-powered Venetian saw, known as Rogar's saw, is located on the right bank of the Krajcarca Brook, near its confluence with the Soča River in the Trenta Valley, within the Julian Alps. It is officially recognised as a cultural monument in Slovenia. The original sawmill burned down in 1902 but was rebuilt in 1908. After severe flooding in 1962, the mill was reconstructed in 1979 and operated until 1993. Minor damage from the 1998 earthquake was repaired, and further restorations were carried out by the Triglav National Park in 1999, with state funding in 2005. The chutes were replaced in 2006 due to diminishing water flow.

Slovenia features two types of water-driven sawmills, both with horizontal-axis waterwheels. The first type uses large wheels, sometimes several metres in diameter, suited for slow-moving streams. The second type, as seen in Rogar's saw, employs smaller waterwheels, typically 60 to 70 cm in diameter, which rotate at a higher speed. These smaller wheels require a more complex transmission system, often relying on textile belts, while larger wheels generally use cogwheels. In Rogar's saw, the small waterwheel measures 60 cm in diameter and 120 cm in length, and the transmission system is driven by belts.

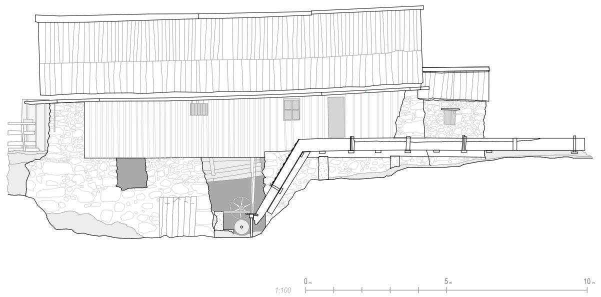
This sawmill has a single blade, and it takes approximately 15 minutes to saw through a log. The driving mechanism operates via metal wheels and belts, while most other components of the saw are made from robust, locally sourced timber. The saw blade, handcrafted by a local blacksmith, has a conical cross-section and requires regular hand-grinding to maintain its sharpness.

The sawmill building is a combination of stone and wood. The stone walls were originally constructed using the dry-stone technique, later sealed with lime mortar after World War II. These stone walls are integrated with a wooden framework, consisting of vertical boards and horizontal laths, forming infill panels. The windows, made from wood with small glass panes, are set into this wooden structure. The main entrance, located on the front of the building, features double doors that facilitate the handling of large tree trunks. The trunks are placed on a wooden cart, which is driven by a windlass connected to the main drive system. A six-metre long beam enables horizontal oscillation of the blade, improving the sawing process.

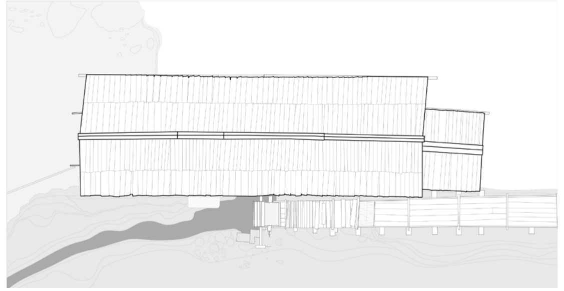
The roof is a triangular structure covered with wooden boards. In the Julian Alps, roofs are traditionally covered with handmade wooden shingles, but for the sawmill, pine boards—sawn at home—are more practical and cost-effective. These pine boards are lighter and allow for easier maintenance by local workers. The roof's structural beams are a crucial part of the mill, providing stability to the entire building. Originally, the wooden components were fastened with wooden pins, although subsequent restorations replaced some with iron or steel nails. Over time, the untreated pinewood naturally weathers, turning from yellow to a light grey.

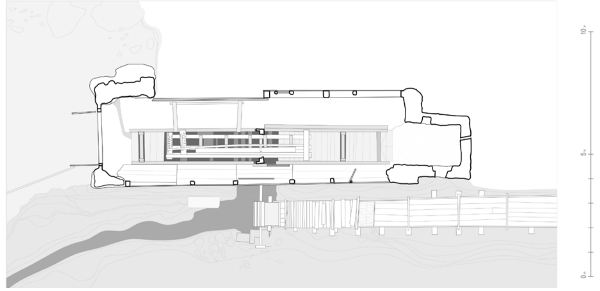
At the rear of the sawmill, there is an attached small room for the sawyer, resembling a chapel, with a separate roof and smaller area compared to the main building.

