SEE MEASURE UNDERSTAND

High-precision measurements in aerial images

WITH **THE** WEBTOOL FOR PHOTOGRAMMETRY

THE MEASUREE

Whitepaper

2024

About the author

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The AVT Group has been working with combined vertical and oblique cameras (multi-head or multi-perspective cameras) since 2015. Right at the beginning of this activity, the need for a proprietary software solution for working with images from multi-head camera systems was recognized. This led to the development of the desktop tool "Geobly" together with the Fondazione Bruno Kessler (FBK) in Trento. Due to numerous customer requests, a new browser-based development of Geobly was started in 2021. The functionality of this new tool, which was given the name " MEASUREE", goes far beyond the original concept. Using MEASUREE, this white paper presents the most important properties of combined vertical and oblique flights.

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Overview

The immense added value for users of aerial image data that comes from the addition of oblique images cannot be overestimated. New application possibilities are constantly being developed and presented, particularly in the administration of cities and regions and their development into **smart cities** and **smart regions**.

Customers who have once recognized the advantages of oblique images no longer want to do without them in future projects: A moderate increase in costs is offset by a much greater additional benefit from the additional oblique perspectives - you literally constantly gain new insights in your daily work. Ultimately, it is only through oblique images that a "**digital twin**" that lives up to this term is possible.

With this white paper we would like to present MEASUREE as an ideal tool for working with oblique air and nadir images.

The text is divided into five chapters:

Chapter 1 (page 4) provides an overview of the most important applications of (oblique) aerial images.

Chapter 2 explains frequently used terms in photogrammetry (page 9). This section can be skipped by experts in this field.

Chapter 3 (page 18) deals with various measurement methods using aerial images and Chapter 4 (page 23) introduces the functional overview of MEASUREE.

The final chapter 5 (page 32) contains a brief introduction to using MEASUREE with some example images.

Introduction

Aerial and satellite images have found their way into many areas of our daily lives in recent years. Digital globes have almost completely replaced printed maps and atlases. Every modern smartphone offers position-based apps such as navigation services, and the data required for this comes largely from aerial or satellite image evaluations.

This white paper deals primarily with the use of aerial images from manned or unmanned aircraft in the municipal sector; however, most descriptions and findings can also be applied to satellite images in a very similar way.

One of the greatest advantages of aerial image data is that the entire area (e.g. a city) is shown in an (almost) completely **homogeneous state**, since the recording takes only a very short time compared to ground-based recordings. For example, recording a large city such as Vienna (approx. two million inhabitants, area size around 600 km^2) with a ground resolution (*Ground Sampling Distance*, GSD) of 5 to 10 cm per pixel takes less than 10 hours. Modern sensor systems for manned flights allow resolutions of up to 2 cm or better, and drone-based recordings even penetrate into the subcentimeter range. In contrast, high-quality satellite images are limited to resolutions in the decimeter range due to the recording geometry and atmospheric influences.

Aerial images are a very important means of **documenting nature or residential areas** on a known date and are also often used as an objective means of clarifying legal issues such as border disputes. Especially in times of rapid global warming and the associated growing challenges for urban areas (overheating, switching to renewable energies, increasing building efficiency), aerial images are becoming immensely important. Not only optical images but also thermal infrared (TIR) and hyperspectral (HS) images are used.

The **most important applications** of aerial images include:

- **Local, urban and regional planning**: production of basic data for a wide range of planning measures, superimposing models of planned buildings or other structures with aerial images
- **Inspection and assessment** of existing buildings: Checking compliance with building permits (height, volume, extensions, outbuildings, swimming pools), suitability of buildings (roof and facade areas) for greening or for equipping with solar elements (photovoltaic or thermal solar panels)
- **Municipal supply**: Inventory of the visible infrastructure of drinking water supply and wastewater disposal (e.g. water valves, shafts, inlet grilles, trenches), power supply (e.g. substations, transformers, distribution boxes, lines) and other above-ground supply facilities (e.g. district heating, gas)
- **Road administration**: condition of traffic areas (roads, parking lots), inventory (e.g. quantity of floor markings to be renewed)
- **Green space**: assessment of the condition of natural or near-natural zones in the public and private sector (without the need to enter these areas), e.g. grass areas (mowing, fertilizing), hedges (cutting), trees (condition, cutting, care, prescribed replanting after construction work)
- **Environmental issues**: sealing density (surface drainage, summer overheating), noise propagation and fresh air supply (simulation using 3D building or city models)
- **Geometry-based tasks**: surveying, route planning and navigation

All of these applications require one or more **basic functions**:

- **Viewing** an area of interest without having to visit it, preferably from several perspectives (sequential or synchronous), see Fig. Fig. 1
- **Understanding** spatial relationships: orders of magnitude, relations, topology
- **Measurement** of simple geometric quantities: 2D and 3D distances (e.g. length of an object, distances or height differences between objects), surface areas of closed polygons (horizontal or on the surface), spatial orientation of inclined planes (compass direction, angle of inclination)
- **3D mapping** of individual objects or entire groups of objects

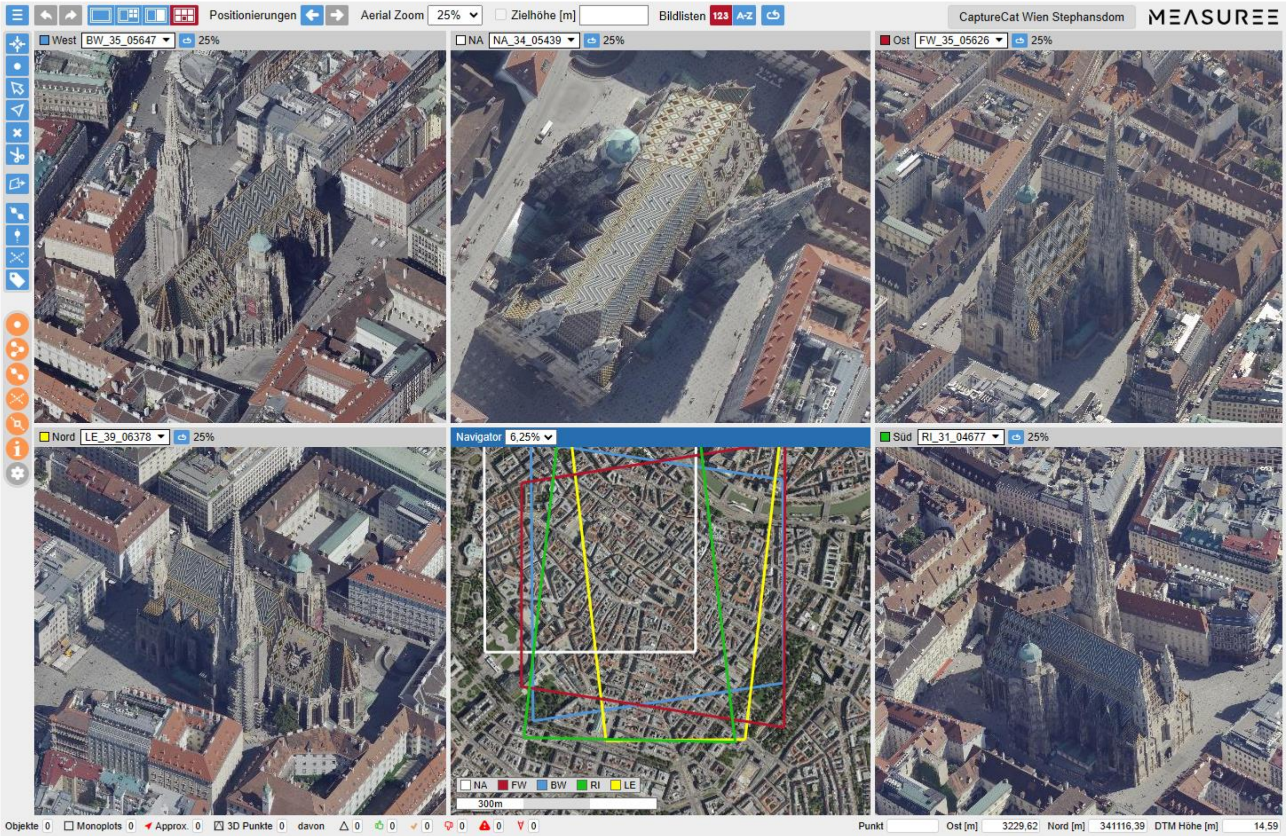


Fig. 1: St. Stephen's Cathedral in Vienna (2020) from different (oblique) image perspectives in MEASUREE

A complete mapping and hierarchical modeling of the above-mentioned objects involves a great deal of human labor. For this reason, such projects are often outsourced to low-wage countries, which is detrimental to value creation in the country itself and also allows external people or companies access to potentially sensitive public administration data.

In addition, in many cases a complete inventory is not even required. Therefore, especially for specific (and therefore often small-scale) questions, it is much more sensible to give those people who need the data the opportunity to collect the data themselves in the level of detail that the application actually requires.

This paradigm shift can only take place sensibly if data collection is as low-threshold as possible. This means that the corresponding tool does **not require expert knowledge** (i.e. is easy and intuitive to use) and delivers correct results with controlled quality. Proof of the accuracy and controllability of the results are particularly necessary when legally binding statements such as (building) permits are issued on the basis of the geodata recorded in this way.

While vertically taken aerial images are already very widespread, **obliquely taken aerial images** are still relatively new in surveying and cartography. Oblique aerial images - or oblique images for short - are characterized by the fact that they make the three-dimensional structure of objects visible - especially when an object to be examined can be viewed from several perspectives at the same time (see Fig. 1).

However, there is still a lack of intuitive and efficient tools that can exploit the full potential that oblique images offer for answering spatial questions. MEASUREE fills precisely this gap by providing the required low-threshold access to oblique images - i.e. not reserved for (surveying) experts.

MEASUREE

The users contribute their technical expertise and MEASUREE enables them to solve their task in a simple and intuitive way using aerial images. In this way, urban environments in particular can be viewed from several angles at the same time and unusual, often very informative insights into spatial relationships can be gained.

Simple measurements such as distances, lengths, height differences or surface areas can be carried out quickly and easily even by inexperienced users. But MEASUREE also offers experts a wealth of options for highly accurate and reliable mapping and 3D modeling of complex objects and scenes as well as for the quality assurance of 3D data sets. Different flights of the same area (e.g. from different flight years or with other sensors such as thermal cameras) can be combined, compared and "synchronized". As a result, the understanding of the natural and man-made changes to our living space develops as if by itself.

Thanks to the **web-based implementation** of MEASUREE, users only need a conventional web browser to start working with the vertical and oblique images from a flight. It also does not require any special and often expensive hardware, as is typically required in "classic" photogrammetry (synchronous stereoscopic measurement) - a standard computer is completely sufficient.

One of the major challenges with combined vertical and oblique image flights is the very large amount of data (depending on the size of the area, often in the double-digit terabyte range) and the lack of clarity of the data set, especially with high-resolution and highly overlapping flight data sets. MEASUREE addresses this problem through effective image compression, tiling and image pyramiding (storing the images in several resolution levels, which are loaded as needed depending on the zoom level when viewing them) as well as through very elegant sorting processes. In this way, the time-consuming search for the images most suitable for a task is almost completely relieved of the user.

Great attention was paid to the **intuitive** and therefore very **user-friendly** operation of the software through an efficient and clearly designed graphical user interface (GUI). The conception and development of MEASUREE also included specialist expertise from the field of user experience design (UX design) in order to make operation simple and effective without requiring any special prior knowledge or complex training of the users.

Terms of Photogrammetry

This section explains terms that are important for understanding this document. Most of these are probably very familiar to people who have experience working with geodata and/or aerial images. This chapter is therefore aimed primarily at those readers who want to learn the most important technical terms in photogrammetry. Photogrammetry experts can safely skip this section.

Aerial image

Due to the central perspective that prevails in photographic images, an aerial image does not have a uniform image scale, as is known from plans and maps. As a result, closer objects are shown larger and more distant objects smaller.

The vast majority of aerial images for surveying and cartography were taken (almost) vertically in the past (**nadir image**). If the image is taken with a view that is significantly inclined to the nadir direction (angles between 35° and 45° are most common), it is referred to as an oblique aerial image or **oblique image** for short. Since the English term has also found its way into the daily work of photogrammetry in German-speaking countries, both terms are used synonymously in this white paper.

Due to the rapid development of camera technology over the last twenty years, oblique images are now increasingly being taken, especially for densely built-up urban areas. There are now **combined nadir and oblique camera systems** from all well-known camera manufacturers such as Vexcel Imaging, Leica/Hexagon, Phase One and IGI. One nadir and four oblique images are taken at each pre-planned trigger point. The oblique images usually have a uniform inclination and are photographed to the front, right, back and left in the direction of flight.

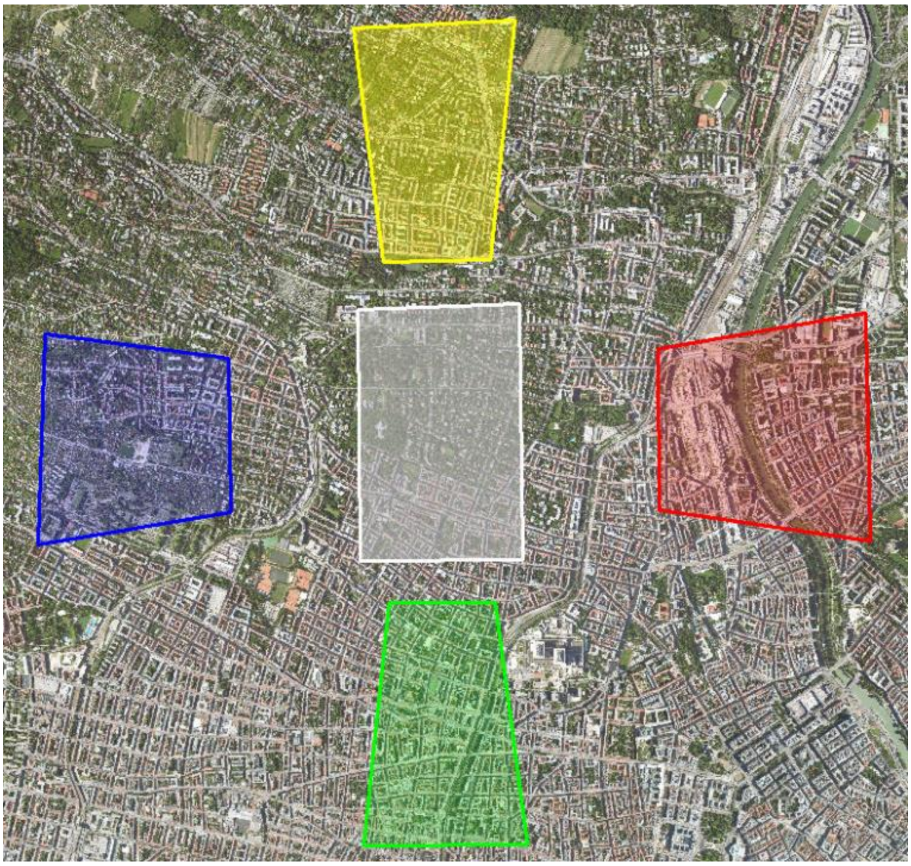


Fig. 2: Footprint of a Maltese Cross camera in the lowlands, flight direction from west to east. Nadir image = grey, oblique images = red (forward), green (right), blue (backward) and yellow (left).

