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PRS

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3D Data Acquisition, Modeling, and Visualization of Archaeological Sites

Geodetic Project Course

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Supervision

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Contents

Nomenclature

Acronyms and Abbreviations

GNSS	Global Navigation Stallite System
TLS	Terrestrial Laser Scan
GPC	Geodetic Project Course
ETH	Eidgenössische Technische Hochschule
RC	Reality Capture
NeRF	Neural Radiance Fields

Introduction

The Geodetic Project Course is a biannual field course offered by the Institute of Geodesy and Photogrammetry, which aims to provide students with practical experience in a geomatics related domain. Of the two available projects this year, ours deals with 3D reconstruction and visualization of historical sites. From the first steps of planning, through the data acquisition and processing to the final product, we are tasked with carrying out the work under appropriate supervision.
Reconstruction and preservation of historical heritage is an important aspect of archaeology and geodesy. In coordination with the archaeological services of the Canton Grisons, with Thomas Reitmaier, we analyse two sites situated in the region of the lower Engadin.
The first site is the Steinsberg Castle in Ardez. The castle which was built in 12th century occupies the highest point of the hill, with walls extending to the boundary of the plateau. Our main interest, however, not only covers the tower, but also the ruins of the chapel, the cliff nearby, as well as the environment around. The second site is the Fortezza Rohan in Susch. The fortress was built in 17th century dating back to the Thirty Yearsâ War. Walls made of small pieces of stones are between 2.5m and 5m with wooden spikes to prevent enemies. There is also a two-floor tower located on the north-west corner of the site. Here, we focus on the whole fortress as well as the environment around. We use a combination of terrestrial laser scanners (TLS), drones, RGB cameras, and GNSS to acquire sufficient data at reasonable levels of detail for the areas of interest.
For our project, we set up two objectives:

1. create data acquisition, modeling, and visualization pipelines specifically designed for historical heritages.

2. reconstruct high-quality 3D models of ruins and their surrounding environments in Ardez and Susch for documentation, archeological analysis, and public demonstration.

Method

Data Acquisition

Four types of instruments haven been involved during the data acquisition, they are: GNSS station, Terrestrial laser scanner, drone, and camera.

Figure 1: Selected instruments for data acquisition (left: GNSS station, middle: terrestrial laser scan, right: drone)

GNSS

In total, 5 Emlid RS2+ GNSS stations have been used during the project. Within each site, 3 of them were mounted on the leveled tripod to form a local RTK network and planned for long term measurements longer than 24 hours. The locations to put stations were picked based on the following criteria: a) open area: to ensure a good sky view and avoid obstacles that can affect GNSS signals or cause multipath effect. b) stable surface: to ensure that stations can stay stable and leveled during the whole measuring process. One of the three stations was used as the base station to send the correction data to the GNSS station, the other two were mainly used for post-processing purposes. In Ardez, this base station was setup above one of Swisstopo's benchmark points where more accurate coordinates were available. In Susch, the station that better fulfilled the criteria listed before was selected as the base station. The remaining 2 GNSS stations were used as rovers to acquire accurate coordinates for targets that were setup in each site. All GNSS stations were connected with the phone through Emlid Flow app where settings for GNSS (mode, GNSS systems, and update rate) and logging (output format, log interval, and etc.) were set. Depending on the type of GNSS stations (base station, or rover), additional settings were set.
To provide references for the registration and georeferencing of laser scanning point clouds, drone photos, and camera photos, a great number of targets were setup in each site. Two types of targets

were available: paper and hard copy targets. Paper targets were taped on the wall of buildings or trees, and hard copy targets were put mainly on the ground with flat surface. Rovers were brought to each hard copy target on a daily basis to ensure the coordinates of the targets remain nearly unchanged. Targets whose location did change were recorded and brought back to the correct location.

Terrestrial Laser Scan

Terrestrial Laser Scans (TLS) are capable of generating high accuracy point clouds of 3D scenes. They work by casting laser rays in a 360 degree view and determine the distance to points of reflection by travel time. These instruments are ideal for capturing detailed scene geometry. We mainly employed a Leica RTC360 3D Laser Scanner. This device is very easy to handle, as it features a highly user friendly interface with few parameters. The four parameters we do have access to are:

- Point density - (low, medium or high)
- Single or double rotation
- RGB 360 Photo
- SLAM for on-the-go registration

All acquisitions were done with double rotation, and with RGB camera and SLAM enabled. The point density was varied depending on the level of detail required. However, this procedure was not strictly followed and most scans were performed in high density mode, resulting in very high density point clouds and more demanding data processing. More on this in the data processing section

An individual scan is referred to as a "setup". Setups are organized into "Jobs", which we use to distinguish between setups belonging to different areas of interest or acquired on different days. Although the RTC360 is capable of determining relative position between setups using the built-in SLAM feature, these positions are quite rough, and require further registration processing. Point cloud registration refers to the alignment of 3D points from different setups to ensure scene consistency. In order to ensure proper registration there should be enough overlap between scenes. Consequently, the setup locations need to be planned in advance in order to cover an area of interest in the least amount of stations. In addition to pure point cloud registration, we employ paper targets attached to vertical surfaces in order to find correspondences between setups. The placement of these targets were based on the placement of our TLS setups. Lastly, we need to ensure that within a well registered set of setups, there are at least 4 visible ground targets, which we measure with RTK, to be able to perform the georeferencing.

Depending on the point density selected, each individual scan takes either 2 min and 40 sec, or 4 min and 21 sec, given all the other parameters remain the same. During scanning all individuals hide from the sight of the scanner, and unwanted objects such as backpacks are removed. The RTC operator typically hides underneath the tripod of the instrument, out of view of the scan. The instrument performs two rotations casting rays to the scene, and one final rotation in order to capture images used to color the point cloud for ease of later registration and human scene understanding.

Drone

For drones, DJI Phantom 4 Pro and DJI Mavic Mini 2 both equipped with an RGB camera were used. They provided large coverage for reconstructing the environment and could collect data from places that are not easy to reach such as rooftop or cliff. Combining photos taken from camera and images take by drones, we acquired enough data for high-quality reconstruction.