Several centuries ago, thousands of water-powered sawmills like this one existed across Slovenia. However, many streams dried up following World War I, and by 1950, these sawmills ceased operation due to the shift from individual ownership to collective economic systems. Today, Rogar's saw is one of the few surviving examples of this once-common technology. Though primarily preserved as a cultural monument, it remains fully functional, offering a glimpse into traditional woodcutting methods that sustained local communities for generations.



## 2D Architectural drawings





## Survey report and data processing

Maj Juvanec

The sawmill is situated by a stream at the edge of the village, in a relatively isolated position. Vegetation, including trees and riparian plants, grows close to the structure, partially obstructing a clear view of the building.

The functioning of the sawmill's mechanism implies water channelling, using a chute, which diverts water from the adjacent natural stream. However, since this channel extends for approximately 100 metres, only the section near the building was documented through photogrammetric surveying. The sawmill remains functional, and specialised tools used for manipulating logs and operating the saw were left in place and captured during the survey.

Inside the sawmill, 700 photographs were taken using a handheld DSLR camera. Artificial lighting was employed to ensure sufficient illumination, particularly in capturing the interior of the roof. Additionally, 482 exterior photographs were captured using a drone.

As the sawmill is located within Triglav National Park, a special permit was obtained from the park authorities to operate the drone.

To maintain consistency in the external photographs (and the subsequent 3D model), some drone images were taken with the drone held manually rather than in flight, to avoid the risk of collision with surrounding vegetation and to access confined spaces around the waterwheel and beneath the saw, where flying was not feasible.

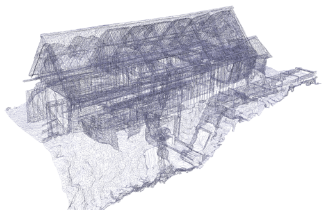
During the post-processing phase, high vegetation recorded during the survey was removed from the 3D model to enhance clarity and facilitate interpretation of the sawmill itself.

Low vegetation and terrain features were retained, as they are essential for understanding the building's placement within the landscape. In total, the point cloud consists of 2,149,326,000 points, and the mesh model comprises 17,630,000 faces.

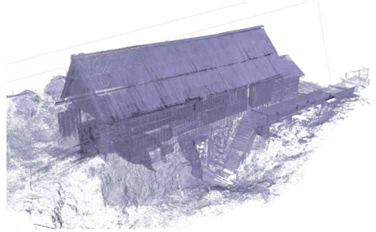
## Trenta´s field survey

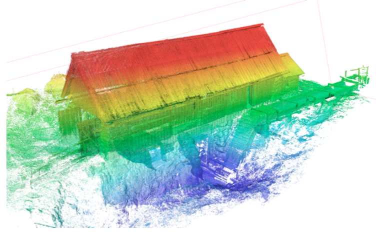
### Exploded axonometric model

### 3D model processing



### Explore the 3D interactive model





Trenta´s field survey

The present section presents a comparative analysis of the SNAP+ photogrammetric surveys focusing on three key dimensions: Context (accessibility, terrain, vegetation, lighting, and environmental constraints), Building Characteristics (geometry complexity, construction technology, physical constraints, and state of preservation), and Digital Processing (methodology, resolution, volume of information, final results, and 3D modelling approach). This analysis highlights both similarities and distinct challenges encountered across these case studies.

**1. Context: Accessibility, Terrain, Vegetation, Lighting, and Environmental Constraints**

Each survey site presented unique contextual challenges largely based on its specific environmental and situational factors. The Tennis Pavilion, positioned within an urban park, was surrounded by dense vegetation that not only obstructed views but also cast shadows on the structure, complicating image consistency and lighting uniformity. Handheld cameras were used in tandem with a monopod for height, supplemented by drone photography solely for the roof. The surrounding vegetation and relatively low height facilitated easy access, though care was needed to avoid damaging flora.