Footprint

The polygon that limits the coverage of an aerial image on the earth's surface is called the "footprint". On flat terrain, the (idealized) footprint of a nadir image is a rectangle. The (idealized) footprints of the oblique images are trapezoidal on flat terrain. The combination of the five footprints of an image trigger point resembles a Maltese cross (see Fig. 2), which is why combined nadir and oblique image sensor systems are also called Maltese cross cameras. In hilly areas or mountains, the shape of the footprints deviates significantly from the trapezoidal shape (see Fig. 3).

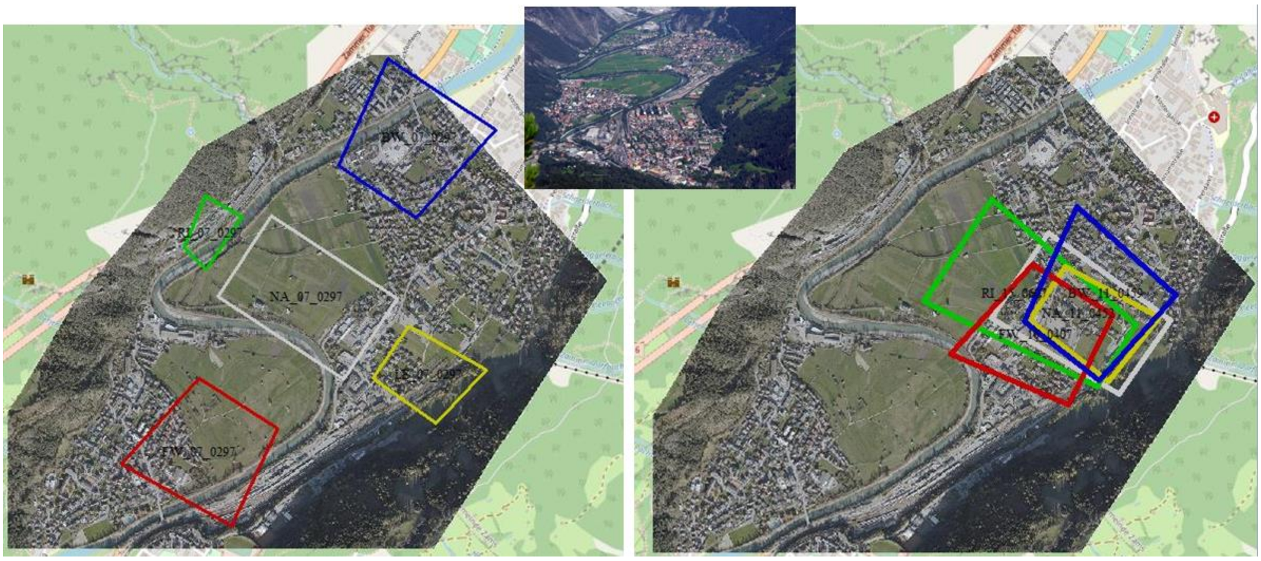


Fig. 3: Footprints of a Maltese Cross camera in the mountains (Zams, Tyrol, 2019). Left = all five images of one trigger point, right = images of all five cameras at one location (different trigger points).

Photogrammetry

Images that meet high requirements for geometric accuracy and color quality (radiometry) are suitable as "measurement images". (Aero)photogrammetry deals with measurement based on (aerial) images.

For measurement using images, on the one hand, knowledge of the **camera's calibration** parameters at the time of recording is required. These include the focal length, the main image point (the point where the optical axis passes through the image plane) and the lens distortion (deviations from the ideal image of a completely error-free lens system). Ideally, these parameters are constant over longer periods of time or, for example, thermal influences on the internal geometry of the camera are modeled and compensated for using the measurement data from temperature sensors in the camera housing.

On the other hand, the 3D position and spatial orientation of each aerial image must be determined at the time of recording. These six parameters (three coordinates, three angles of rotation) are collectively referred to as **exterior orientation** (EO) and are usually determined together for an entire aerial photographic flight as part of an aerotriangulation.

When taking a picture, the sunlight reflected from the earth's surface is collected using the lens system and projected onto the image plane. The (three-dimensional) space is thus reduced to a (two-dimensional) plane. This process cannot therefore be reversed using a single image - the distances (depth) of the photographed objects from the recording point (projection center of the camera) remain unknown.

The **three-dimensional reconstruction** of objects is made possible by adding a second image of the same scene from a different perspective (different recording point and possibly also a different direction of view). This process is called **stereo photogrammetry** and is a technical reproduction of the spatial vision of humans and animals using a pair of eyes.

In aerophotogrammetry, two aerial images of a similar perspective (usually nadir) taken one after the other in flight are used for synchronous, stereoscopic (or two-image) measurement using special hardware (graphics card, screen, glasses). Traditionally, nadir images are taken in such a way that they overlap by at least 60% in the longitudinal direction (**longitudinal overlap**, LO). This ensures that the entire scene captured by the flight image can be viewed stereoscopically.

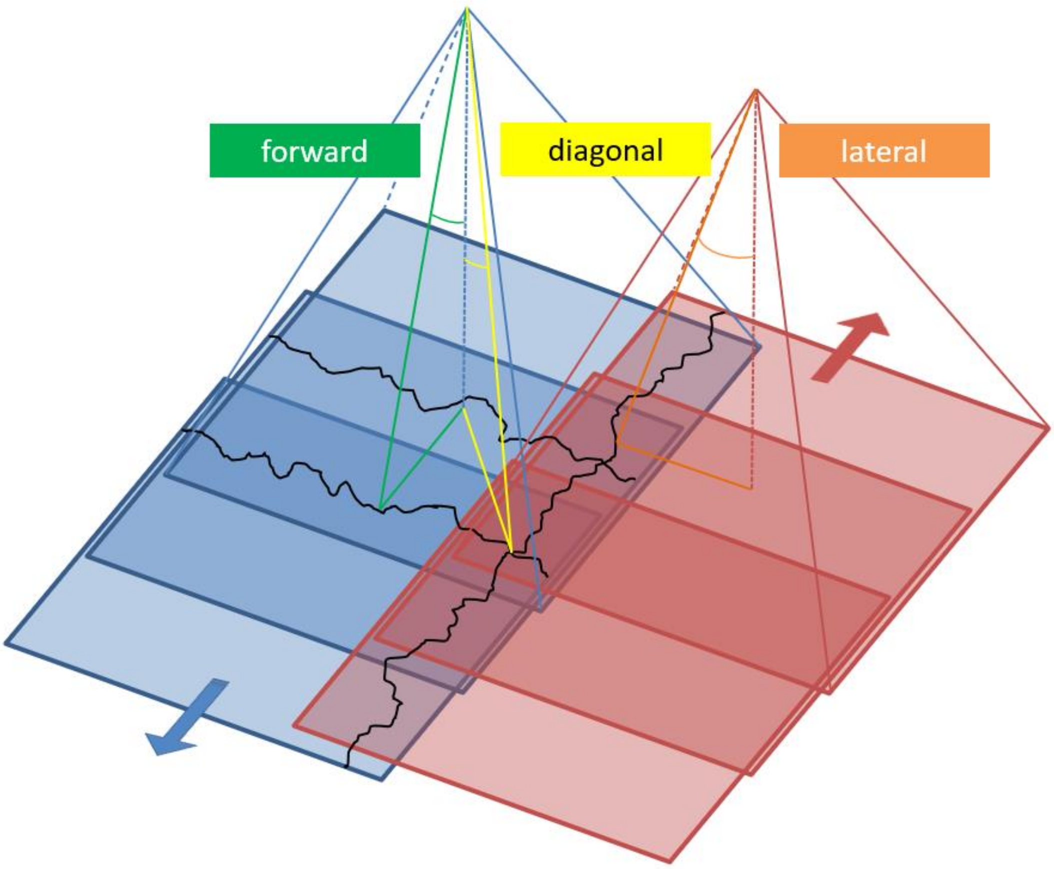


Fig. 4: Image flight with 60% longitudinal and 25% transverse coverage, with intersection lines of the orthophoto mosaic. Used area of individual images in longitudinal, transverse and diagonal directions.

To survey larger areas such as entire cities, the flight is carried out using several, usually parallel flight strips. The overlap of the nadir flight strips across the direction of flight (**cross overlap**, CO) is based on the topography and the building density of the area to be surveyed and is typically between 20% (flatland) and 40% (mountains) of the flight strip width (see Fig. 4).

Orthophoto

An orthophoto is a scaled image of parts of the earth's surface. In order to convert an aerial image into an orthophoto (ortho-rectification), the spatial structure of the scene recorded must be known. If a digital terrain model (**DTM**) is used for this (**conventional orthophoto**), objects that protrude from the terrain are shown with a position offset (image collapse). The size of the image collapse depends on the position of the object in the image (the more central, the smaller) and the height difference to the terrain (the higher, the greater), see also Fig. 4. If, on the other hand, a digital surface model (DSM) is used for ortho-rectification, no image collapse occurs (**true orthophoto**). In an **orthophoto mosaic**, larger areas are covered by a large number of individual orthophotos.

Note: Although terrain and surface models are spatial models that usually have a constant grid width, they are not strictly speaking 3D models. The reason for this is that in such a model only a single height can exist for each grid point in the covered area. Therefore, no vertical or overhanging structures can be reproduced. This is why they are also referred to as 2.5D models.

3D mesh

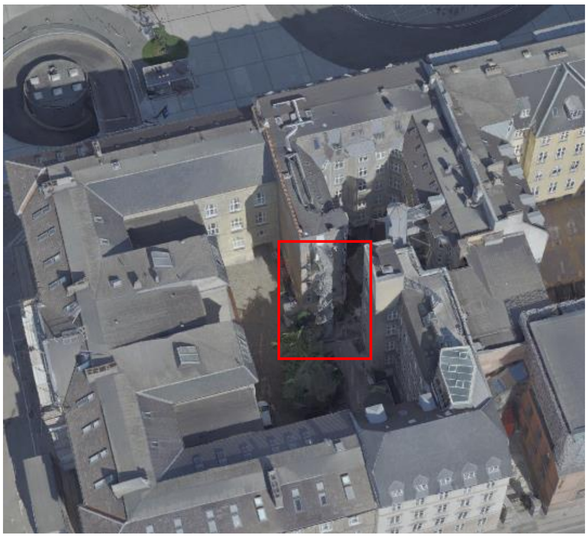
A mesh describes an object or a scene using an irregular triangular mesh (*Triangulated Irregular Network* or TIN). The size of the triangles, which recreate the surface using plane pieces (facets), depends on the geometric complexity of the objects and the desired level of detail of the modeling. This means that the more complex the object and/or the higher the desired level of detail, the smaller the facets in the mesh.

Vertical and overhanging surfaces can also be recreated using a 3D mesh. The facets can be textured using (oblique) aerial images, resulting in (almost) photorealistic models with a freely selectable viewing perspective (see Fig. 5). It is precisely this flexibility of the viewer's point of view and angle of view that is the great strength of a 3D mesh compared to actual aerial images, the perspective of which is determined by the recording.

Fig. 5: Detail from a 3D mesh of the city of Copenhagen from 2021 (GSD of the aerial images: 2.5 cm)

The disadvantage of the mesh lies in the limitations of the automatic processes used to create it. *Dense Image Matching* (DIM), i.e. pixel-by-pixel linking of all sufficiently overlapping images and/or laser scanning, is usually used. DIM has developed rapidly over the last fifteen years, but problems still exist with complex or only partially visible geometries and especially with surfaces that are in the shadow of other objects.

Therefore, the zoom level at which a mesh can be viewed should be limited to an integer multiple of the actual resolution of the underlying images. If there is no such limitation and the viewer can "bring" the object as close as they want, the errors become obvious and lead to uncertainty, which can even lead to the data material being discarded entirely (see Fig. 6). At the same time, it also becomes clear that a 3D mesh is **not** suitable for detailed measurements with high accuracy and reliability.



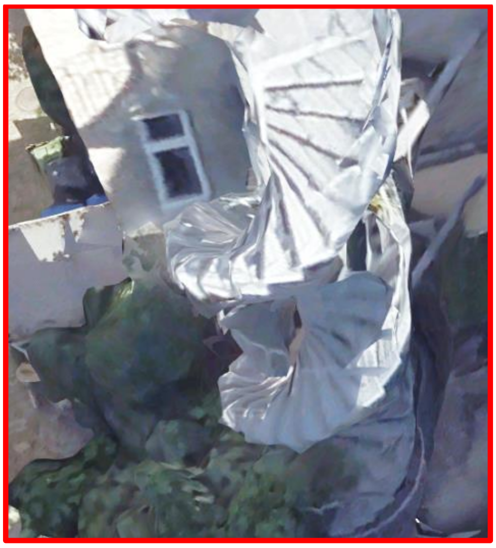


Fig. 6: Problems in the 3D mesh of Copenhagen 2021 become visible at (too) high zoom levels (right)

3D point clouds

A 3D point cloud is an irregular and unstructured reproduction of a scene (hence the term "cloud") based on 3D points. Such data sets are created during surveying using laser scanning (active scanning of the surface with a laser beam that is continuously realigned) or DIM. In a classified point cloud, the points are divided into different classes (e.g. soil, vegetation, water, buildings, pipes, vehicles, etc.). This is done using manual and/or automatic methods. An example of an ALS point cloud with class-based coloring is shown in Fig. 7.