Before each drone flight, corresponding plannings were made. For each site, a rough flight was always planned ahead. The rough flight aimed to acquire images that could be used for photogrammetry to create a detailed terrain model for further planning. The rough flight plan was made in

the Drone Harmony, and rule of thumb was to keep the altitude high, and the covering area large so that more information about the Areas of interest could be collected while ensuring the flight safety at the meantime. The drone photos acquired during the rough flight were then imported into the Metashape. Within the software, drone images were aligned and points clouds as well as the textured mesh model of the terrain were produced.
After acquiring the terrain model, detailed flight plans were created for each area of interest. The steps can be summarized as:

1. Choose a point on the flat terrain near the area of interest and set it as the home point for the drone to take off and land
2. Create a polygon around the area of interest to define the interesting zone where the drone flight will focus
3. Create polygons around tall trees or forests to define the restricted zones to avoid colliding.
4. Specify the flight settings depending on the purpose of the flight, the parameters that should be adjusted are:
    - Camera model: correct camera models should be set for Phantom and Mini 2 so that proper focal length can be determined.
    - Resolution/Image overlap: for resolution, large GSD, usually 1.0, is set for missions aiming to capture the environment, and 0.5 is set for other missions. For image overlap, 70% is usually used to facilitate the image alignment in later steps.
    - Safe distance/Min altitude: these two together determine how close the drone can fly to the area of interest and are mainly for obstacle avoidance purpose. Different combinations are tested in the sight and flight plans are also adjusted accordingly.
5. Export flight plans in kml format and import into the Drone Harmony.

While most of time terrain models were good enough for planning, it didn't work so well in our second site Susch where forests locate very close to the area of interest. The images taken during the rough plan was enough to reconstruct the general structure of the terrain but failed to reproduce even the basic structure for trees which significantly increased the risk for collision during the flight. In this case, manual flights were also planned.

Camera

Since terrestrial images of objects have higher resolution than drone images, they can be used to create detailed texture and also can serve as a complement to drone data for reconstruction, especially for near-ground areas and drone-restricted areas. We used Nikon D2Xs and Nikon D3X to take photos. For initial state adjustment, there are several important parameters to set up, which can take the exposure compensation value as reference during adjustment.

- Aperture value: set the aperture size to as small as possible to have a larger depth of field
- Shutter speed: keep a fast enough shutter speed to avoid motion blur
- White balance: set white balance to a reasonable number such as 5k-6k
- ISO Sensitivity: it determines the camera's sensitivity to light. Adjust ISO from a small value and not use high ISO

These photos should have sufficient overlap both vertically and horizontally for at least 50% and adequate visibility of target markers, which are both important for further image alignment in Reality Capture. An efficient way to ensure a certain degree of overlap is to find an object as a reference and check its relative movement on images between different locations. When taking pictures, keep parameters constant and try to keep the same distance from target object. We took photos for chapel, tower and cliff in Ardez, and for wall, spike and tower in Susch. For chapel in Ardez, photos are taken with 35mm focal length and 18mm focal length separately. The longer the focal length is, the smaller the distortion while the field for each frame narrows, thus with less information of the target object.

Data Processing

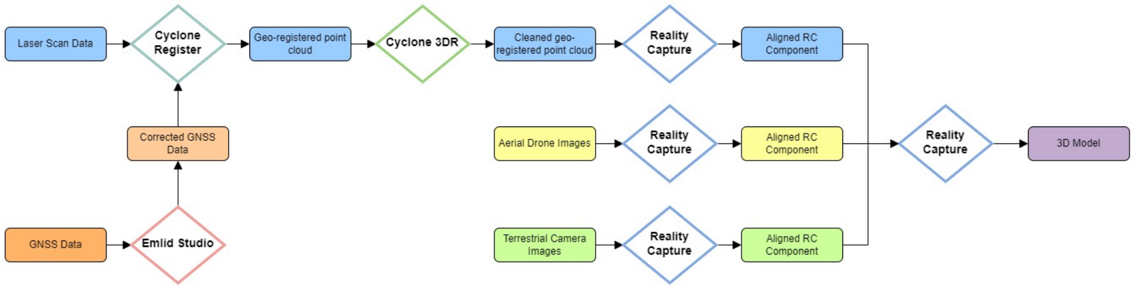


Figure 2: A simplified flowchart illustrating the data sources, software and outputs of the entire data processing pipeline.

GNSS

For the post-processing step of the GNSS data, two different softwares were used. Emlid Studio is a simple application designed for post-processing GNSS data. To determine the precise position of the base-stations that were set up, Reach 7 in Ardez and Reach 10 in Susch, the raw data of those two receivers and the raw data of a constantly operating reference station (CORS) were processed using this software. As the CORS station the AGNES reference station in Ardez (ARD2) was chosen for both sites. Every coordinate that has a FIX solution was then averaged so that one final solution could be determined. In Ardez the base station was set up on a benchmark point. Therefore, as an additional checkup, the coordinates of this beckmark point was used to test the accuracy of our GNSS measurements. In Table 1, the difference between the base station coordinates that was used for the RTK measurements and the benchmark point coordinates, as well as the difference between the post processed base station coordinates and the benchmark point coordinates are shown.

	Y-coordinates	**X-coordinates**	**Height**
Raw data	0.5370 m	0.6560 m	0.8881 m
Emlid Studio	0.0170 m	0.0210 m	0.0120 m
Bernese	0.6318 m	0.6492 m	0.0887 m

Table 1: Difference between the benchmark point coordinates and the measured coordinates at different processing steps.