In contrast, the Tes Windmills were located in open, unobstructed fields, eliminating vegetation interference. However, the lack of interior lighting and absence of power sources due to the isolated location required innovative solutions; a 360-degree camera was employed on a tripod to maximise exposure and reduce lighting issues. The exterior presented minimal constraints, with the open terrain proving highly favourable for drone-based exterior imaging, even in moderate wind conditions.

The wooden Church was situated in the heart of the village, encircled by a stone wall. While not heavily vegetated, the confined and dimly lit interiors posed significant lighting challenges, necessitating the use of reflectors to illuminate its decorated walls. Additionally, limited access to certain sections, particularly the attic and tower, hindered complete visual capture, ultimately impacting the precision of these areas in the final point cloud. The Sawmill, positioned on the edge of a stream in Triglav National Park, was also surrounded by dense riparian vegetation. This required careful manual handling of the drone in vegetated sections to avoid damage and collision while capturing the structure's external geometry. The site's location within a national park required additional permissions, further adding to procedural complexity.

Side Elevations, Orthophoto

**2. Building Characteristics: Geometric Complexity, Construction Technology, Physical Constraints, and State of Preservation**

The Tennis Pavilion exemplifies a relatively simple rectangular geometry, albeit with subtle complexities due to surrounding greenery impacting photographic consistency. The pavilion's low height and straightforward form allowed for a comprehensive photogrammetric approach, but the building's location and interaction with its environment presented obstacles in achieving uniform lighting.

Conversely, the Tes Windmills offered a unique geometric form; their cylindrical shape with limited windows complicated interior chunk alignment. The circular configuration of interior mechanisms necessitated the use of a 360-degree camera to capture the full interior while minimising the number of camera positions. The windmills' vernacular construction and functional simplicity contrast sharply with the decorative complexity seen in other structures but posed a challenge due to limited available control points for alignment and calibration.

The wooden Church presented a different architectural complexity, with its decorated interior and structural intricacies, such as the attic and tower, which were challenging to access and document fully. The building's historical construction, combined with valuable religious artefacts and decorations, required that these items remain in situ. These decorations partially obstructed clear views but were essential to maintaining the building's authenticity, influencing photogrammetric clarity.

The Sawmill represented both geometric and operational complexity, with functional mechanisms and water channelling infrastructure that partially obstructed views. The presence of dense vegetation required selective clearing within the 3D model to enhance clarity. Additionally, the functional state of the sawmill introduced further constraints, as

all logging equipment and water channels had to be preserved and documented, complicating interior photogrammetry due to spatial constraints and light inconsistencies.

### 3. Digital Processing: Methodology, Resolution, volume of Information, Final Outcome, and 3D Modellingg

Each survey adopted a tailored approach to point cloud segmentation and data processing to address the unique challenges posed by each structure's context and characteristics. For the Tennis Pavilion, the extensive 1,370-photo dataset was processed into seven distinct chunks, each representing different sections of the building and its surroundings. This high-resolution data produced a comprehensive 3,077,070,000-point cloud that required extensive post-processing due to the pervasive vegetation. Processing took approximately 27.5 hours on a high-performance PC, with an additional nine hours to create the 3D model's external view.

The Tes Windmills involved a different approach due to their cylindrical form. With a smaller 360-degree image set for the interior, the total photo count was reduced to 702 (303 interior and 399 exterior). Despite the lower number of images, careful alignment was required to compensate for the limited control points. The exterior point cloud, comprising 29,987,000 points, was significantly smaller compared to other structures, aligning with the simpler geometry. The final 3D model, featuring 9,805,000 faces, reflects the modest complexity and specific capture strategy.

For the Wooden Church, 1,885 photographs were divided across five sections, with external and internal chunks carefully aligned using 31 targets and 37 scale bar measurements. The total point cloud was extensive, with 2,215,971,000 points, processed in just over four hours. Storage requirements were particularly high due to the ornate interior detail, resulting in a final project size of 515 GB.

The Sawmill's dataset included 1,182 photographs, producing a point cloud of 2,149,326,000 points. During processing, high vegetation was digitally removed to enhance the model's clarity, while low vegetation and terrain details were preserved to retain contextual accuracy. The final 3D mesh consisted of 17,630,000 faces, reflecting the model's high detail and the necessity of manual drone operation in vegetated areas.