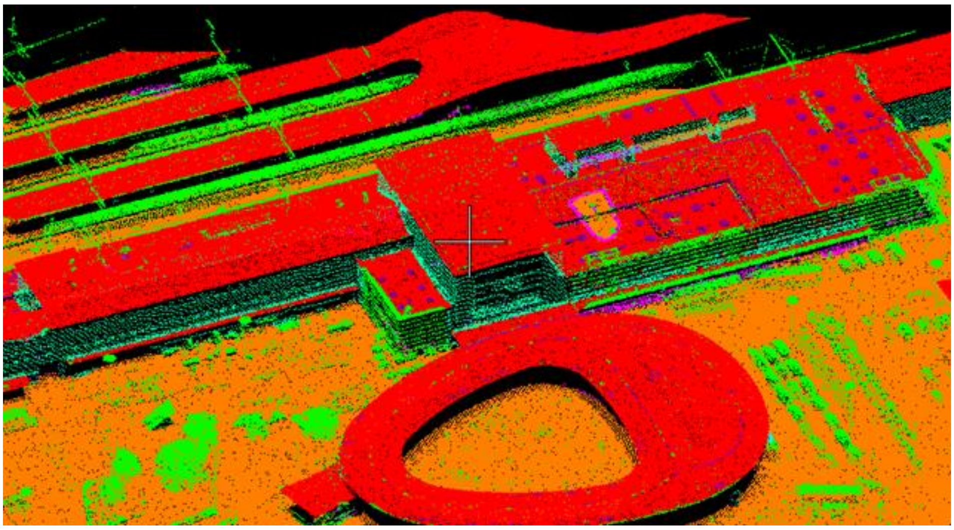


Fig. 7: Example of a classified point cloud from the city of Graz from 2018 (main station)

In terrestrial laser scanning (TLS) or mobile laser scanning (MLS) with road vehicles, the distances between the sensor and the scene are usually small (a few meters), while in **airborne laser scanning** (ALS) they are significantly larger (hundreds of meters to a few kilometers). Consequently, ground-based laser point clouds are significantly more detailed (typical point distances in the millimeter to centimeter range) than ALS point clouds (typical point distances in the decimeter to meter range).

The point density of a (photogrammetric) DIM point cloud corresponds to the GSD of the underlying (aerial) images (centimeter range). As a rule, laser-based point clouds have better geometric (height) accuracy. In addition, they are (largely) free of major errors that can occur in DIM due to incorrect image links, particularly in shadows or overgrown areas.

ALS-based point clouds in particular have only a low level of edge sharpness, for example from building roofs, because the exact distribution of measurement points on the surface cannot be planned in advance. The *CityMapper* from Leica/Hexagon is the world's first hybrid sensor system for aerial surveys in which a multi-perspective camera and a laser scanner are installed in the same housing. This makes it possible to generate point clouds colored with true colors in a very elegant way.

However, if the 3D position of a measurement point is to be derived from the laser data (instead of using photogrammetric multi-image measurement), interpolation must be carried out, since the GSD of the camera is better than the measurement point density of the ALS point cloud. This interpolation can be carried out by including DIM, but this again leads to the disadvantage of pixel-by-pixel image linking (which is susceptible to "optical illusions"). Therefore, such hybrid point clouds are only suitable for detailed, high-accuracy measurements with limitations.

Highly overlapping image flights

With the advent of digital aerial cameras since the mid-2000s and the immense increase in the performance of modern computer, storage and network systems, the overlap in photogrammetric image flights has also increased. Urban environments are now usually flown over with 80% LO and 60% to 80% CO of the nadir images. This means that with 60% or 80% CO, (almost) every point in the recorded area is included in 15 nadir images (five images lengthways in three flight strips each) or 25 nadir images (five images lengthways in five flight strips each) (see Fig. 8). If such a high-coverage image flight is also carried out with a combined nadir/oblique camera, the number of images showing the same part of the scene increases fivefold. So you often have 100 images or more to choose from at any point in the area you are flying over.

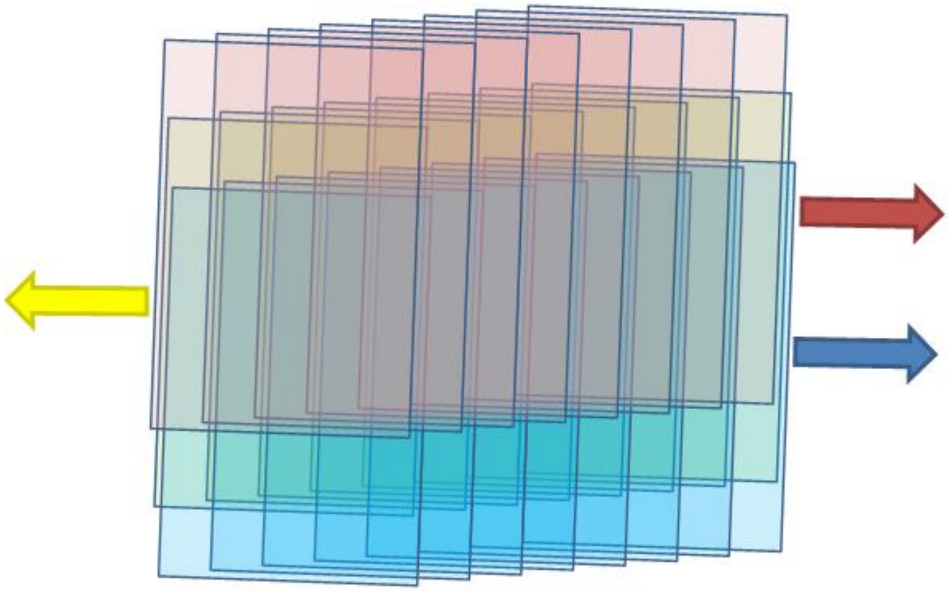


Fig. 8: Flight with 80% overlap in longitudinal and transverse direction (exemplary with three flight strips of eight images each).

This raises a very important question for practical purposes: Which images are best suited to recognizing and understanding the spatial relationships at a specific point in the object space? The obvious answer is that the images should be selected in which the point being viewed is as central as possible. Consequently, the center of each image projected onto the ground (or the terrain model) must be determined and the distance to the desired object point must be determined.

In combined nadir-oblique flights, the images are ideally sorted and grouped not by the direction of flight, but by the direction in which the images were taken. It will often happen that the image of a specific viewing direction in which the object being sought is as central as possible is not suitable because other objects (in the foreground and/or higher or larger) obscure the view. In this case, it is very helpful if an alternative image can be selected from the list of images available at this point.

Measurement methods based on oriented aerial images

Basically, the measurement methods that can be used with oriented aerial images can be divided into two categories:

Single image measurement (mono image measurement or **monoplot**)

An object point is only measured in a single image: As described in the **Terms of Photogrammetry**, a single image is not suitable for reconstructing the recorded scene in three dimensions. However, if a spatial model of the scene is known, a measurement can also be carried out in mono mode. The accuracy of the result depends not only on the accuracy of the image orientation but also on the quality of the measurement and on the quality (e.g. level of detail, accuracy) and timeliness of the spatial model used. A suitable model for this can be (see Fig. 9):

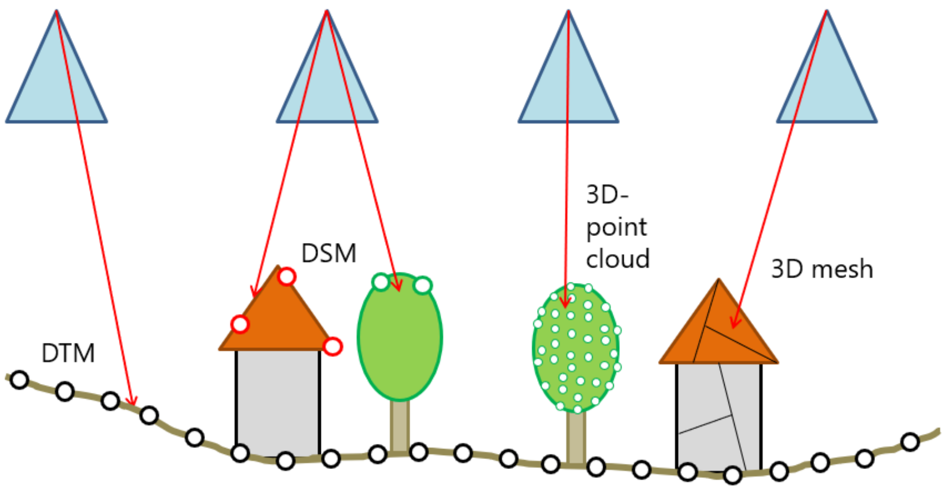


Fig. 9: Monoplot variants

- **DTM**: The individual measuring beam is intersected with the DTM (the intersection point of the measuring beam with the model is determined). This approach is only useful for ground points.

- **DSM**: The single measuring beam is intersected with the DSM. This approach usually does not produce accurate results, as 2.5D models cannot correctly represent objects with vertical boundaries (e.g. buildings). However, a DSM monoplot can be a useful approximation position to support a multi-image measurement.
- **3D point cloud**: Only in the rarest of cases will the individual measuring beam hit exactly one existing point in the point cloud. It is much more likely that the measuring beam passes between several points. The 3D point closest to the beam can be used or interpolated between several nearby 3D points. This measuring method is used, for example, in the City Mapper sensor system from Leica/Hexagon, as it is a hybrid system that includes both a nadir oblique camera and a laser scanner.
- **3D mesh**: The individual measuring beam is intersected with the facet of the mesh that it (first) penetrates. In this case, the accuracy of the result is also determined by the generalization of the mesh (thinning and smoothing of the point cloud when generating the triangular mesh).

Multi-image measurement

An object point is measured in two or more images: The accuracy of the result depends not only on the accuracy of the image orientations, but also on the quality of the measurements and the intersection angle(s) between the measuring beams. In the case of two images, the optimal geometry is achieved when the two measuring beams intersect at right angles. With multiple image measurements, there are several options:

Synchronous stereo image measurement: As described in the chapter on **Terms of Photogrammetry**, simultaneous stereoscopic measurement is the classic approach to 3D reconstruction of a scene in photogrammetry. However, this method can only be used if the images have similar viewing directions and the image base (the position difference between the recording points of the two images) can be rotated parallel to the axis of the human observer's eyes. In this case, the brain of the (experienced and equisighted) observer can put the two images together to form a 3D image of the scene.

Therefore, both the nadir images and the oblique images inclined around the aircraft's longitudinal axis (left- and right-wing images) are suitable for stereo image measurement within a flight strip. For the oblique images inclined around the wing axis (forward, backward), stereo image pairs can be formed from neighboring flight strips (see Fig. 10).

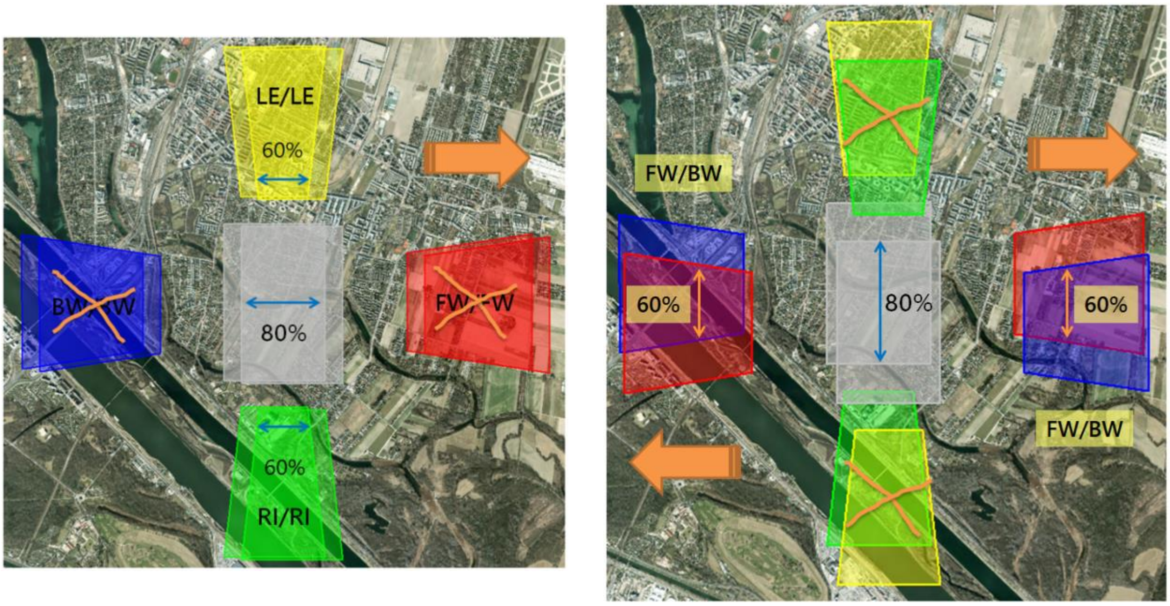


Fig. 10: Configuration of possible stereo image pairs with a nadir oblique camera within a flight strip (left) or between two flight strips (right), orange arrows = flight direction.

Depending on the camera geometry (lens aperture angle), stereo measurement with 60% longitudinal overlap results in a typical intersection angle between the measuring beams of 15° (normal angle lens) or <10° (telephoto lens) - regardless of the position of the object point in the stereoscopically covered area. This relatively small intersection angle leads to a two-fold worse accuracy of the measurement result in the viewing direction of the images (depth). While this only affects the height in the nadir images, the height and the horizontal position are equally affected in oblique images inclined at 45° (see Fig. 11 middle).

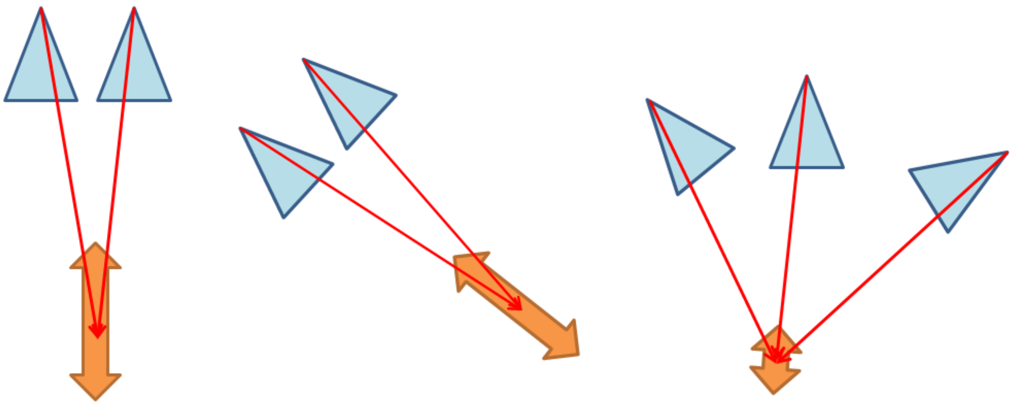


Fig. 11: Poorer depth accuracy in stereo measurement nadir (left) or oblique (middle), higher accuracy in multi-image measurement with variable viewing directions (right).

Asynchronous multi-image measurement (or multi-image measurement): This is the most important measurement method in MEASUREE. The 3D reconstruction is carried out by sequentially measuring the same object point in two or more images, whereby any viewing directions can be combined (no stereo effect has to occur). The images only have to overlap (without a minimum amount of overlap). This often brings the intersection angle of the measuring beams much closer to the optimal case of 90° (see Fig. 11 right). However, it is important that the same object point is actually measured, which is not always "trivial" due to the sometimes very different perspectives.