The second software that was used for post-processing the GNSS data is Bernese. For post-processing the raw data using Bernese, the rinex files that were exported from the Emlid RS2+ receivers had to be converted to the right format in a first step. As Bernese needs Rinex 2.11 files the Rinex 3 files that were exported had to be downgraded using the program GFZRNX. The Emlid RS2+ receivers record data for 24 hours, therefore the rinex files include data from two different days. For this reason, the files had to be split by day and put together afterwards, so that a single rinex file only includes data for one specific day. For these steps the TEQC software was used.
The Bernese software has five processing steps:

1. Preparation of the earth orientation parameters, GNSS orbits and GNSS satellite clock information
2. Conversion to the Bernese input file format and synchronization of the observation data using the program CODSPP
3. Form baselines and preprocess the phase data, so the coordinates and troposphere parameters can be estimated in part 5
4. Resolve the phase ambiguities
5. Compute the ambiguity-fixed network solution to get the estimates of the station coordinates

For the processing with Bernese, three reference stations from Agnes, ARD2, DAV2 and SAM2 were included, so the software was able to do a least squares adjustment using several baselines. The data was downsampled from 1 s to 30 s and only the data from GPS and Glonass satellites were used for processing with Bernese. The a posteriori RMS that was determined is 1.5 mm.
After the coordinates were determined using Bernese, the difference between the raw coordinates that were used for RTK and the post-processed coordinates were calculated to determine the offset. To increase the accuracy of the georeferencing, this offset has to be applied on each target point, that was used for georeferencing the model. In Table 2, these offsets are shown for the base-stations at both sites.

	Processing technique	**Y-coordinates**	**X-coordinates**	**Height**
Ardez	Emlid Studio	0.0163 m	-0.0204 m	0.1642 m
	Bernese	-0.6330 m	-0.6485 m	1.5895 m
Susch	Emlid Studio	1.2303 m	1.3675 m	-0.7437 m
	Bernese	0.5459 m	0.7344 m	0.7375 m

Table 2: Difference between the base station coordinates that were used for RTK and the coordinates after post-processing.

Looking at the offsets, determined by the results from Emlid Studio, the offset in Ardez is much smaller than the one in Susch, which can be explained due to the proximity of the CORS station, that was used for post-processing. At the base station in Susch some problems with the batteries were encoutered, which led to the fact that this receiver was not operating continuously during the data acquisition. This factor may be a further reason for the lower positioning accuracy in Susch. The offsets determined by Bernese are more consistent at both sites than the Emlid Studio offsets. The biggest offsets can be seen in the height component, which was expected as GNSS is not able to determine the height component as accurately as the x- and y-coordinates. To increase the accuracy of the georeferencing, either one of those offset values can be added to the final model.

Terrestrial Laser Scan

For registering and georeferencing the point cloud measured by RTC, the software Cyclone Register 360 was used. After importing the point clouds, the links between the individual settings had to be found. For this step, the point clouds were aligned manualy, then an optimization was carried out by the software.
For the site in Ardez, the point clouds of the chapel and the tower had enough overlap to register those two areas together, however there amount of overlapping point clouds was very low. Only two links could be found with an overlap of 12% and 59% respectively. Doing the georeferencing in a next step, showed that the error of the target coordinates were between 1 mm and 3 cm. The targets with the lowest error values, were those that were located near the tower, the targets located near the chapel had error values of roughly 1 cm. This showed that the registration of those two larger areas, tower and chapel, was not stable. For further processing, the two areas were separated. The errors of the target coordinates after georeferencing the chapel separately

were between 0.2 cm and 1.2 cm. The scans of the cliff in Ardez were registered in a separate project as there were no scans that could have connected those areas.

For the site in Susch, all the scans could be linked and registered in one project. After completing the registration, the point clouds were once again georeferenced using the raw coordinates that were measured on site. The targets that are visible in the scans were then used as control points for the registration.

After georeferencing, the point clouds were denoised and cleaned with the software Cyclone 3DR. The basic principle is that we want to keep areas of interest (chapel, tower and cliff in Ardez, fortress in Susch). We also keep bushes and some terrain features around the areas of interest that could be recognized as features. Noisy points, unnecessary grass and trees are deleted.

Drone and Camera

In our project, the extent of the photogrammetry data processing is limited to data cleaning of unused, over/under exposed photos, and the simple organisation of the data into different "components" and the alignment of the images within these components. Unfortunately, we do not perform any color correction pre-reconstruction, nor do we perform any feature enhancing steps for facilitated reconstruction. This in spite of the fact that Reality Capture manages such files quite well with the concept of *image layers*. We leave this for future work.

Component alignment is theoretically quite a simple task, given that the datasets exhibit sufficient overlap and structure. In that case the result of the image alignment in Reality Capture should be one single consistent component. When this is not the case, we have to manually define control points in the scene that are visible in several images of several components at once. In general, it is sufficient to define 4 points in two different images from each component. Then Reality Capture will make a number of suggestions which we can adjust, confirm and add to the list of control points. Performing the "Merge Components" operation will then merge the individual components. In general we try to merge two components at a time until only one remains.

Color correction has been applied to some images for testing purpose. Before conducting any drone or camera missions, photos of the color plate were taken under the corresponding light condition. Theses photos were first imported into the Lightroom Classic to build up a color profile. The same color profile was applied to all photos within the mission. In addition, white balance was also conducted.

Modelling

Most of the modeling process itself is performed within the software called *Reality Capture* (RC). RC is a photogrammetry software enabling the generation, texturing and rendering of 3D models from simple sets of images. The basic steps of the modelling process can be summarized as follows: add input images to project, align images to find tie points and reconstruct scene vertices, manual alignment using control points in case RC cannot merge all components, scene reconstruction through the creation of a mesh, and finally model texturing. To perform these steps RC reads the camera parameters from the image file metadata.

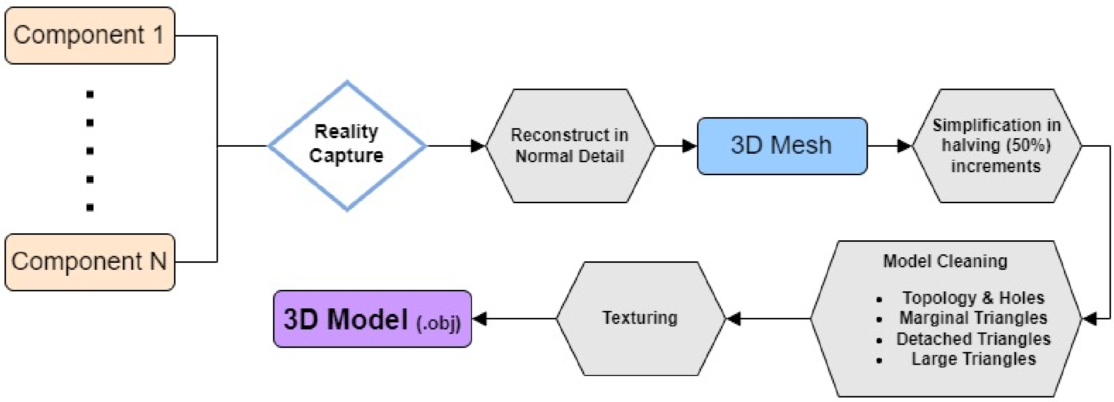


Figure 3: A simplified flowchart illustrating the 3D model generation in Reality Capture. This chart assumes the individual components have already been aligned.