### Comparative Insights

In summary, each structure's survey required distinct methodological adjustments to accommodate unique environmental and architectural challenges. The Tennis Pavilion and Wooden Church surveys were influenced heavily by their surrounding environment and internal complexity, while the Tes Windmills and Sawmill required tailored approaches to address constraints related to their circular and functional designs. The Tennis Pavilion and Sawmill also required significant post-processing to manage vegetation interference, whereas the Village Church necessitated elaborate file management due to its decorative intricacies.

The contrasts in geometry—from the simplicity of the Tennis Pavilion to the circular intricacies of the windmill and the detailed ornaments of the church—required a range of equipment, from conventional and 360-degree cameras to drones. Despite differing in complexity and size, the projects shared a commitment to preserving authentic details, balancing photogrammetric clarity with respect for the structures' contexts. The result is a rich set of detailed 3D models, each embodying the specific demands of their architectural form and environmental setting.

Explore the Survey synthesis table: Attachment 1 :

### SNAP+ equipment and tools

For handheld photography, the survey team resorted to a Nikon SLR D810 with 36-megapixel resolution and full frame (35.9 x 24 mm) CMOS, paired with ultra-wide-angle Nikkor 14-28 mm f/2.8 lenses. To minimise lenses distortion 28 mm zoom was always employed. High lenses aperture allowed working in low light situation. To extend the reach of camera remote trigger and monopod was frequently used. Photographs were saved in lossless RAW format to allow for post processing (mainly lightning adjustments) in Photoshop software, prior to photogrammetric processing.

Front Elevations, Orthophotos

For drone photography light-weight DJI Mini 3 pro was utilised, with weight under 250 grams being compliant with European legislation for the easiest operations. It's equipped with gimbal mounted 48-megapixel camera, saving photographs in RAW format for further post-production.

Ricoh Theta X 360 camera was used in sawmill case study, mounted on special (almost invisible) tripod. Two fish-eye lenses cameras produce 11-megapixel 360-degree photographs.

Photographic calculations were made with Agisoft Metashape Pro software (version 2.1.3 at the end of the project). Runing on standard, but a little build up – but by now also a little out-of-date, personal computer (two Intel Xenon processor running at 3,5 GHz each – altogether 16 cores, 128 GB of RAM, Nvidia Quadro graphical card with its own 24 GM of RAM).

Architectural modelling from point clouds was made using ArchiCAD software.

Table: Manual survey vs Photogrammetry survey

| **Requirements** | **manual** | **photogrammetry** |
|---|---|---|
| equipment | • tape meter<br>• laser meter<br>• paper | • tape meter<br>• laser meter<br>• camera optional<br>• water lever<br>• drone |
| typical time required on site | • measurements 1/2 day<br>• hand draw requirements, time consuming | • preparing the scene 1/4 day (if needed)<br>• photographing 1/4 day |
| precision | • dependable on time spent on site (more time/higher details) | • dependable on equipment quality, not on time spend |
| staff | • typically, two persons, at least one with basic survey knowledge | • typically, one person, with basic photo-graphical and photogrammetric survey knowledge |
| level of details | • low | • high |
| abstraction | • made on site by surveying personnel | • none |
| survey accessibility | • where humans can safely go | • where humans can safely go<br>• where camera can be located (using accessories: monopod, giraffe, ...)<br>• where drone can safely fly |
| rubbish | • easily omitted by human | • recorded on survey (or more time needed for preparing the scene) |
| possible errors | • medium, random (human error) | • low, systematic |
| conditions (weather, other obstacles, ...) | • resilient | • sensitive |

# 6 | GENERAL CONSIDERATIONS

Ana Lima, Gilberto Duarte Carlos & Maj Juvanec

**Ready to use Photogrammetry?**

**Photogrammetry in Architectural Surveying: A synthesis of applications, advantages, and potentials**

Photogrammetry has emerged as a transformative technique within architectural surveying, enhancing traditional methods with its ability to capture and process data in three dimensions (3D). As a non-destructive, remote sensing technology, photogrammetry allows for the documentation of buildings and structures with unparalleled detail. Compared to conventional surveying, photogrammetry offers significant advantages, particularly in creating 3D models and capturing texture details that are essential for accurately representing materials. These qualities make photogrammetry helpful in fields requiring detailed visual representations, from architecture and archaeology to heritage management, civil engineering and environmental monitoring.