Measuring the same object point (identical point) in two images already leads to "over-determination" or "redundancy". This means that there are more measurement variables than are needed to clearly determine the position of the object point. A clear 3D point would be created, analogous to a monoplot, by intersecting a single measuring beam with a general plane in space. The more images the object point is measured in, the higher the redundancy and the better the accuracy and reliability of the position determination.

MEASUREE allows the measurement of an identification point in an unlimited number of images, whereby the overdetermination is resolved by a least squares adjustment. From a statistical point of view, this produces the optimal result for the position of the object point. The adjusted position is mapped back into all images involved in the position determination and compared with the measurement in each case.

The difference between calculation and measurement is called reprojection error and is a very reliable measure of the quality of the positioning. If there are major discrepancies in the measurements (which is usually due to point confusion on similar-looking objects), MEASUREE supports users by marking the images accordingly (error circle). The measurement can then be improved interactively until the discrepancy is within a configurable error tolerance.

Fig. 12 Display of a measurement contradiction based on an error circle in MEASUREE

Table 1 summarizes the advantages and disadvantages of the measurement methods based on (oblique) aerial images. The table cells are colored like a traffic light: green = favorable, yellow = average, red = unfavorable. It is immediately clear from this summary that MEASUREE is an ideal solution for many applications.

Method	**Monoplot (z.B. MEASUREE)**	**Synchronous stereo measurement (3D evaluation station)**	**Asynchronous Multi-beam measurement (MEASUREE)**
Measurement process	Very fast, but only 2D (monoscopic)	Very fast and 3D (stereo-scopic)	Slightly slower and 3D (sequential)
3D accuracy	Low to moderate (depending on the model)	Good (depth determined poorly)	Good to very good (optimal cutting geometry possible)
Reliability	Low to moderate (depending on the model)	Moderate (optical illusions possible, e.g. due to shadows)	Very high (control through other perspectives)
Availability	Anywhere (only mono coverage required)	Reduced (only for stereo coverage from similar perspectives)	(Almost) everywhere, since any viewing direction can be combined with each other
Requirements for human operators	Low in terms of the measurement process but high in terms of the assessment of the result	Setting up the measuring mark requires equal-sighted eyes and a lot of practice and experience	Low, but spatial imagination when looking at an object from different perspectives
Hardware and software requirements	Low (standard calculator)	High (special, usually high-priced hardware required for 3D visualization and 3D measurement)	Low (standard calculator)

Table 1: Advantages and disadvantages of measurement methods using aerial images (traffic light coloring according to properties)

Function overview MEASUREE

MEASUREE is a **web application** for working with aerial images and, thanks to its extensive functions and **intuitive user interface**, is the ideal tool for surveyors and other users.

The application is available in two different versions:

MEASUREE CLASSIC is based on the use of images from multi-head or multi-perspective cameras, MEASUREE VERSATILE aimed at single cameras (e.g. from drone flights).

Features

General

- **No installation** on users' computers - a modern web browser is sufficient
- **Session persistence**: Continue working even after restarting MEASUREE, the browser or even the computer
- Support for familiar functions such as undo/redo (with the entire session's workflow), drag & drop, keyboard shortcuts and context menus
- Available in various languages (currently German, English and Italian, new languages can be added at any time)

Aerial images

- Use for **different flight platforms** (aircraft, drone) and sensor systems (nadir, oblique and combined; thermal infrared, hyperspectral)
- Support for digital and (scanned) analogue aerial images (historical flights)
- Synchronization of different flight data sets (e.g. different flight years) to visualize **terrain and construction changes**

Viewer

- **Customizability** of the multi-view layout (zoom in/out, duplicate, split)
- Working with **multiple monitors**: individual views (windows) of MEASUREE can be distributed across different monitors
- Creating **screenshots** for the creation of documents (e.g. reports)
- Customizability of **image display** (brightness, contrast, saturation and hue)

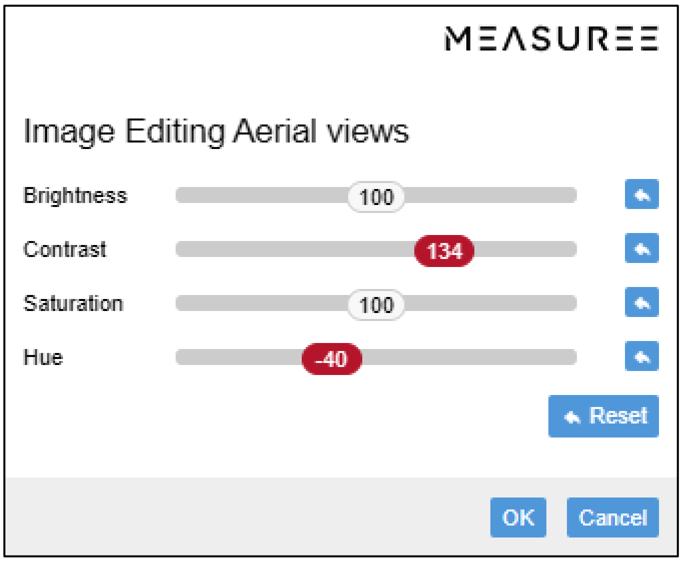


Fig. 13: Customization options for image display to increase the recognizability of objects in aerial images

- Positioning on crosshairs or known positions (2D or 3D)
- Display of image trigger points and image covers ("Maltese crosses")

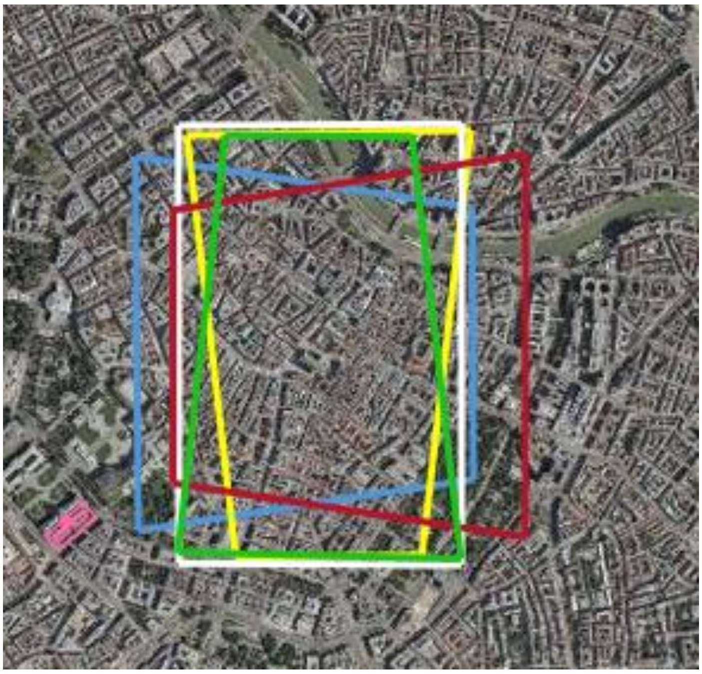


Fig. 14: Image coverage of a region by different cameras (shown in different colors)

Asynchronous multi-image measurement

MEASUREE has a **highly accurate measuring method** by blending the measuring beams from two or more completely different perspectives (images). This eliminates the need for time-consuming and costly calculation of a 3DMesh and results in an extremely short “time to first measurement”.

Fig. 15: Surveying the Kunsthistorisches Museum in Vienna with MEASUREE

- Display of measurement uncertainties due to reproduction errors and cutting angles for **quality assurance**
- Display of the line of sight of a monoplot for fast 3D measurement

Fig. 16: Example of a line of sight (right image) of the monoplot (created in the left image) in Ferrara/Italy

- Automatic determination of route lengths and distances (3D)

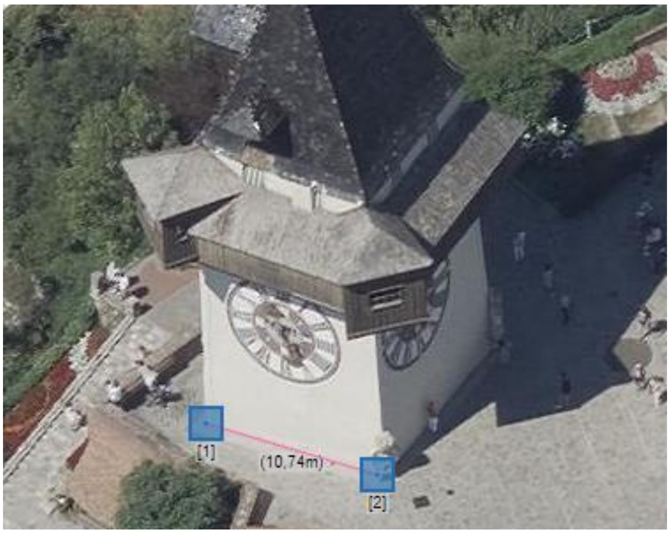


Fig. 17: The distance between point [1] and point [2] is automatically determined and immediately displayed

- Filtering of measurement points according to data quality

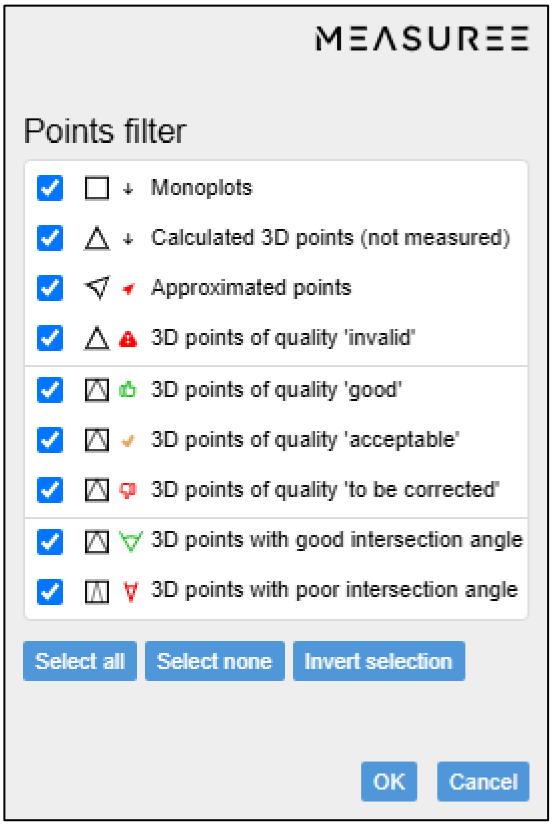


Fig. 18: Point filter with display of point types (monoplots, 3D points) and their qualitative evaluation

- Auxiliary lines in three-dimensional space enable the reconstruction of hidden object points.

Fig. 19: Guide lines (dashed blue) help with the construction of objects in areas of the image that are difficult to see

Hierarchical data model

The **Measuree** data model enables the organization of measured objects within (nestable) levels (e.g. streets / houses / components) to improve clarity with large amounts of data.

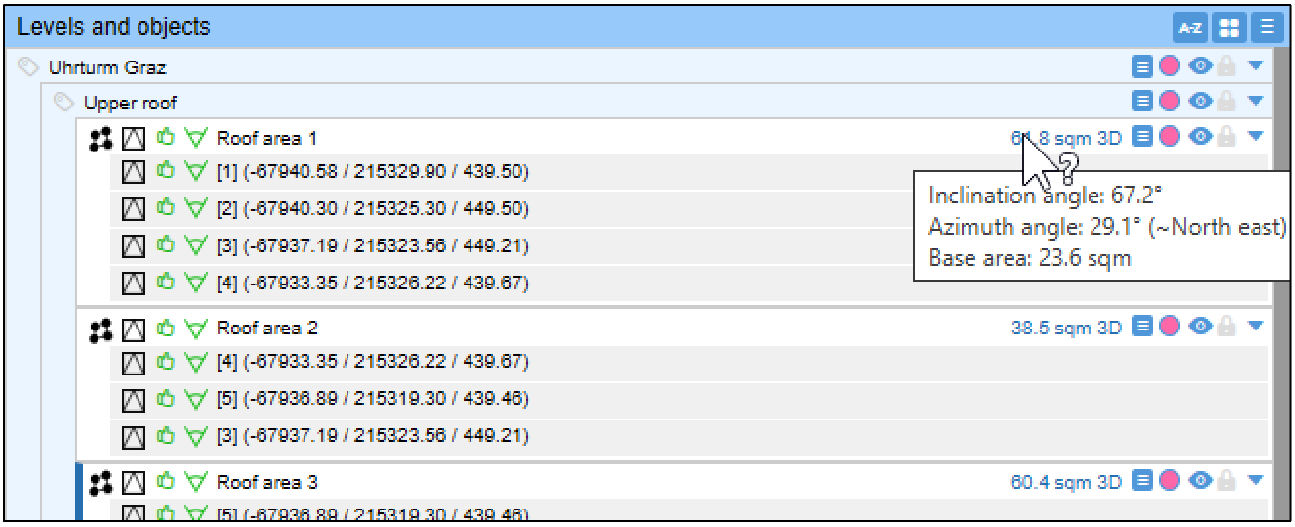


Fig. 20: Example of hierarchical data structuring using levels and objects

- Configurable **layer prototypes** for semantic labeling of data
- Supported **object types**: point, line, polyline, polygon
- Automatic determination of **area dimensions** (2D) with base area, inclination angle and azimuth angle (3D)
- Opening/collapsing layers and objects to improve clarity with large amounts of data
- Changing color and visibility for each object or layer
- Locking correct points and objects to avoid erroneous modification
- Option to assign freely definable attributes for measurement points (e.g. quality criteria)
- Import/export of individual objects or layers

Object footprints

MEASUREE offers an automated detection of all images that contain one or more objects in whole or in part ("object footprints"). These images can be selected for further processing in MEASUREE or exported as a list.