3D reconstruction is a computationally tedious task and requires a lot of computational resources. To alleviate this we divide our data into different "components". Components allow us to separate a large task into a number of smaller and more manageable tasks. Reality Capture also performs better with smaller, well composed datasets, as it has a tendency to find statistically significant although incorrect correspondences when operating with large numbers of images. In addition to the computational benefits, it also has greater control of what data is used for what purposes, or even included in the model. This without having to realign all the images again if we decide to make changes. For the modelling process it is also interesting as it allows us to use the different modalities in complementary ways, such as by disabling texturing for laser scans, or disabling meshing for terrestrial photogrammetry for faster reconstruction. Components are the outputs of image alignment, and can be exported from the project as "Reality Capture Alignment Components" for later use. When importing a component into a new project or when opening on a new computer, the absolute path used to reference the input images may not be valid anymore. Luckily RC handles this pretty well. For every folder containing a set of input images, RC asks you to locate the path of one of these images in the new environment, and then automatically infers the path of the rest. This allows for relatively easy workload distribution amongst several computers.

As with the image alignment, if the "Merge Components" operation does not result in one component, control points are needed for further alignment. Next we reconstruct the scene in "Normal Detail". This operation is the most demanding one, and may typically take several hours depending on the size of the dataset. In our case reconstruction at normal detail level took 05h45m for Ardez and 04h50m for Susch, with a resulting mesh of 302M and 538M triangles respectively, all using 16GB GPUs. This is too much detail for most applications, and way too many triangles for RC to display at once. Therefore we perform simplification steps, reducing the number of triangles by half until we reach a reasonable number. We decided to aim for less than 40M triangles, as this is the typical upper limit RC is able to render at once. Simplification operation may take several hours for the first step, but then computation time is significantly reduced as the number of triangles decreases. In addition to the rendering issues, models with several hundred million triangles are large and occupy a lot of disc space. For reference our models represent ....

Once the desired number of triangles is reached we may clean the model. In particular we want to solve topological defects, remove detached triangles, remove large triangles and close holes in the mesh. Although this is the recommend way of cleaning meshes as suggested in RC's own tutorials, one needs to make sure that no unwanted triangles are selected and filtered, resulting in loss of information.

Next we want to texture our model. Before texturing we need to unwrap the model by defining a desired texel size. Typical texel values include 2mm, 4mm and 10mm. Due to the size of our models we employ a fixed texel size of 10mm. We ensure that the laser scan inputs are not used

for texturing by toggling the option in the selected input settings. Additionally we make sure that large triangles, such as those resulting from closing holes, are also textured by increasing the "Large triangle removal threshold" to 1000 in the unwrap settings.
Once the mesh is textured we can visually inspect our model and check for any mistakes. Now we have a fully textured model, of which we can create fly-through videos and render images directly in Reality Capture for showcasing purposes. Once the model has been sufficiently captured, we can export the model as an *.obj* file with the textures enabled and stored as *jpg*.

NeRF

Neural Radiance Fields (NeRF) is one of the state-of-art techniques in computer graphics and computer vision. It is a powerful deep learning-based tool for representing and visualizing complex 3D scenes. We planned a circle drone flight for Ardez tower specifically and apply NeRF on the captured 100 images. Software nerfstudio on Linux is used for our nerf view syntesis. Figure 4 shows the pipeline for NeRF generation.

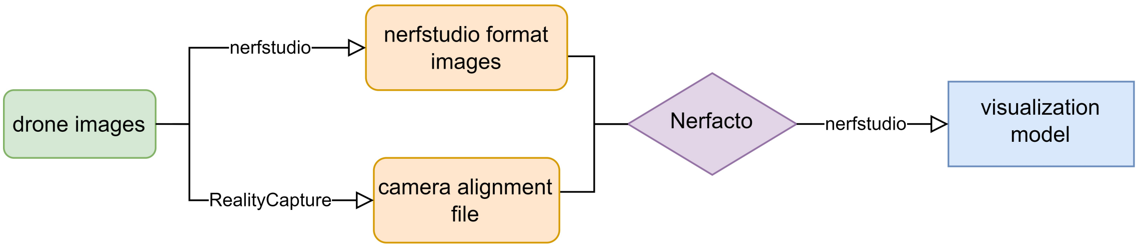


Figure 4: A flowchart illustrating the NeRF model generation in nerfstudio.

Drone images have to be converted into nerfstudio format for further processing. Besides drone images, nerfstudio also needs internal/external camera registration parameters of these images to train NeRF model. These images are first aligned in Reality Capture and their registration file is then exported, which serves as input together with converted images for model training in nerfstudio. In terms of the concrete method to train NeRF model, there are plenty of NeRF techniques from published work provided in nerfstudio. Nerfacto is finally selected, which is also the default method for real data captures of static scenes. Final results can be exported as mesh or cloud points and fly-through videos can be rendered as well in this software.