One of the principal strengths of photogrammetry lies in its non-invasive approach, which makes it possible to capture highly detailed information without disturbing the surveyed objects or environments. This quality is essential in sensitive settings, such as natural habitats, historical sites, and vulnerable environments where conventional methods may be invasive or unsafe. In such cases, photogrammetry minimizes ecological and structural impact, preserving both natural and built environments for future study.

Applications in Complex and Remote Environments

Photogrammetry excels in capturing complex geometries and irregular structures, particularly in hard-to-reach or hazardous areas. It has proven effective in documenting intricate architectural details, such as those found in historical and vernacular buildings, where precise documentation of form and texture is vital for conservation and reconstruction. Additionally, photogrammetry is frequently used in challenging environments, such as mountainous regions, dense forests, underwater sites, and even areas affected by natural disasters. In these contexts, it enables safe, remote data acquisition, which is particularly valuable for assessing structural integrity and material conditions in places that may pose risks to human health, including areas exposed to radiation, toxins, or infectious agents.

Precision and Efficiency in Data Acquisition

Photogrammetric methods are not only precise but also efficient, making them suitable for real-time decision-making in critical scenarios. When using high-resolution cameras or mobile devices, photogrammetry achieves impressive precision. Advanced setups can capture data with resolutions up to 100 microns, rivalling even the most sophisticated 3D scanning systems. This precision is particularly beneficial in fields requiring high levels of detail, such as medicine, forensic analysis, and industrial inspection.

The growing accessibility of photogrammetric devices, often equipped with automated features, has further streamlined the surveying process. Many modern devices enable real-time 3D mesh generation, providing immediate feedback during scanning and simplifying workflows. Various applications allow for easy capture, scaling, and georeferencing of 3D models, making photogrammetry more user-friendly and accessible for a wider audience, including professionals and students alike.

2D and 3D Registration Capabilities

A key capability of photogrammetry is its ability to convert two-dimensional (2D) photographs into detailed 3D models, accurately capturing both the geometry and textures of surveyed objects. By overlapping multiple images from different angles, photogrammetry creates accurate models that faithfully represent the dimensions, colour, and material properties of the original structure. This process is essential in areas such as architectural conservation, where an exact visual and spatial replication is required to monitor deformations or alterations in historic structures. Additionally, the technology's capability for automatic data processing allows for quick and precise monitoring of civil infrastructures, including dams, tunnels, and bridges, as well as for analyzing environmental changes, such as in forest ecosystems and coastal zones.

Expanding Applications and Future Directions

The versatility of photogrammetry continues to drive its adoption across a variety of fields. In architecture, engineering, and construction, photogrammetry enhances the design and restoration processes, while in urban planning, it aids in terrain analysis, flood modeling, and land development. In more specialized areas, such as nuclear power plant inspection, photogrammetry minimizes human exposure to hazardous conditions by capturing data remotely. The technology is also finding applications in medicine for reconstructing anatomical models, in underwater archaeology for documenting shipwrecks, and in criminology for visualizing crime scenes in 3D.

Advancements in computational power and sensor technologies are likely to further enhance the accuracy and applicability of photogrammetry. The integration of laser scanning and photogrammetry is expected to improve data capture precision, creating hybrid methods that streamline workflows and expand the scope of applications in 3D modeling.

## Advantages of Photogrammetry

1. Non-invasive technology.
2. Ability to access remote and hard-to-reach locations.
3. Speed and precision in data acquisition.
4. High accessibility and user-friendly applications.
5. 2D and 3D registration capabilities.
6. Simultaneous capture of geometry and object properties.
7. Automatic and real-time data processing.
8. Effective data capture at macro and micro scales.
9. Increased accuracy and resolution with accessible devices.
10. Growing potential in various industries and emerging fields.

**Remember!**

**This combination of non-invasive capabilities, accessibility, and precision underscores the value of photogrammetry as a vital tool in modern surveying, making it an ideal choice for students and professionals working on complex architectural and environmental projects.**

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