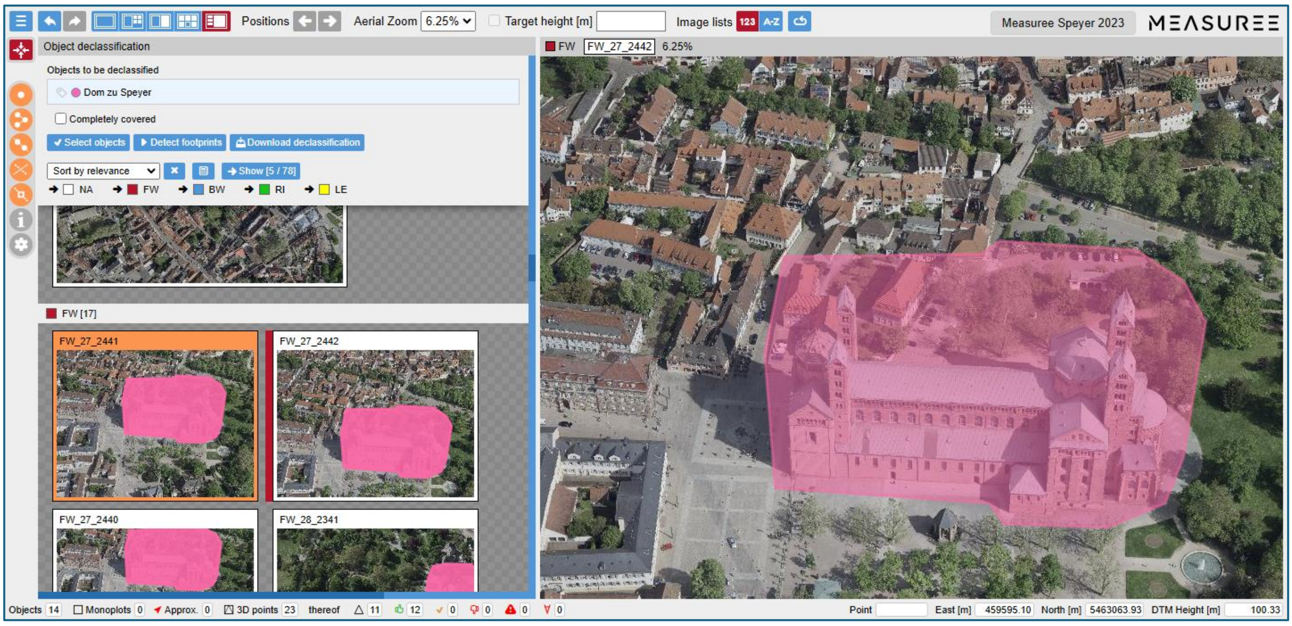


Abb. 21: Object footprints and preview of a selected image (Speyer Cathedral)

Object declassification

Sometimes aerial images contain sensitive objects that must not be accessible to the public (e.g. military facilities, power plants). Automated localization of such objects is a major challenge, especially in oblique images.

MEASUREE offers a tailored solution here:

1. **Automated detection** of all images in which these objects are at least partially contained (object footprints, see above).

2. **Automated declassification** to generate new images from the original nadir or oblique aerial images in which the selected objects are removed or rendered unrecognizable (blackening, pixelation, blurring).

Interfaces and extensibility

- **Import/export** of data in industry-standard file formats (Shape, GeoJSON, DXF)
- Possibility of setting up individual **interfaces** to third-party applications (e.g. calling from web GIS applications such as ESRI WebOffice) or databases
- Adaptability and expandability of user interface and functionalities to **individual requirements**

History

- The work history is documented step by step
- Powerful undo and redo function
- History of view positioning in the aerial images

Required input data

- Images with tiling (512 x 512 or 1024 x 1024 pixels) and in several resolution levels (image pyramids): This data is generated semi-automatically from the original images (TIFF) using a batch process. The images are also rotated if necessary, so that the sky is always in the upper half of the image (sky-up, "natural" viewing method).
- External orientations of all images: This file also specifies the coordinate system.
- Calibration data of the camera system: The focal length, the coordination of the principal image point (PPA), the physical pixel size and the number of pixels in the longitudinal and transverse directions are required for each sub-camera.
- Orthophoto mosaic of the area of interest with tiling (512 x 512 or 1024 x 1024 pixels) and in several resolution levels (image pyramids): The orthophoto mosaic forms the basic data of the overview image (“navigator”).
- DTM of the area of interest (grid width as required)
- Optional: DSM of the area of interest (grid width as required)

Web server

MEASUREE requires a web server that enables the application to be called in the web browser.

- Support for common web servers (Microsoft IIS, Apache, etc.)
- No database is required to operate MEASUREE.
- The application and/or image data can be stored on the customer's own servers. Alternatively, AVT also offers its own hosting services.

Starting MEASUREE

MEASUREE can be called in the web browser with (optional) parameters to

- start MEASUREE in the **desired language** version
- automatically center MEASUREE on a **desired position** (by specifying east and north coordinates) (at the same time a crosshair is created).
  This can be done, for example, by a previous search in a calling system (e.g. WebOffice) (postal address, property number, point of interest (POI) or coordinate pair).

Introduction to MEASUREE and example pictures

During the start-up process, a configurable splash screen is displayed with a progress bar that shows the loading and processing of the various input data sets (e.g. external orientations, DTM). (Fig. 22).

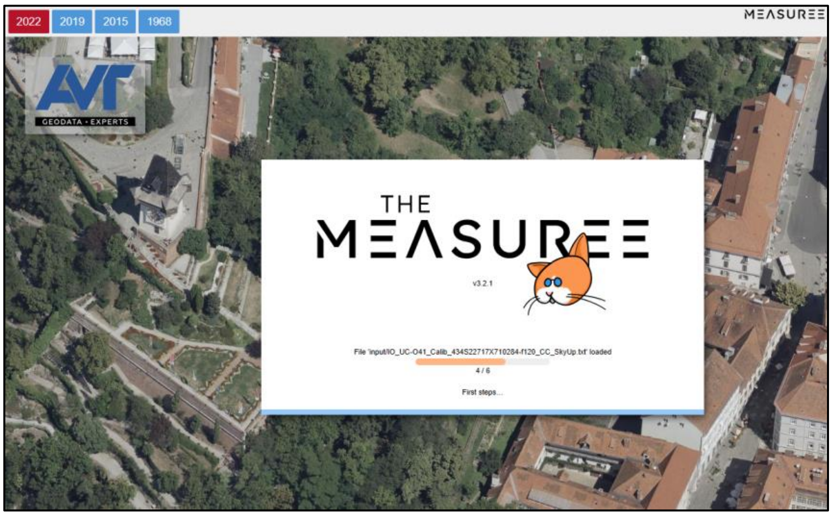


Fig. 22: Graz 2022 start screen with loading process and progress bar

Then the so-called **navigator** (usually an orthophoto) is displayed:

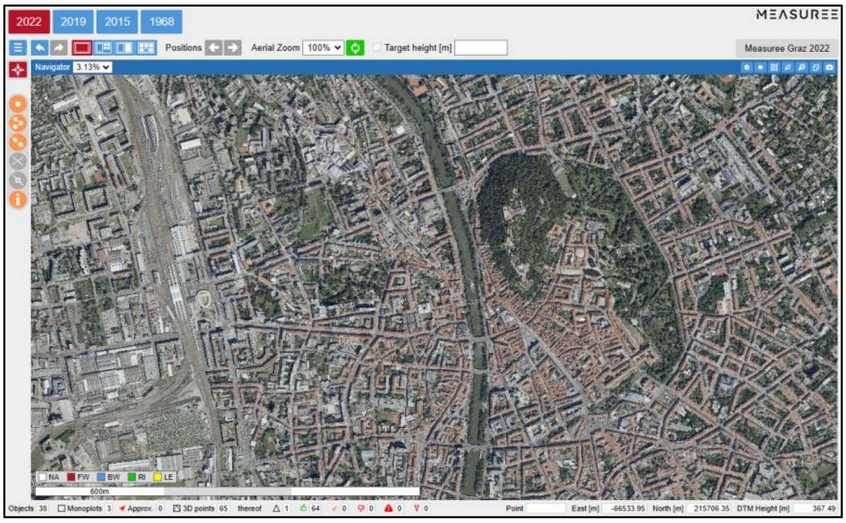


Fig. 23: Navigator view with centering tool (Graz 2022)

Default layout

In the navigator, you can switch to standard mode (**default layout**) by selecting any pixel, where aerial images from all available viewing directions are displayed simultaneously (see Fig. 24).

The top three sub-windows (so called "views") and the two outer views in the bottom row of the standard layout are collectively referred to as "**Aerial Views**". Image measurements can be taken in these windows.

The navigator is also displayed as a sixth image in the middle of the bottom row (in a dark blue border). In the right-hand area, from top to bottom, there are the three views "Layers and Objects", "Points and Measurements" and "History".

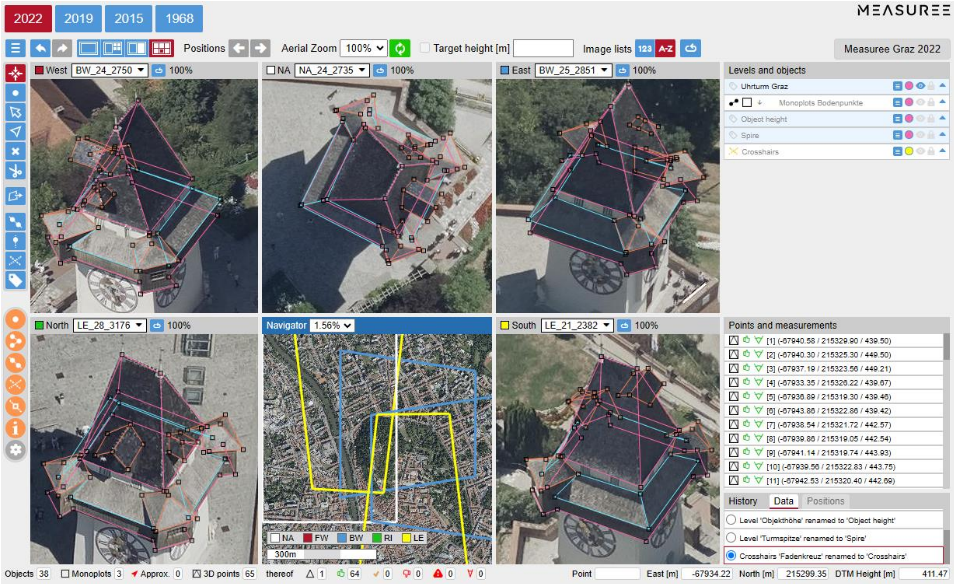


Fig. 24: Default layout with aerial views from all directions and navigator (Graz 2022)

The sizes of the views can be changed at any time. In addition, copies of the views can be transferred to a new browser window and displayed full screen. This is particularly useful for precise measurement tasks on computers with more than one screen.

A **status bar** at the bottom of the window provides an overview of objects already created and their measuring points at any time:

Fig. 25: Left part of the status bar with object, point and quality statistics

Image selection in Aerial Views

For each aerial view MEASUREE determines all images of the corresponding viewing direction that cover the previously selected pixel and displays them in the image selection list in the title bar of the view.

The image that contains the pixel as ideally as possible (i.e. closest to the image center) is preselected.

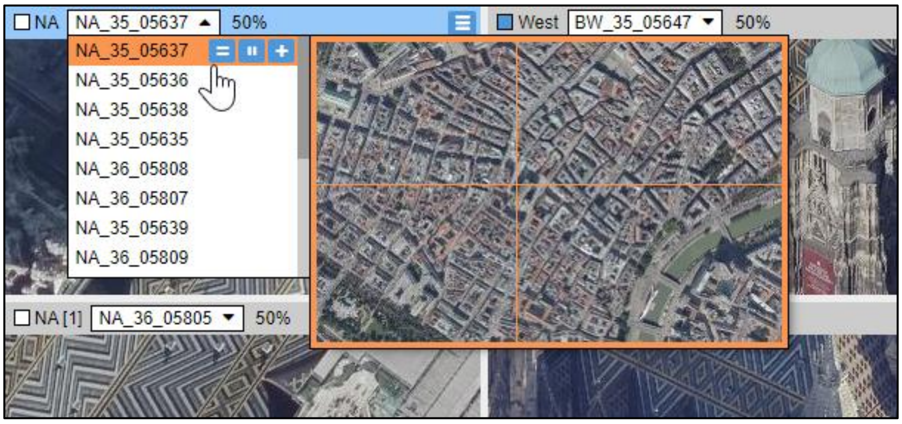


Fig. 26: Aerial View with opened image selection list with image preview

You can now switch to another image in this image selection list. Alternatively, you can split the view (horizontally or vertically) or open the alternative image in a new browser window (and move it to another screen).

Navigator with image selection and the Free Layout

As an alternative to the standard layout described, it is possible to display any number of freely selectable images from all viewing directions in an individual layout (Free Layout).

The **navigator with image selection** is used for this purpose.

If you click on any point in the navigator, all images (grouped by viewing direction) that cover this point are displayed in the right window:

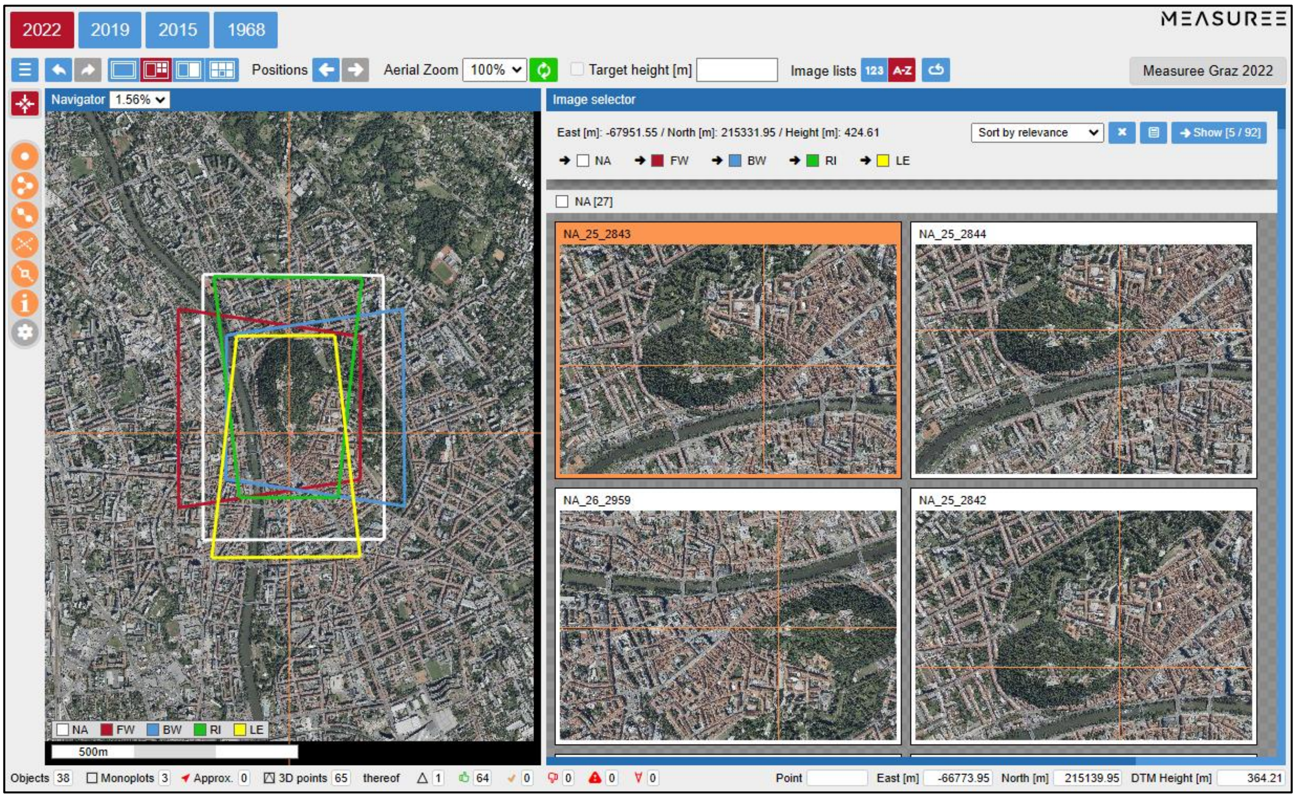


Fig. 27: Navigator with image selection: The previously selected point is marked in the navigator with an orange crosshair, as in the images.