Results

Geometry

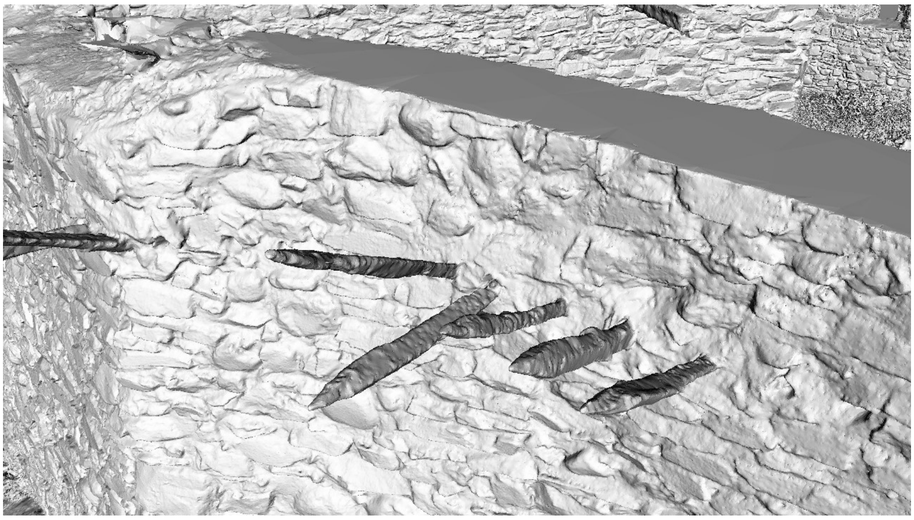
In 3D reconstruction, the most important thing to get right is the geometry, in other words the accuracy of the mesh. The accuracy required depends on the purpose and intended use of the model. A model purely for visualization purposes hosted on a website requires way less detail than an archived digital twin. Given the instruments provided for this project, it is within our reach to reconstruct our sites in relatively high detail. Moreover, we also want to show our objects of interest in their surroundings, which significantly increases the size of our area of interest. Acquiring the entire model in the same level of detail would be too daunting, and due to large amounts of vegetation, an nearly impossible task. Hence we aim to acquire our objects of interest in high-fidelity geometry, and just capture the main physical features of the surroundings. Mesh quality is solely evaluated visually.

We display the geometry and texturing separately to avoid one overshadowing the other. Inaccurate, plain or deformed geometry can often be hidden by well captured textures. The term geometry in this context refers to the mesh created from the 2D image correspondences cast into 3D points, and is the product of the reconstruction step. The mesh itself is composed of a number, several million typically, of 3D triangles. This is the most common way to represent 3D surfaces in computer graphics. As described in section we simplify our models in halving steps. We hereby refer to each of these models by the name of the site and the number of triangles in the mesh.

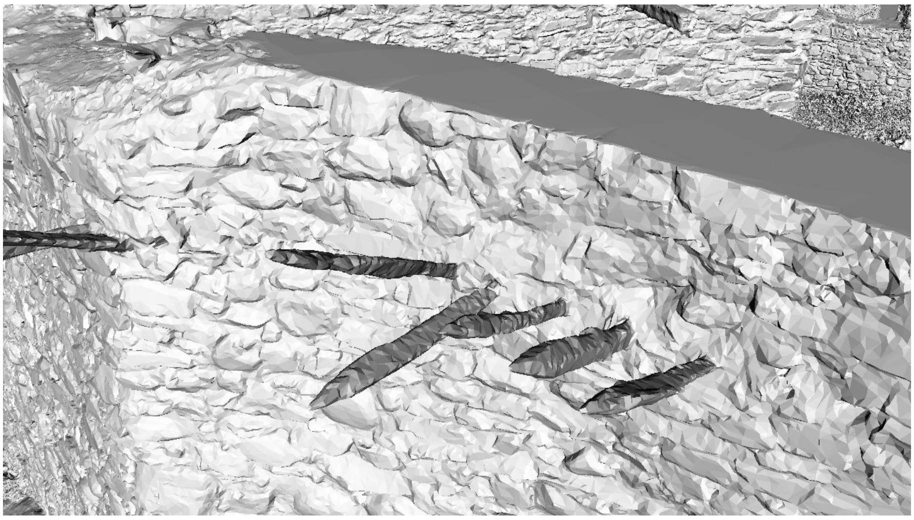
Showcased in this report are the models in normal detail, before cleaning, and the cleaned simplified models. In normal detail we create meshes of several hundred million triangles. This is not ideal for certain purposes, but the geometry contains a lot more detail. Indeed, upon inspecting our mesh we see that the objects of interest - the stone masonry, wooden spikes, doorways - are captured in a high level of detail. For instance figure 5 showcases a close up of the tower at the Ardez site, where we can clearly make out every stone in the wall, idem for the wall from the Fortezza Rohan in figure 5. Even the vegetation is captured in high detail, meaning a high number of triangles. This is not ideal however, because the vegetation is not captured accurately and exhibits a high level of noise. Additionally this information is not needed.

Simplification steps	**Ardez**	**Susch**
0	302M	538M
1	150M	269M
2	75M	135M
3	37M	67M
4	...	34M

Table 3: The different models after simplification, referred to by their number of triangles in millions.

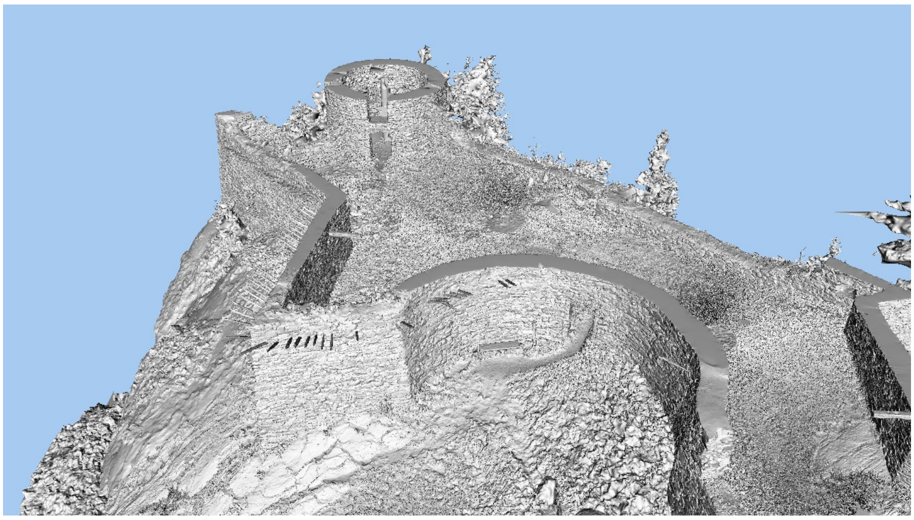


(a)

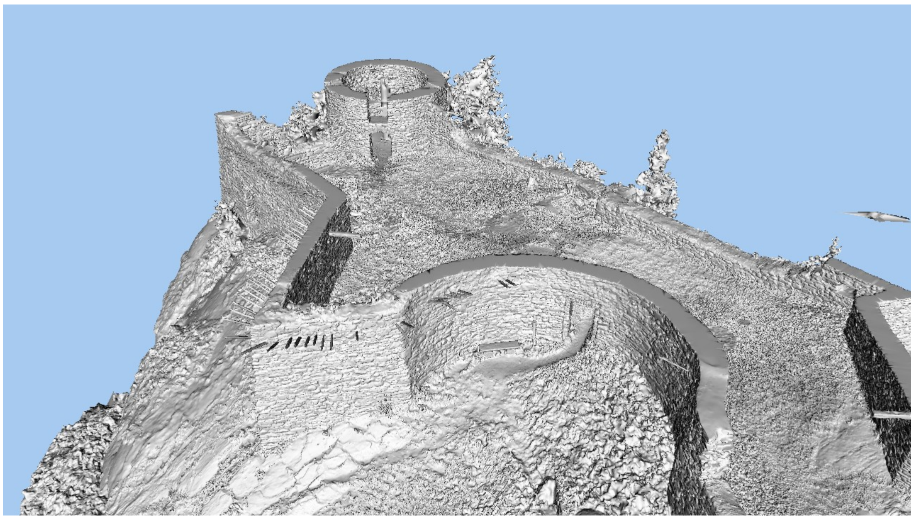


(b)

Figure 5: (a) A rendered image of the south-facing exterior wall of the susch_538M model. (b) As for (a) but with the simplified susch_34M model. We see that the details of the stone masonry is captured in high accuracy, same for the wooden spikes. Notice the lower number of triangles in (b). The top of the wall is flat due to a mistake in defining the reconstruction area, which cuts through the wall.

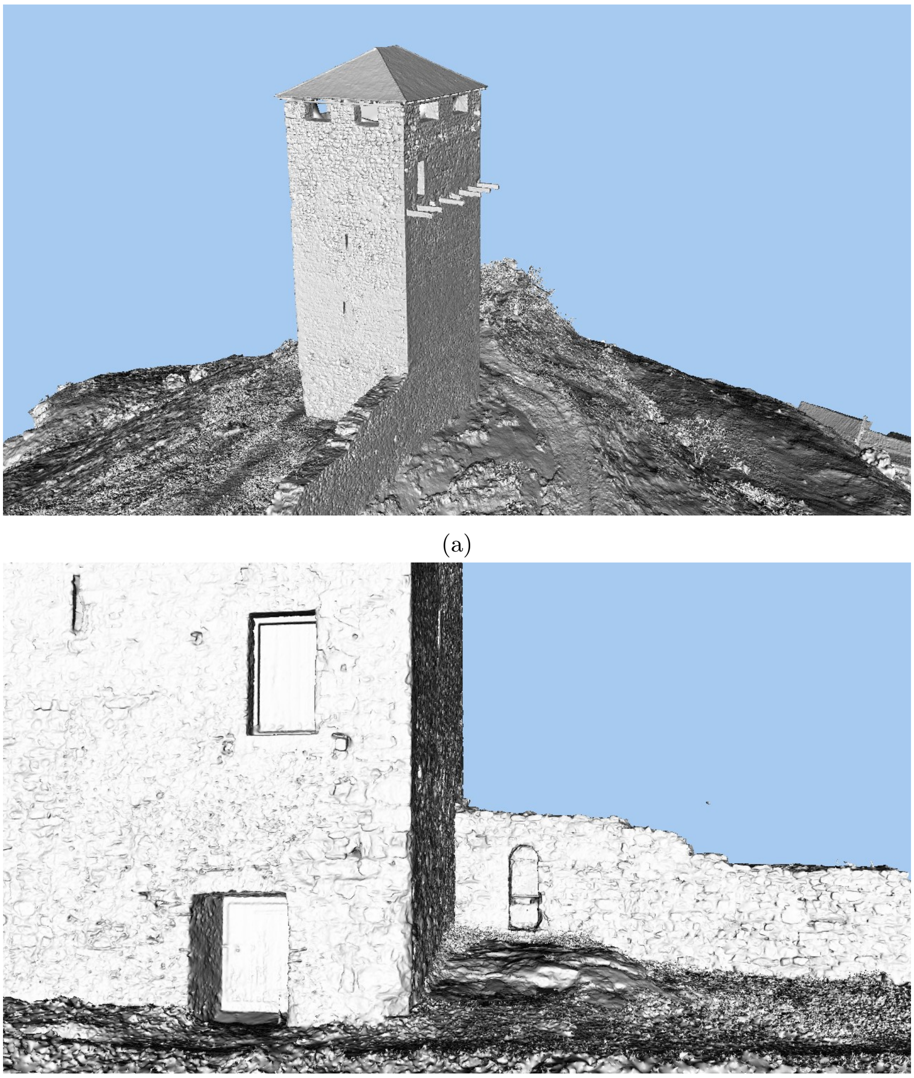


(a)



(b)

Figure 6: (a) A bird's eye look on the susch_538M model. (b) As for (a) but for the susch_34M model.



(a)

(b)

Figure 7: (a) Steinberg Castle tower from the Ardez tower. Model with 302M triangles. (b) Showcasing the details on the doorways of the Steinberg Castle tower with 302M triangles.

Texturing

Model texturing first and foremost serves the purpose of visualization. Hence we aim to achieve realistic looking textures, able to capture interesting and vivid details on the objects of interest- Additionally, as the data acquisitions campaign lasted several days, we might encounter the problem of inconsistent texturing due to color differences or differences in lighting.

The textures look good from afar, but some challenges still remain to achieve high resolution texturing. One reason might be how we save the textures in one file instead of several different jpg files. This has however not been investigated further.

(a)

(b)

Figure 8: (a) Bird's eye view of the inner fortress section of the Fortezza Rohan, rendered with texture from the 34M model. (b) A rendered image from the Fortezza Rohan entrance using the same textured model.

(a)

(b)

Figure 9: (a) A textured render of the Steinberg Castle at the top of the Ardez site. Textured model with 37M triangles.