Now you can select as many images as you like (they are framed in orange). The best image for each viewing direction (i.e. the one in which the selected point is as close as possible to the center of the image) is preselected.

The footprints of the selected images are displayed in the Navigator in the color assigned to the corresponding camera.

Clicking on the "Show" button displays the Free Layout:

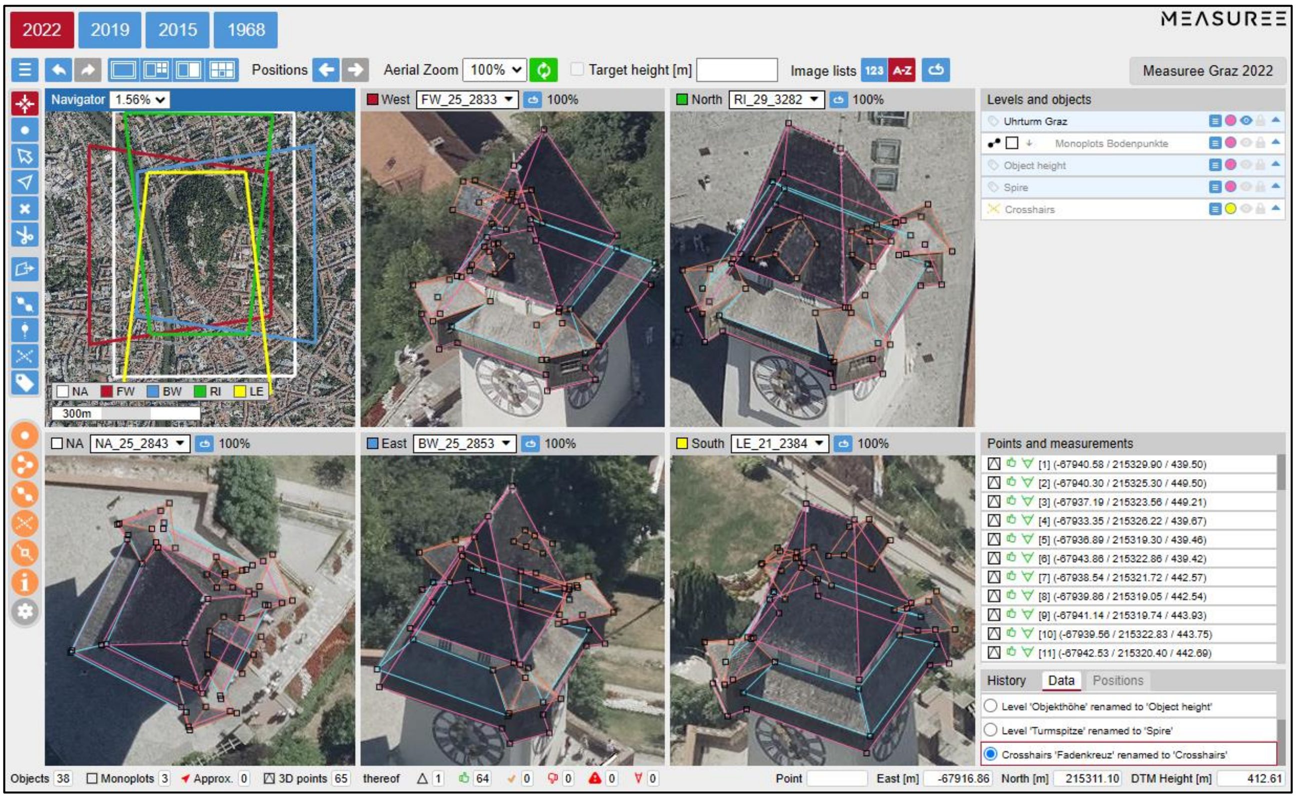


Fig. 28: Free Layout with the previously selected images

Note on Measuree Versatile

As already mentioned, **Measuree Versatile** is used when working with images from individual cameras. In this case, **Measuree** starts with the navigator with image selection after displaying the splash screen. The standard layout does not exist here.

Example images

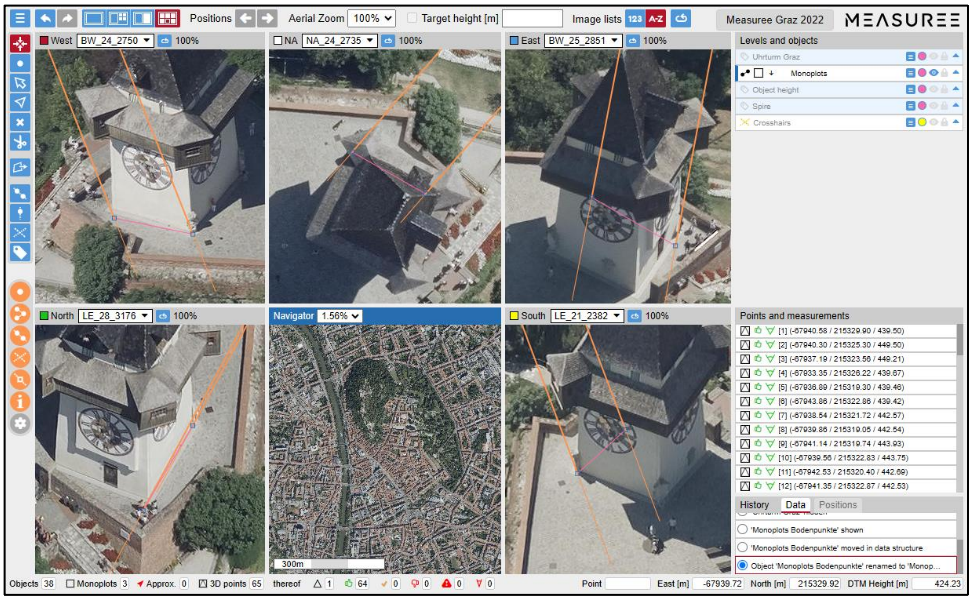


Fig. 29: DTM monoplot of two ground points with distance between the two points (Graz 2022)

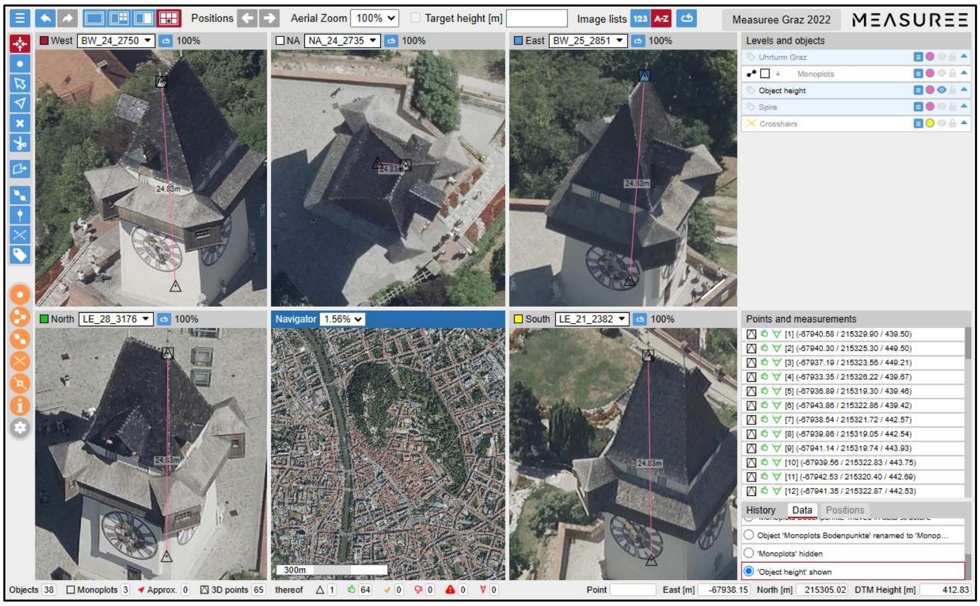


Fig. 30: 3D measuring point with projection onto the DTM to derive the object height (Graz 2022)

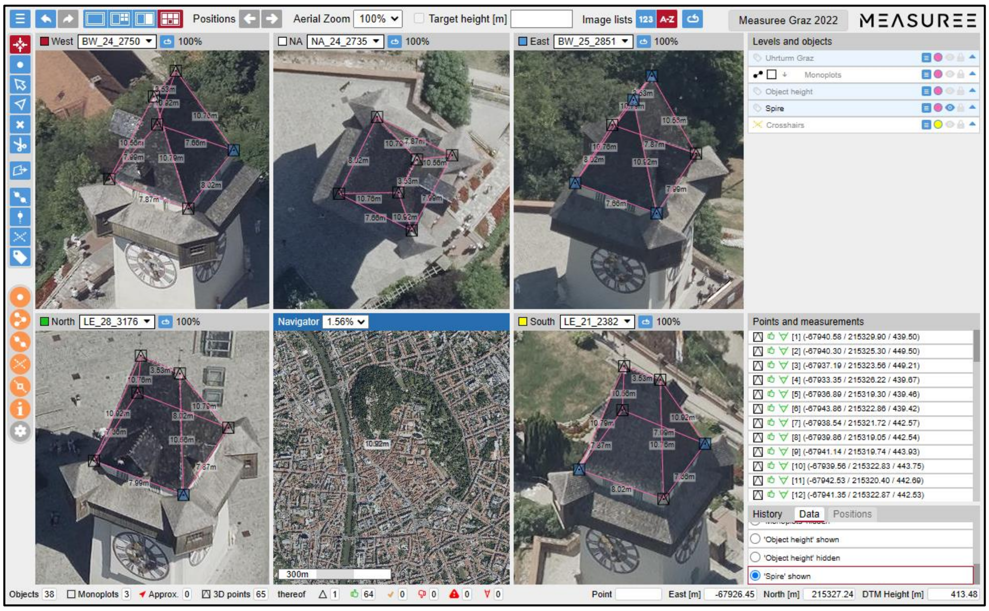


Fig. 31: 3D evaluation of the main roof surfaces of the clock tower (Graz 2022)

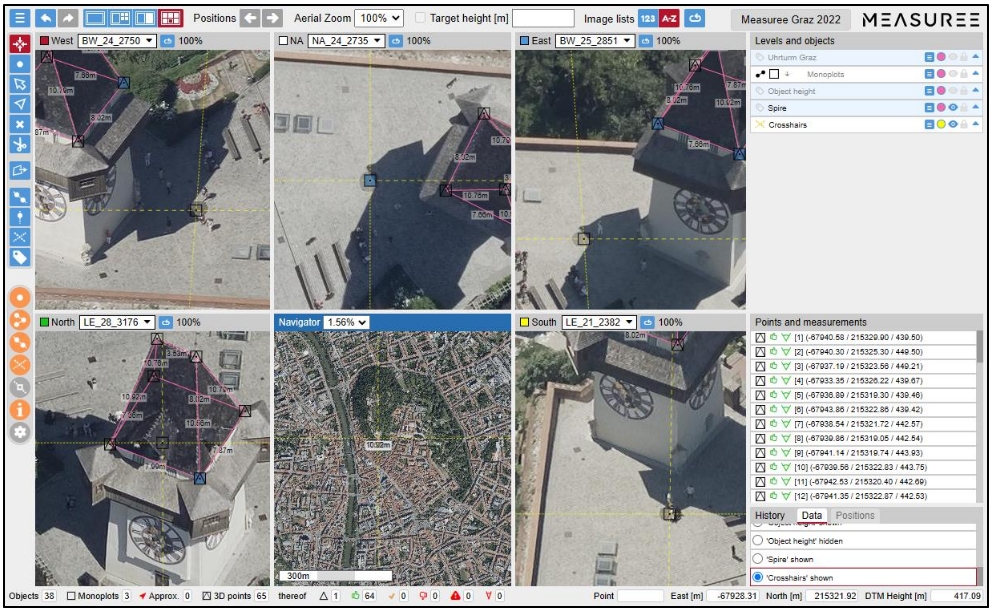


Fig. 32: Inserting a crosshair to synchronize multiple flights (Graz 2022)

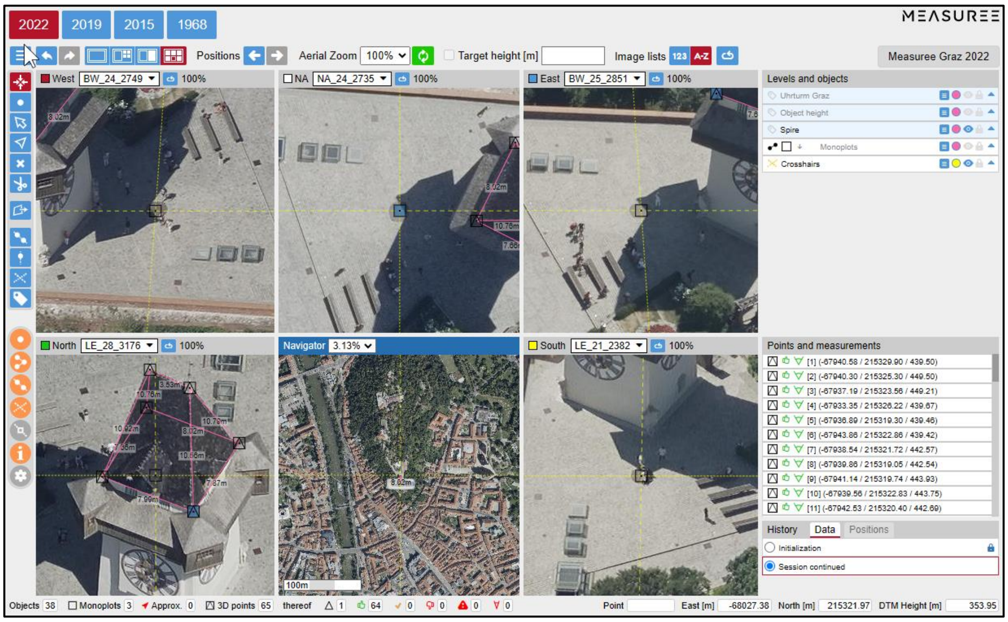


Fig. 33: Centering the Aerial Views on the Crosshairs (Graz 2022)