NeRF

The output of the NeRF is a fly around video about the area of interest, which can be found in the *04_final/01_nerfstudio* folder. See appendix C for more information on folder structure.

Figure 10: NeRF: Steinsberg Castle (Ardez)

Discussion

Modelling

Our assessment is that the models both achieve satisfactory level of detail and coverage. The geometry is integrally represented, and the textures are in general satisfactory. Nevertheless we encountered a few issues we would like to mention.

One of the main challenges was the computational resources, paired with the amount of manual work to clean and align data. Hence our first take-away is to plan for more efficient data acquisition. For example, we did not have to perform all scans in high density. Additionally, some setups exhibit a superfluous level of overlap, leading us to conclude that the site could have been captured with fewer scans. This is particularly relevant for measurements done at the start of the project, when we had less experience and knowledge. Second, we would like to highlight the issues with automatic alignment in RC. Especially for terrestrial photogrammetry this was challenging. Consequently we lost a lot of time aligning these scenes manually. Third, we had some issues cleaning the laser scans. Laser scans were cleaned in order to remove dense point clouds on objects we judged less essential, like the ground and vegetation, especially in monotonous areas. This task was further complicated for the Susch acquisitions, due to an inability to zoom in properly in the Cyclone 3DR software. The result of this was far too much detail on areas such as grass, which occupies computational resources. A potential solution to this would be to employ a more intelligent simplification scheme, in which we select the desired areas and simplify them independently from areas such as the walls where we want to maintain the high level of detail.

Problems

We have encountered many problems during GPC:

- Software error: drone flight plan generated from Metashape can not be imported into Drone Harmony successfully due to the software bug. Reality Capture crashes down when processing too much data.

- Field work condition: severe windy days for drone flight. Sites are surrounded by tall trees and cliffs, which makes it difficult to fly drones and instruments set up. Plans sometimes would be interrupted by inhabitants with limited knowledge about geodetic work.

- Color correction for images: color correction images can not be correctly applied during the texturing of the model. The results basically do not change before and after color correction with codes.

- Registration and alignment failure: point clouds sometimes can not be registered even with manual control points, the same situation also for image alignment.

- NeRF for Susch: NeRF can not work well when handling all aligned images (2,278 images) of Susch collected by different instruments or devices.

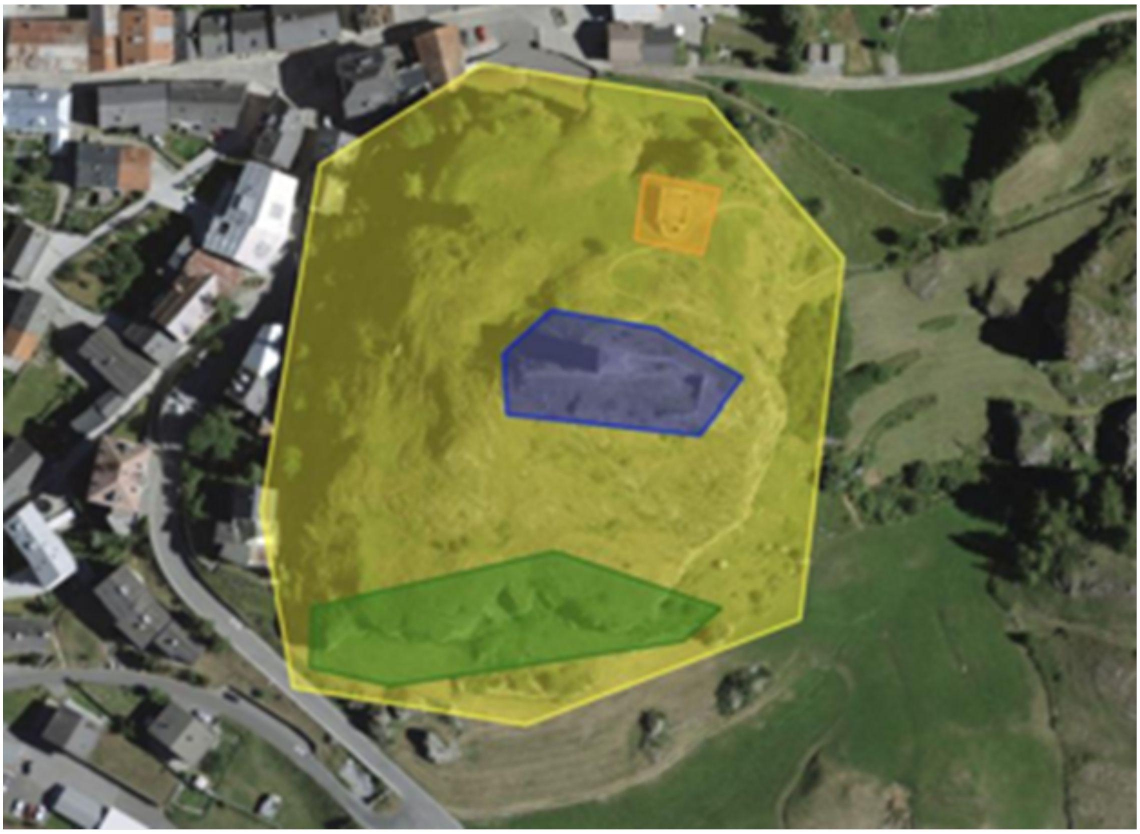
Future direction

There are some directions to be explored in the future:

- Modify the current pipeline and explore a faster data processing procedure maybe with stronger computing power
- Make comparisons of models created by different methods and softwares
- Set weights for different data sources when texturing to get more detailed and realistic textures on the mesh
- Create host model on website
- Compare BLK2GO data and RTC data

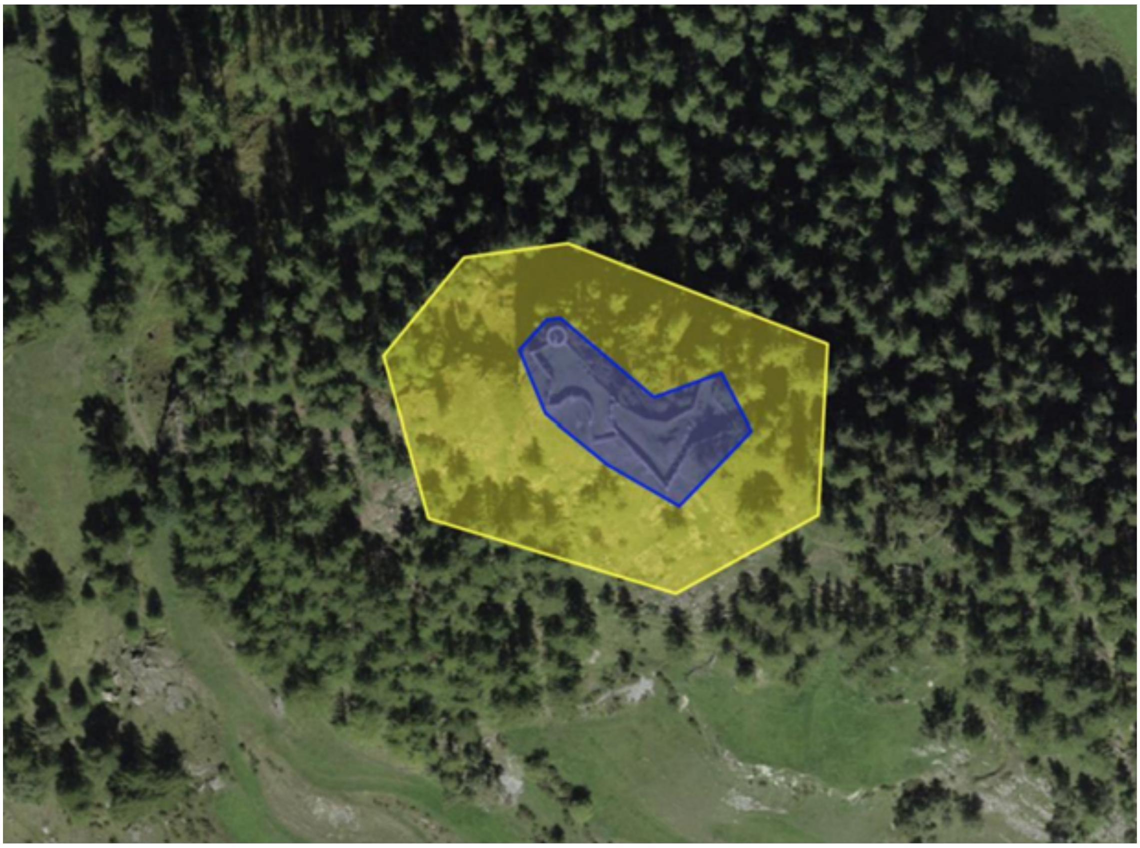
Appendix A

Sites



Ardez

Figure A.1: Area of interest in Ardez



Susch

Figure A.2: Area of interest in Susch

Appendix B

GNSS

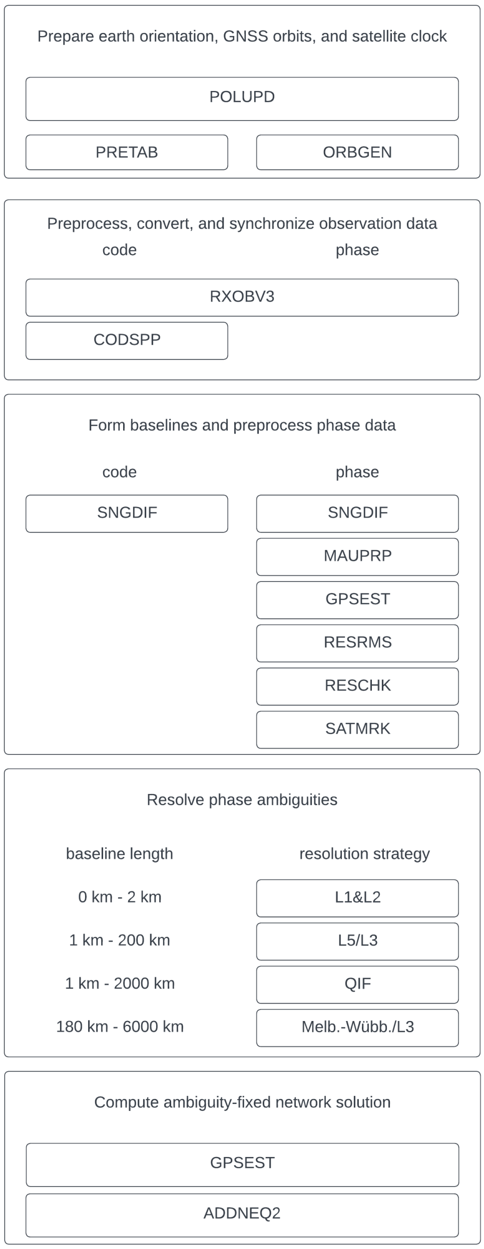


Figure B.1: A flowchart illustrating the processing steps of the software Bernese.

Appendix C

Folder Structure

```
-gsgstud/
    -12_GPC2023/
        -01_3DVisualization/
            -01_Document/   _______________________ (documentation)
            -02_raw/    ___________________________ (raw data)
                -01_ardez/  _______________________ (site)
                    -01_drone/  ___________________ (instrument)
                        -0620/  ___________________ (acquisition date)
                        -...
                    -02_camera/
                    -03_tls/
                    -04_gnss/
                -02_susch/
                -03_BerneseInputs/
            -03_processed/  _______________________ (processed data)
                -01_ardez/
                    -01_data/   ___________________ (color corrected drone data)
                    -02_areas/  ___________________ (components)
                        -.../   ___________________ (data separated by component)
                        -05_alignment_components/ _ (aligned RC components)
                    -03_models/
                        -model_*triangles*M/    ___ (folder with .obj model file)
                        -.../
                        -ardez_MASTER.rcproj    ___ (RC MASTER project for modelling)
                -02_susch/
            -04_final/  ___________________________ (final and submissions)
                -01_nerfstudio/ ___________________ (nerf results)
                    -01_ardez_tower/
                    -02_susch/
                -02_resultsimgs/    _______________ (screenshots and renders)
                -03_videos/ _______________________ (fly-through videos Ardez)
                -04_gnss/
                    -Bernese_results.xlsx
```

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