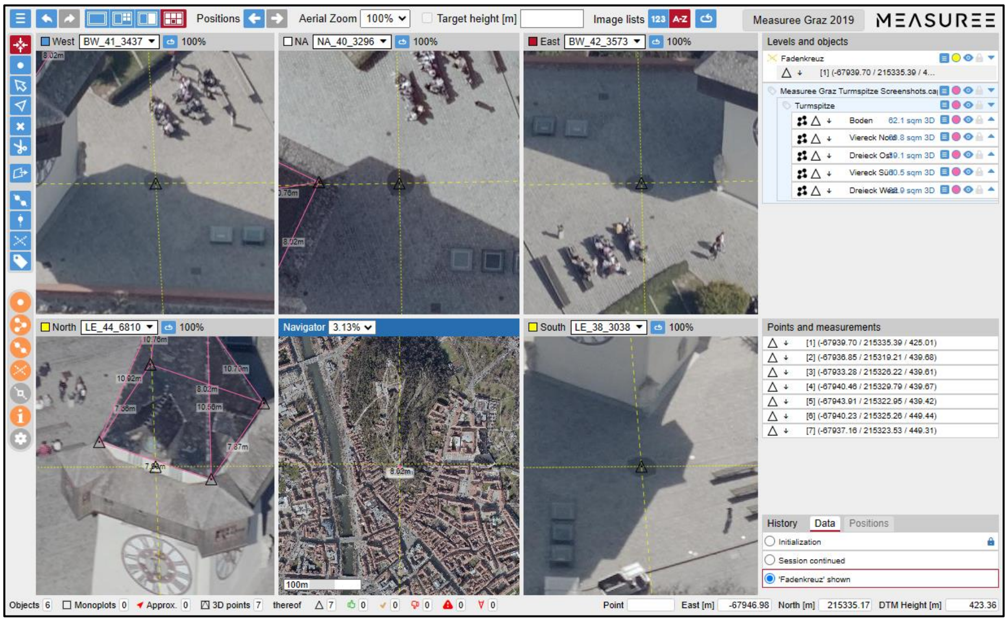


Fig. 34: Synchronization of the Graz 2019 flight to the crosshairs

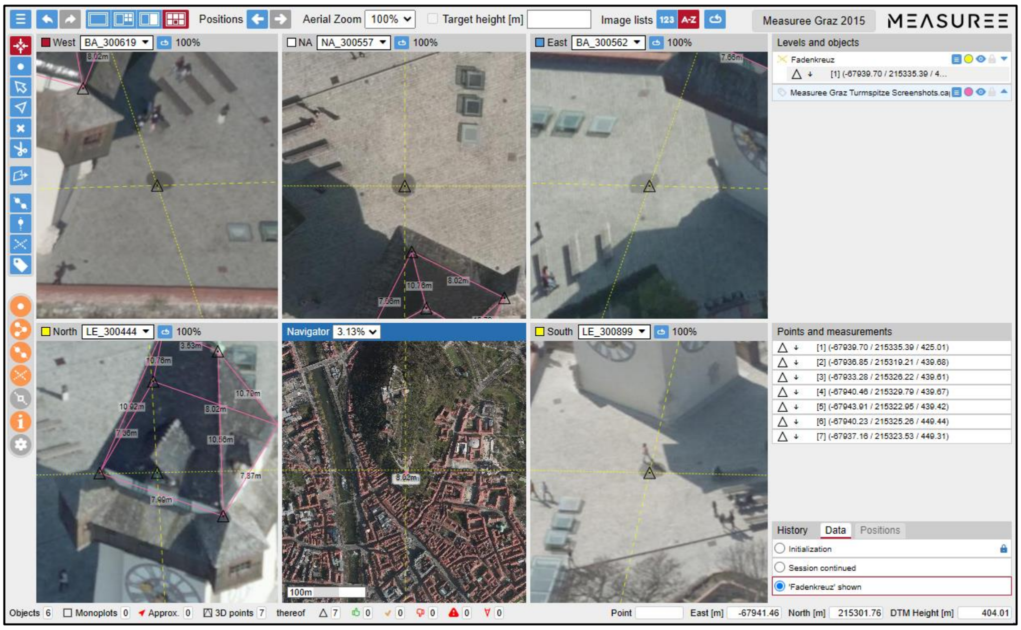


Fig. 35: Synchronization of the Graz 2015 flight to the crosshairs

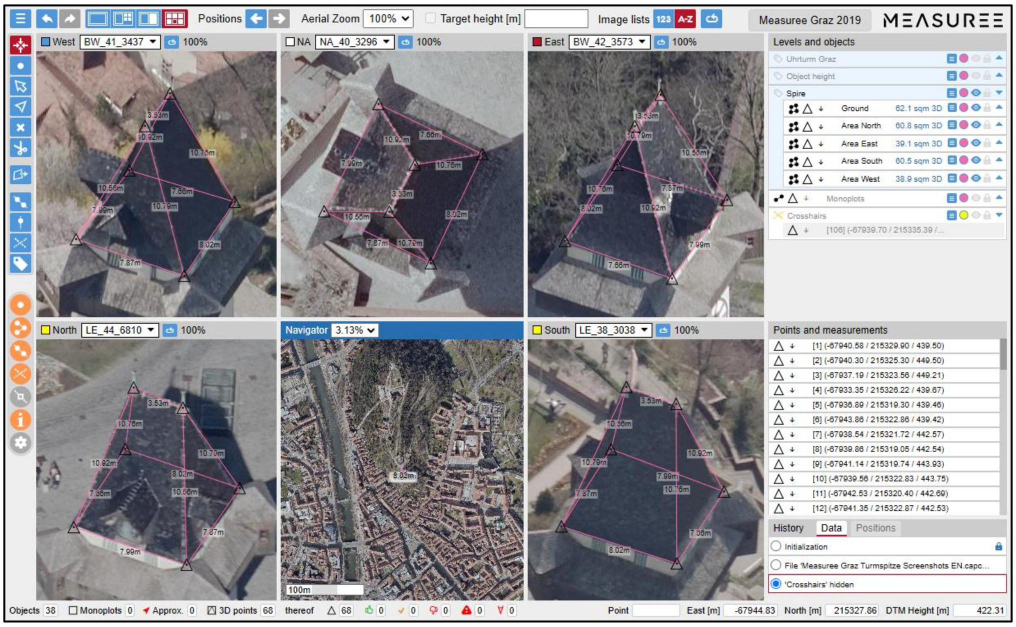


Fig. 36: Main roof surfaces of the clock tower of Graz 2022 imported to the flight 2019

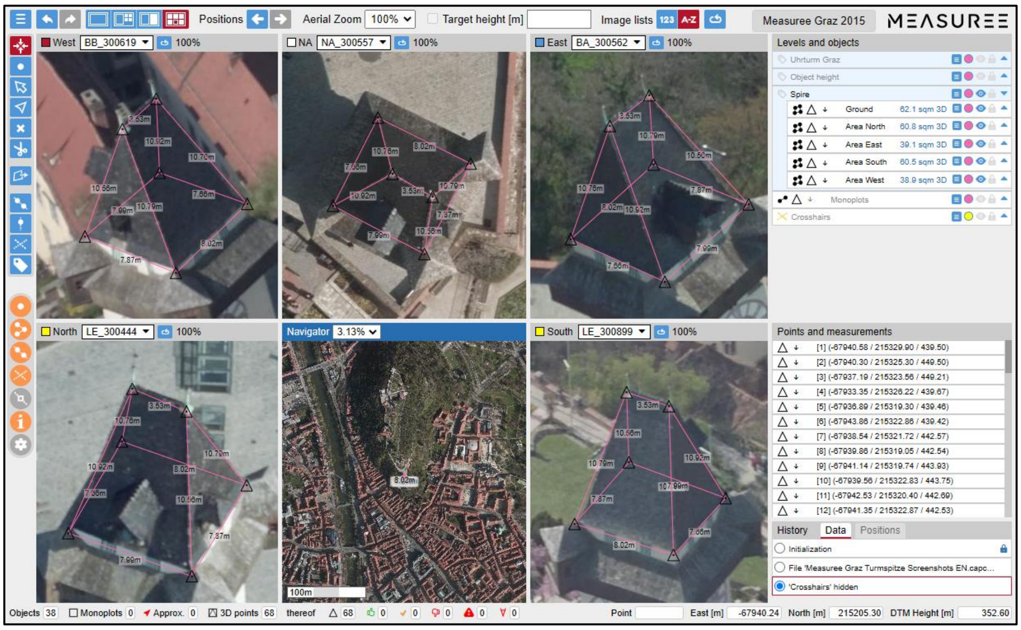


Fig. 37: Main roof surfaces of the clock tower of Graz 2022 imported to the flight 2015

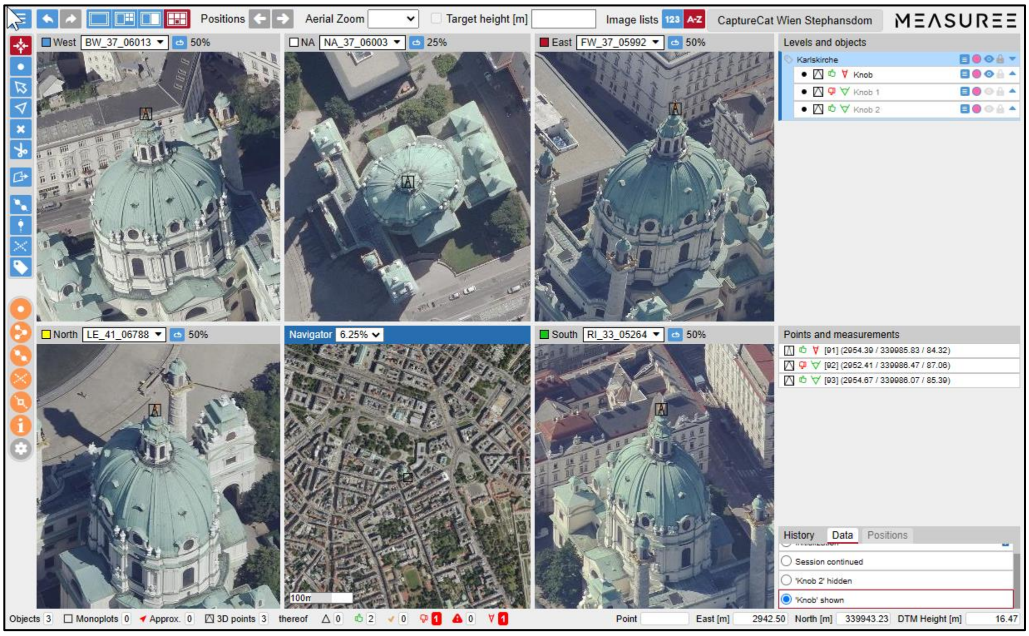


Fig. 38: Knob of the main dome of the Karlskirche Vienna (2020) measured in two nadir images with too small a cutting angle (strong height offset is visible in the oblique images)

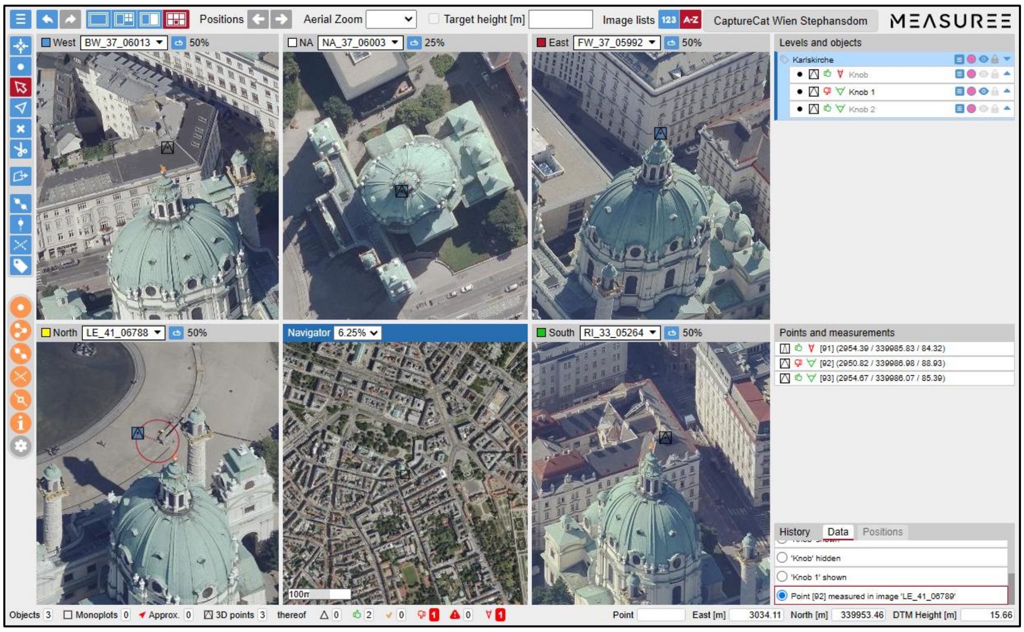


Fig. 39: Knob of the main dome of the Karlskirche Vienna (2020) measured in one nadir and two oblique images with a gross error in the north-facing image (largest error circle)

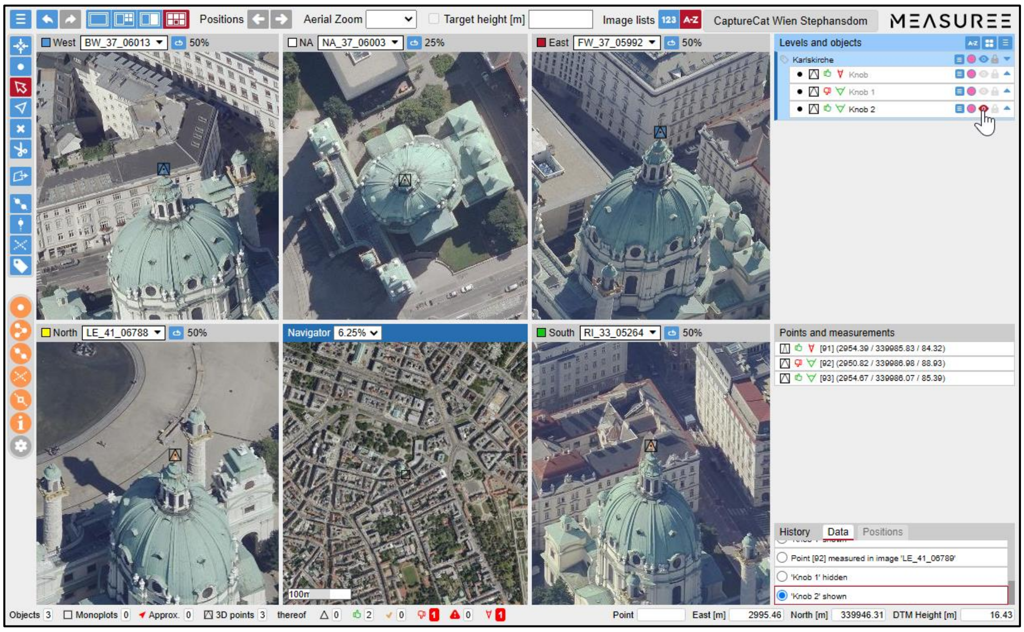


Fig. 40: Knob of the main dome of the Karlskirche Vienna (2020) correctly measured in a nadir image and two oblique images

Tracking construction changes based on several flights using the example of the Mur run-of-river power plant in Graz-Puntigam (Austria)

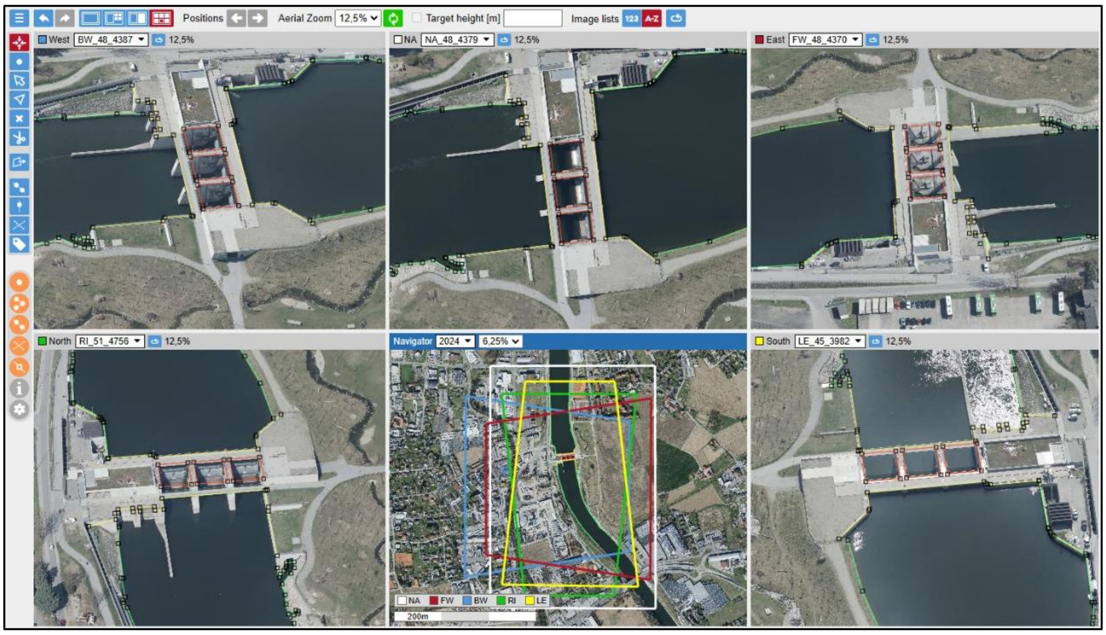


Fig. 41: 2024

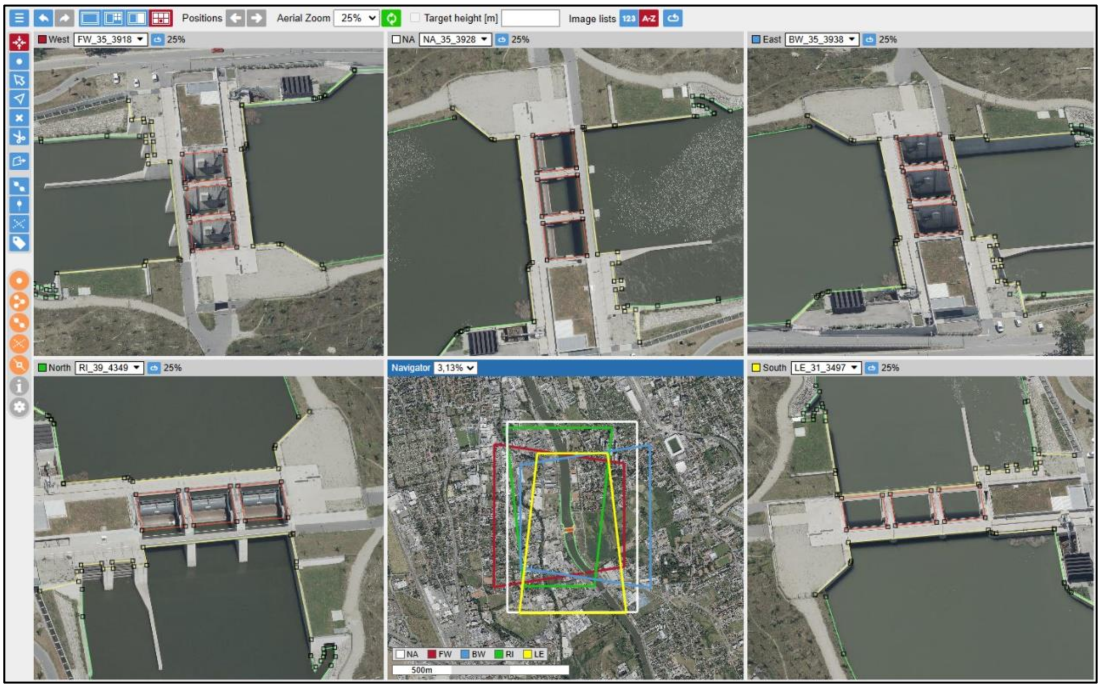


Fig. 42: 2022

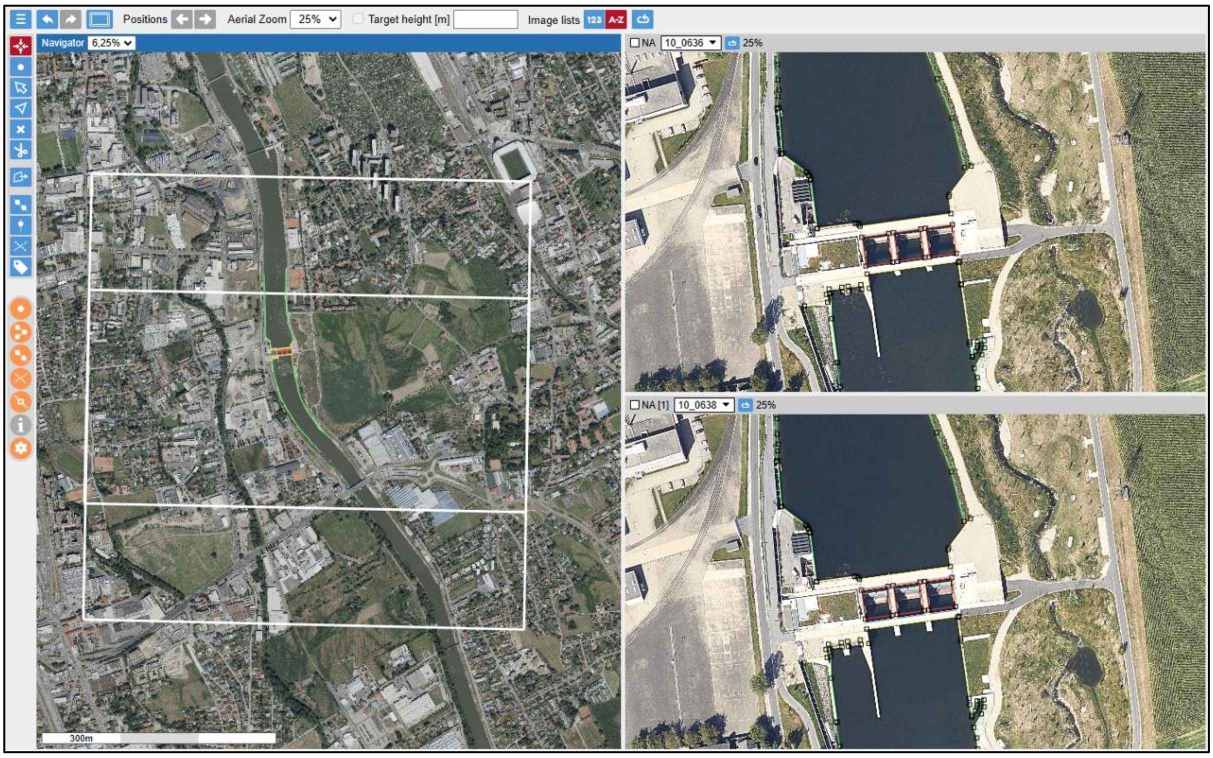


Fig. 43: 2021

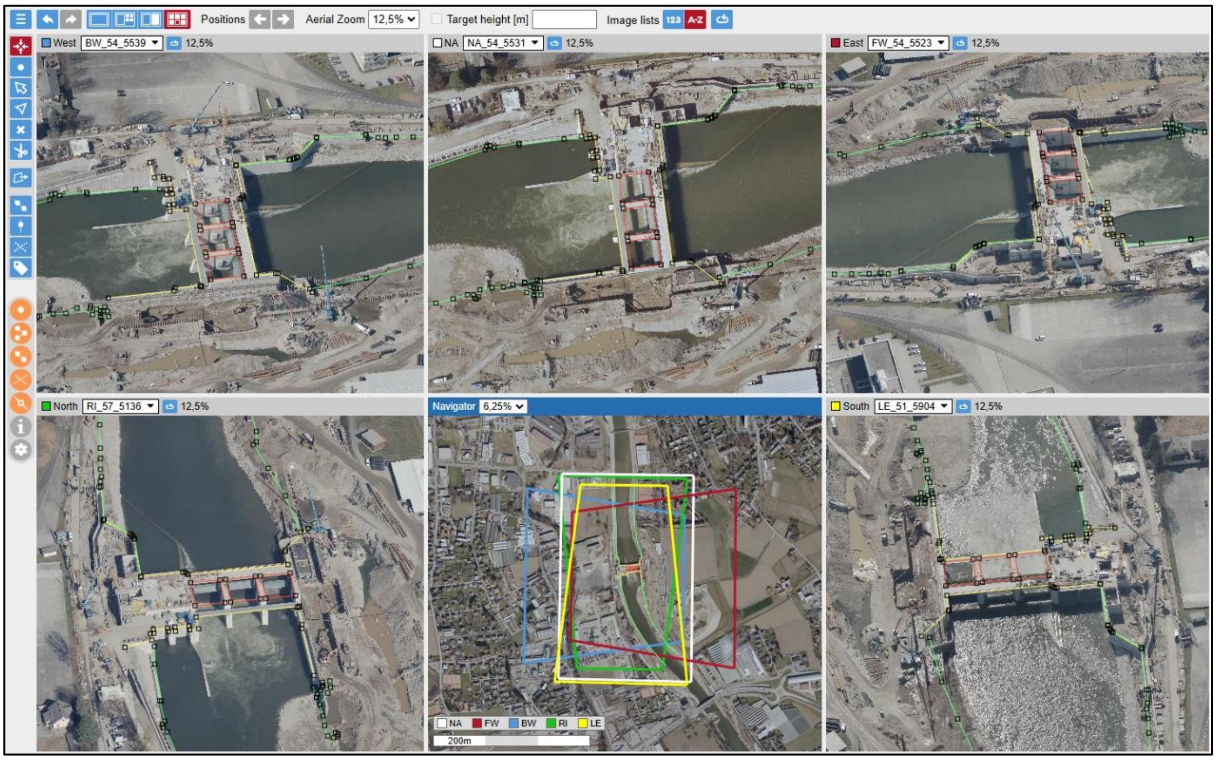


Fig. 44: 2019

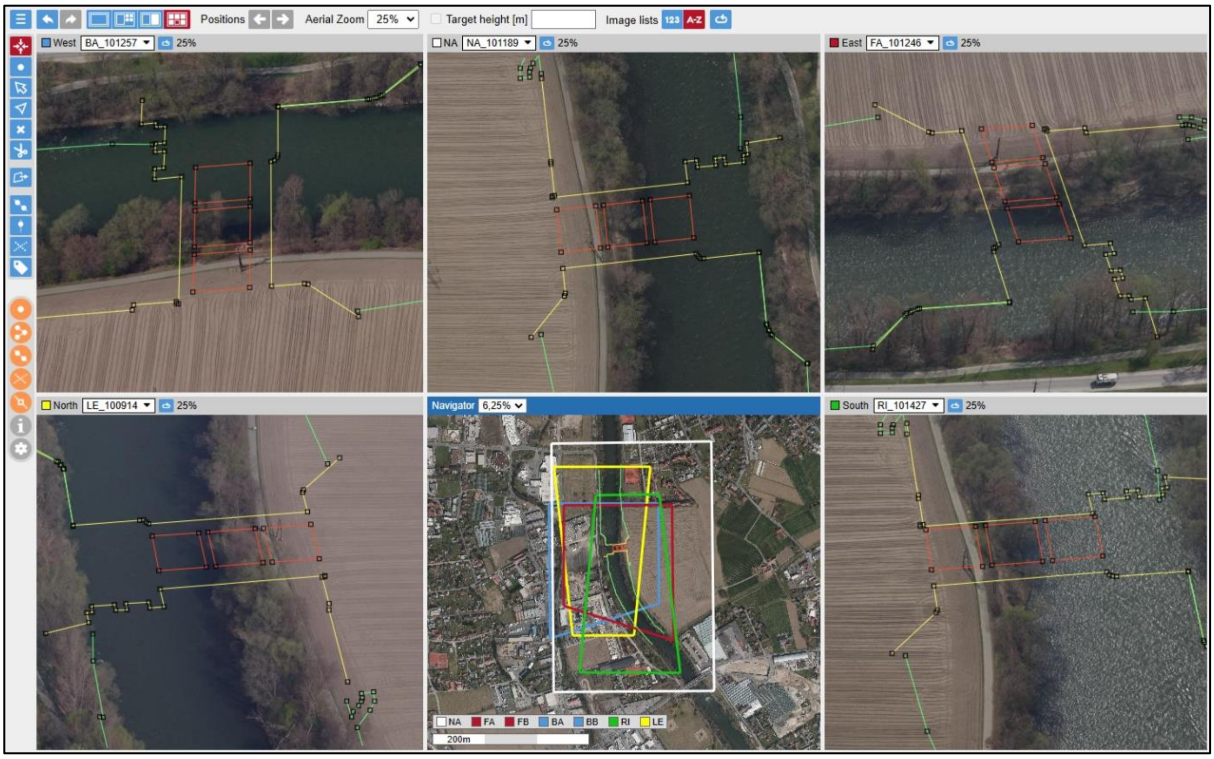


Fig. 45: 2015

Fig. 46: 1968


Positions
Aerial Zoom
50%
Target height [m]
Image lists
123
A-Z
Navigator
25%
N2
1959021_002C_2617
50%
N2 [1]
1959021_002C_2619
50%
N1
N2
90m

Fig. 47: 1959